Collins' Advanced Science Series.

NAVAL ARCHITECTURE:

A TREATISE

ON

LAYING OFF AND BUILDING WOOD, IRON, AND COMPOSITE SHIPS.

BY

SAMUEL J. P. THEARLE,

Fellow of the Royal School of Naval Architecture; Member of the Institution of Naval Architects; of the Controller of the Navy's Department, Admiralty, Whitehall.

LONDON AND GLASGOW:

WILLIAM COLLINS, SONS, & COMPANY.

1876.

PREFACE.

UNDER the general title of Naval Architecture are included the principles of Naval Design, and the arts of Laying Off and Shipbuilding. It is with the latter of these divisions that we are concerned in the following pages.

The want of a treatise upon the modern practice of Laying Off has long been felt. Since the appearance of Fincham's work on that subject, little more than a quarter of a century ago, one or two others have been promised, but, unfortunately, circumstances have prevented their appearance.

Fincham's *Laying Off* was fully equal to the wants of its period; but in this progressive age, a lapse of only thirty-three years has rendered his book almost entirely obsolete. It can hardly be hoped that this work will be as successful as was its more pretentious predecessor.

In preparing that portion of the book which treats of Laying Off, I have been guided to a great extent by a recollection of the wants experienced by myself, in common with others, when pursuing my studies at the Royal School of Naval Architecture, and I have endeavoured to produce both the text and plates in such a way as would have commended itself to my ideas at that time. It was my desire to employ only the common language of the shipyard; but finding that the idioms and technical expressions used in Laying Off vary very considerably in the different private and public establishments throughout the country, it was found necessary to adopt many terms used in *Descriptive Geometry* in order to attain a uniform nomenclature to be generally understood. An explanation of the meaning of those terms will be found in the first chapter. In addition to the uniformity of expression thus sought for, it is hoped that the employment of exact language (already familiar to many of the young men of the Royal Dockyards) will tend to encourage the study of a branch of geometry which is of the greatest assistance to the naval architect.

It is believed that this volume will be found to contain nearly all the problems in Laying Off which occur in actual practice on the mould loft floor; and, in addition thereto, a number of problems which, while not met with in practice, are yet valuable as exercises to strengthen the student's knowledge of the subject, and are often set in examinations to test that knowledge. I am indebted to Mr. G. Crocker, of Devonport yard, for assistance in preparing Chapter VII., which is devoted entirely to the consideration of a difficult class of these problems. Mr. J. Logan of Chatham yard has also kindly assisted me in the preparation of Chapter X., which treats of Laying Off iron ships of war.

In endeavouring to discuss the details of shipbuilding within the limits of this work, want of space has rendered it necessary to consider only the operations carried out on the building slip, prior to launching.

Owing to the extensive character of the subject, nearly all the existing works on *Naval Architecture* are very large, and consequently expensive; thus placing them beyond the reach of workmen and a great many students of the profession. Works such as *Naval Architecture*, by Mr. J. Scott Russell; *Shipbuilding, Theoretical and Practical*, edited by the late Professor Rankine; and *Shipbuilding in Iron and Steel*, by Mr. E. J. Reed, C.B., which discuss the subject in the most detailed and masterly manner, are included among those referred to; and while this modest volume cannot expect to compete with either of these, yet it is hoped that it will, perchance, supply a want for which they may not be adapted.

Although primarily intended for the use of the students in the Science Classes in connection with the Science and Art Department, this book has also been arranged with a view to its being used by persons in the Royal and private shipyards.

S. J. P. T.

LONDON, *October, 1873.*

CONTENTS.

PART I.—LAYING OFF WOOD SHIPS.

PART II.—LAYING OFF IRON SHIPS.

PART III.—WOOD SHIPBUILDING.

PART IV.—IRON SHIPBUILDING.

PART V.—SHEATHED AND COMPOSITE SHIPBUILDING.

NAVAL ARCHITECTURE.

PART I.—LAYING OFF WOOD SHIPS.

CHAPTER I.

1. Laying Off is the name given to that art, by the aid of which the shipbuilder determines the forms of the various pieces of which a ship's hull is composed, so that, when they are put together in their proper positions, they shall collectively constitute the frame of a ship, having the form and dimensions intended by the designer. It is sometimes styled the *Geometry of Shipbuilding*, and is, in fact, a practical application of Descriptive Geometry to that art. Its various problems are solved upon the floor of a building, known as the Mould Loft, where the drawings furnished by the designer are transferred in chalk lines on full size, and then by the aid of geometry, and in the manner discussed in the following pages, the draughtsman determines and draws in the shapes of the various components of the frame. Moulds are made to the lines, and with these moulds and other data furnished by the draughtsman, the workmen are enabled to trim the timbers, or bend the angle-irons, and place such marks upon them as shall leave nothing but the putting together and fastening them in their places in order to construct the frame of the ship.

At the present day, the application of geometry to shipbuilding is become almost universal. In some small yards, however, schooners, brigs, and such minor craft, are not laid off; but the stem, stern-posts, and the keel having been set in position, the form of the hull is shaped in on one side with battens bent to please the eye; and moulds having been made to the timbers on that side, they are reversed for the timbers on the other side. The timbers are kept in place by cross spalls, shores, and ribbands, the frame is planked, and thus the hull is built. Although this mode is practically not very objectionable in vessels of such description, that no special design is required, it could not be entertained for a moment in the Royal Dockyards or large private firms, where all the ships are built from well matured designs, that must be adhered to in their entirety; besides which, owing to the ships being of so large a size, this *mocking* system is economically impracticable.

2. Purpose of the Art.—To an ordinary observer, the determination of lines on a ship's surface presents itself as a series of problems of no little intricacy; and, indeed, were it not that all, or nearly all, such lines as the naval architect requires, are produced by plane intersections with the ship's surface, their determination, owing to the undevelopable nature of that surface, would be both approximate and difficult. To solve these problems is the province of *laying off.* A study of this subject will be greatly assisted by a previous perusal of the preliminary pages of Woolley's *Descriptive Geometry;* and a clear conception of certain of the more difficult parts of this book will be found impossible, without an acquaintance with that portion of Descriptive Geometry which treats of "straight lines and planes." This will be found particularly the case in the chapter on the *Double Cant Timber.*

Before proceeding with the practical operations in *Laying Off,* it is necessary to state and explain the following preliminary proposition.

3. Proposition.—*A point in space is determined, or fully known, when its distances are given from three planes mutually at right angles.*

Consider AOCD, BOCF, AOBE, fig. 1, to be three sides of a square-cornered cubical box of unlimited dimensions: that is, let each of these plane surfaces extend indefinitely from OB, OC, and OA. For the present, suppose OBEA to be the bottom; then, if the perpendicular distances of a point in the bottom from the sides OB, OA be given, a mechanic with his rule and square will immediately find its position by measuring from the point O along OA, the given distance OX of the point from the line OB, and also measuring from the point O along OB, the given distance OY of the point from the line OA; then by squaring out lines from the points X and Y, he knows that their intersection is the point P required. This action in the every day life of the skilled mechanic, is no other than that of determining a point whose co-ordinates are given; the distances OX and OY being the co-ordinates, and OB and OA are termed the *axes*.

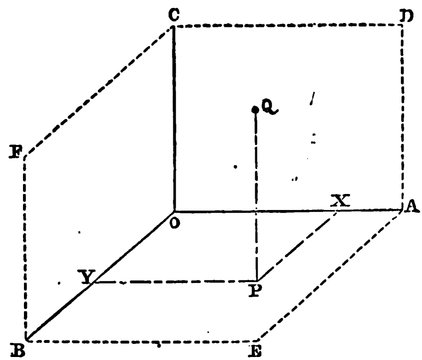


Fig. 1.

But a ship being a solid and not a plane, another dimension must be introduced before the required point can be determined, viz.:—height or depth; hitherto, only length and breadth have been considered. Returning to fig. 1, it is seen that if a line be drawn through the point P perpendicular to the plane OBEA, or, which is the same thing, parallel to the line OC, there are any number of points in this line, each of which is distant PX and PY from the planes AOCD and BOCF respectively, but at any fixed distance from the plane AOBE. If, then, a height PQ be taken in this line, a point Q is found, which is distant PX, PY, and PQ from the planes AOCD, BOCF, and AOBE respectively. Now there is only one point which fulfils these conditions, for only one perpendicular can be drawn through the point P, and there is only one point in that perpendicular which is distant PQ from the plane AOBE. Hence the point Q has been determined by having given its distances from three planes mutually at right angles.

The planes AOCD, BOCF, and AOBE are termed in geometry *planes of reference* or *co-ordinate planes*, and have their laying off counterparts in the *sheer*, *body*, and *half-breadth* plans respectively.

As we have already stated, nearly all the lines on a ship's surface, which are employed in laying off, are contained in planes; hence, they are drawn upon a plane surface, and in order to have a correct conception of the forms of the lines, they are projected upon three planes of reference.

4. Definitions and Axioms.—*The projection of a point on a plane* is the foot of the perpendicular let fall from the point upon the plane.

The projection of a line upon a plane is the line which passes through the feet of all the perpendiculars which can be let fall from the line to the plane.

The plane upon which the perpendicular is let fall, is termed the *plane of projection;* and the perpendicular itself is known as the *projecting line.*

When a straight line is projected upon a plane, the plane containing the *projecting lines* is termed the *projecting plane.*

When a line is in a plane parallel to the *plane of projection,* the projected length and form are the same as the true length and form of the line; but if the planes are not parallel, the projected line will not be similar to the real line; and the latter can then be determined by what is termed *rabatting,* to which we shall refer presently.

The intersections of lines with planes, and of planes with each other, are termed their *traces;* it is evident that the former are points, and the latter straight lines.

The projections of all lines which are in a plane perpendicular to the plane of projection, are straight lines, which evidently coincide with the trace of the former plane upon the latter.

When a line is perpendicular to the plane of projection, its projection will be the trace of the line produced to meet the plane.

The projections of a point upon two of the planes of reference, are all that is required to determine the point without the aid of the third plane. For, referring to fig. 2, let P_1 be the horizontal, and P_2, P_3 the two vertical projections of the point P; it is seen that in each of the planes OA and OB, two dimensions enter—viz., length and depth in OA, represented by OD and P_2D respectively; and length and breadth

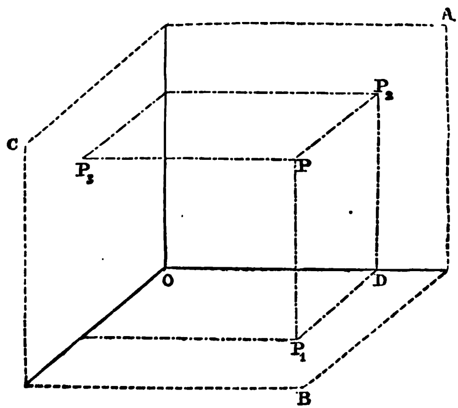


Fig. 2.

in OB, represented by OD and P_1D respectively. Hence, if only these two plans are given, the three dimensions required—viz., length, breadth, and depth, are known, which are sufficient to determine the point. The projection of the point P on the plane OC at P_3, gives the dimensions breadth and depth; and as these are already known, the projection on that plane is not essential to a knowledge of the point, when the projections on the other two planes are given. It is thus seen, that for the representation of the form of the vessel by the method of projections, it is only necessary to have two of the three planes of reference; the three are, however, retained in order to give a clearer conception of the body projected, and for corroborative evidence; besides which, each of the plans contains lines which cannot be shown in their true shape in either of the others.

5. Rabatting.—It frequently happens that a line is in a plane which is not parallel to either of the planes of projection, and hence its projections do not show its true form. In order to obtain the latter, an operation, termed *rabatting*, is performed, which consists in hinging the plane containing the line about its trace with the plane on which it is required to represent the line, or with a plane parallel to the last mentioned plane. In the first case, *rabatment* gives the line at once, and in the second case it has to be projected after being *rabatted.*

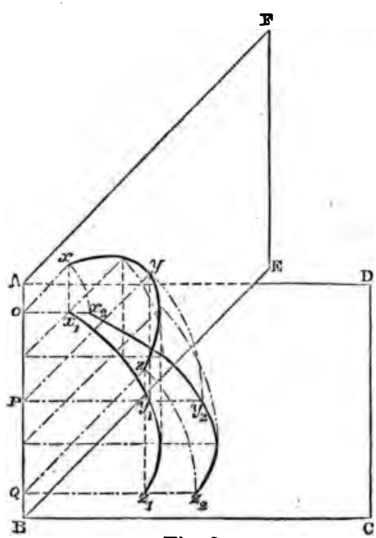


Fig. 3.

As an example of how a line is so rabatted, consider the following:—In fig. 3, let AB be the line of intersection of the two planes ABCD, ABEF, also, let xyz be a line in the latter plane which it is required to represent in the former. It is evident that the projection $x_1 y_1 z_1$ of the line is not its real shape, the planes not being parallel; it is therefore necessary to *rabat* or hinge the plane ABEF about AB, until it coincides with the plane ABCD. From any points x, y, z, in the line xyz, draw xO, yP, and zQ, in the plane ABEF, perpendicular to AB; and from the points O, P, Q, draw in the plane ABCD the straight lines Ox_2, Py_2, Qz_2, perpendicular to AB. Then take $Ox_2 = Ox$, $Py_2 = Py$, and $Qz_2 = Qz$; through the points x_2, y_2, z_2, draw the line $x_2y_2z_2$, and if the number of points x, y z, taken are sufficient, the line $x_2y_2z_2$ will be the same as the line xyz.

Having thus briefly, and as simply as possible, stated the geometrical principles upon which the art of laying off is founded, and by which it is practised, we will proceed to examine the manner of applying these principles, and their equivalents in the art itself.

6. The Three Plans Explained.—The three planes of reference are termed the *body*, *sheer*, and *half-breadth* planes; these being the transverse vertical, the longitudinal vertical, and the horizontal planes respectively. The various lines which are projected upon these planes constitute the body, sheer, and half-breadth plans.

In the body plan, all such lines as are in planes parallel to the horizontal plane, or perpendicular to the transverse vertical plane, will appear straight, as they are the traces of the last-mentioned plane with the planes containing the lines. In the sheer plan, all lines which are in planes parallel to the horizontal plane, or perpendicular to the longitudinal vertical plane, will appear straight, for they are the traces of the longitudinal vertical or sheer plane with the planes containing the lines. Similar remarks apply to the half-breadth plan. In the body plan lines appear in their true form, if the planes containing them are parallel to the transverse vertical or body plane; and similarly with regard to the other plans.

7. Planes of Intersection.—For the purpose of representing the form of a ship upon plane surfaces and laying her off, she is supposed to be cut by three sets of planes parallel to the planes of reference. Three sets of lines are thus given by the intersection of these planes with the ship's surface, and their projections are termed *level lines*, *buttock* or *bow* *lines*, and *square stations*, according as they are produced by intersections of the surface with horizontal, longitudinal vertical, and transverse vertical planes, respectively. The first appear straight in the body and sheer plans, but curved in the half-breadth plan; the second are straight in the body and half-breadth, but curved in the sheer plan; and the third are straight in the sheer and half-breadth, but curved in the body.

By means of either two of these three sets of lines, having given two of the plans, the other plan may be drawn; or having given only one of the sets of lines in the three plans, and the projection of another set of lines on one of the three planes of reference, the projection of this set on each of the other planes of reference can be determined. All this readily follows from the principles of projection already explained.

Besides the preceding, other lines are introduced into the plans for special purposes to be named hereafter; of these the most important are *diagonal lines*. These are produced by the intersection of planes perpendicular to the body plane, but inclined to each of the other planes of reference; their horizontal projections are termed *horizontal ribband lines*, but the lines themselves are known as *diagonal lines*.

By cutting the ship's surface more perpendicularly than those before mentioned, the diagonal planes give better intersections, and are thus of great service in "*fairing the body*," a process to be described further on: they have also other uses, which will be referred to in their proper place.

8. The Sheer Draught.—The portion of the design which contains the three plans we have just been describing, together with the positions of decks, ports, and general outline of the hull, is termed the *sheer draught*, and this is the drawing which is chiefly required in laying off. Other data are required, but these will be given in their proper places; at present we will confine our attention to the *sheer draught*. And here it may be remarked that the several processes of laying off are dealt with in the following pages in the same order as the draughtsman lays off his ship upon the mould loft floor.

Before proceeding further, it is necessary that we should examine the *sheer draught*, in order that we may become acquainted and familiarize ourselves with the names and uses of the various lines composing it.

Plate I. shows the sheer draught of a sloop of war drawn to a scale of one-sixteenth of an inch to a foot, or one quarter the usual scale of such drawings. This is a fair type of a sheer draught as prepared at the Admiralty for the construction of vessels in H.M. dockyards. A sufficient number of lines are shown upon it to fully determine the form of the hull. The sheer plan shows the projected forms of these lines upon a longitudinal vertical plane, or, as we prefer to call it, the sheer plane. The body and half-breadth plans show the projections of the same lines upon the body and half-breadth planes.

In Plate I., the lines marked 2WL, 3WL, etc., are the projections of the intersections with the surface of the ship of planes parallel to the load water plane; they with LWL, the intersection of the load water plane, are called *water lines.* It may be here remarked that, unless it is otherwise stated, by "the surface of a ship" is meant the outside of the frames and not of the exterior plank, as, after the form of the ship has been designed, the plank is taken off by a process to be afterwards described,* and thus the building draught shows the surface of the frames.

The dotted perpendicular lines at the extremities, marked FP and AP, are the perpendiculars between which the length of the ship is measured. The other perpendicular lines in the sheer and half-breadth are termed *square stations;* they are projections, upon these plans, of intersections of transverse vertical planes with the ship's surface. In the body plan is projected only the intersections of the planes with the port side of that portion of the ship on the fore side of her fullest part or *dead flat,* as it is termed; and with the starboard side of that portion abaft *dead flat.* By this means we have, without confusion, the projections in the body plan of the whole of the traces of these vertical planes with the surface. It will be observed that the section at the fullest part is marked thus ⊗, a symbol for "*dead flat;*" those in the fore body are marked alphabetically, and those in the after body numerically. At the present time the alphabetical desig-

* Chapter VIII.

nations are sometimes discontinued, and the numerical mode is used for the two bodies, commencing forward. These plane sections are made at the joints of the two sets of timbers composing wooden frames, and at the sides of angle iron frames; they are generally equidistant, those given in the sheer draught being usually spaced two or three frame spaces apart. In Plate I., the drawing being on so small a scale, we have spaced them four frame spaces apart. We have stated that the square stations are *generally* equidistant. Until within recent years it was customary to make the dead flat interval five-fourths the breadth of the others; this being done in order to allow room for a single timber frame, about which the relative positions of the component timbers of the frames were shifted—all the timbers on the fore side of the single timber being disposed by a certain rule, and those abaft it being disposed in a contrary manner (see fig. 2, Plate XII.). It should be further stated that the spaces between the joints of the frames of some recently constructed wooden war ships, have been greater towards the extremities than at amidships, in order to lighten the framing at those parts which receive least buoyant support.

Again, referring to Plate I., TS is the topside line, and besides this the form of the upper deck, as projected in the three plans, is also shown; these being given in order to represent the form of the vessel above the water lines. Generally, a line, termed a *top-breadth* line, is drawn somewhere between the topside and load water line; and, in large ships, lines at the port sills are given for the same purpose. The reduction in the number of decks in war ships, consequent upon the introduction of armour plating, has rendered the two latter of these almost obsolete; and the form of the portion of a ship's side between the topside and load water line is usually given by a line at the main deck, or else the sections in the body plan are the only data provided for the draughtsman's guidance in laying down the portion of the ship above the water.

The lines marked K show the upper and lower edges of the keelson, and at their extremities are shown the stemson and sternson.

The dotted line marked A is the upper part of keel, the two lines next below are the upper and lower edges of rabbet of keel; and below these are shown, in succession, the lower edge of keel and the two pieces of false keel. The three lines marked UDL in the sheer plan are, beginning at the uppermost, the lines of upper side of upper deck at middle line, upper side of upper deck beams at middle line, and upper side of upper deck beams at the ship's side respectively; these being usually known as *deck at middle*, *beam at middle*, and *beam at side* lines. The vertical distance between the first and second is, of course, the thickness of deck plank; that between the second and third is the round up of the beam—it is at once seen that the latter meet at the extremities of the deck. Besides the lines just noticed, there are also shown the knee of head, head rails, stern and munions, ports, masts, and other details.

The upper edge of rabbet of keel is selected as the base line of the sheer draught shown in Plate I. This is a conventional usage which is adopted when, as in the present instance, the joints of the frames are perpendicular to the keel. Before passing on, it should be stated that the line termed the upper edge of rabbet, which is usually chosen as a base line, is incorrectly named, being merely a line parallel to the lower edge of rabbet—a fixed line—and distant from it the thickness of the bottom plank. By making this the base line, and the ship not being on an even keel, causes the water lines to be curved in the body plan, as shown. In some cases the frames stand perpendicular to the LWL, and in such cases a line drawn parallel to the latter, and near the keel, has been chosen as a base, thus causing the square stations in the body plan to end successively one below the other, as shown by Plate II., instead of mostly at a point, as in Plate I., and the water lines in the same plan to be straight. The water lines in such drawings are known as *level lines:* they will be referred to more fully in the next chapter.

CHAPTER II.

9. The Sheer Draught is usually prepared on a scale of one-quarter of an inch to a foot. This is copied to full size upon the mould loft floor, in performing which operation it is found that errors, almost inappreciable in the one-quarter scale drawing, become very apparent when thus magnified forty-eight times. The three plans which, when upon paper, coincide as nearly as the draughtsman's powers will permit, when copied to full size are found to disagree sufficiently to prevent the various problems of laying off from being solved with that degree of accuracy which is necessary, in order to obtain a fair surface to the ship. Hence a fairing, or correcting process, has to be performed before the timbers can be laid off.

10. Fairing the Body.—The mutual dependence of the three plans upon each other has already been shown; this property is utilized in performing a tentative process, termed *fairing the body.*

In the preceding chapter, it was shown that the projections of each of the sets of lines generally used in this process, viz., level lines, square stations, bow lines, and diagonal lines, appear straight in one or two of the plans; so that, by the aid of a straight-edged batten, they can be drawn fair very readily in such plans. The property which a wooden or metallic batten has of bending in a fair curve, is brought to our aid in drawing the lines fairly in the plans where they appear curved. For, since the intersections of lines with each other are points, the points of intersection of two sets of lines in one plan are transferred to their relative positions in others, so that points which, when in one plan, were in a straight line are now in a curved line; a batten is penned, or bent, to pass through as many of the points as is consistent with absolute fairness, and the line is drawn. Thus, by a series of interchanges, the various lines are copied from one plan into another, until at length all the plans coincide, the lines composing them are continuous curves; and, having thus evidence of a continuous surface, the body is said to be *fair*. We will now go through these operations in detail, commencing by copying the drawing upon the floor.

It is a great advantage if the seams of the boards forming the floor of a mould loft are perfectly straight and parallel, as they thus afford considerable assistance in the several processes of squaring and drawing parallel lines which are involved in the practice of laying off.

The first thing to be done is to strike a base line on the floor; if the board edges are arranged as just stated, it will be necessary to place the base line either parallel or perpendicular to the lines of the seams. Should the floor be rectangular, about two feet from the wall or other boundary of the floor is a very convenient position for a base line. As before stated, a line parallel to the lower edge of rabbet is usually taken as the base, except in the case already cited. Whichever line, however, is chosen, the depth of the keel, the lower edge of rabbet, and the upper side of keel, are set off from it, at distances measured from the sheer draught; also, the fore and after edges of stem, together with the fore edge of rabbet of stem, which latter is, of course, a continuation of the lower edge of rabbet of keel. The post is next copied with the after edge of its rabbet, also the margin of stern and the various square stations in the sheer plan, including the fore and after perpendiculars. These, with the beam at middle lines, are termed the *fixed lines* of the sheer plan, being indeed unalterable, except in so far as drawing them fair is concerned. To economise space, the half-breadth plan is generally drawn upon the same part of the floor as the sheer plan, the base line of the former, or a line parallel thereto, serving as the middle line of the latter, and in this way the same square stations will do for the two plans. There are few mould loft floors upon which vessels of more than 100 feet long can be drawn in one length to full size; hence it is necessary to lay them off in two, three, and, in some cases, even more parts. The usual practice, with a wooden ship, is to set off the two perpendiculars at such distances from the ends of the floor, as will permit of the head rails and stern timbers being laid off; whereas with an iron ship, the perpendiculars can be so placed as to just give room for drawing the contour of the stem and the rake of the counter.

When the positions of the perpendiculars are fixed, as much of the fore and after bodies are drawn as the length of the floor will allow, and if there still remains an amidship part, it is laid off separately; so that there are two, or even three, sets of lines overlapping each other. However, since these bodies are not both laid off simultaneously, no confusion occurs.

We will presume that there is room upon our floor to lay off our ship in two parts, and will consider first the fore body, *i.e.*, that portion of the ship on the fore side of dead flat.

11. To Copy the Body Plan.—Having already copied the sheer plan, we will now copy the body plan, doing so as near as possible to the former, at the same time not allowing the lines to cross if it can be avoided. However, this is a mere question of room and convenience. On a small floor the same base line may well serve for the three plans, one of the square stations at amidships being taken as the middle line of the body plan.

A base and middle line for the body plan having been drawn upon the floor, before copying that plan it will be necessary to put certain additional lines in the body plan of the sheer draught, in order to assist the draughtsman in copying, and subsequently fairing it. By reference to the sheer draught shown on Plate I., it will be seen that the water lines are curved in the body plan. Now the process of *fairing* is materially assisted if lines which are curved in one plan are straight in another. We have already explained the cause of the curvature of these water lines when projected upon the body plane; we will now draw a series of lines parallel to the base line of the sheer plan, and equidistant from each other. These lines, being produced by the intersections of the surface with planes parallel to the horizontal or half-breadth plane, will appear straight in the body plan, and will, in fact, be drawn similarly to those in the sheer plan. We will therefore draw in the body and sheer plans about as many of those level lines as there were water lines, and copy the lines upon the floor; besides which we will put in level lines near the top side line, top breadth line, and at other intermediate positions, according to the height of the ship above the load water line.

Besides these, in order to obtain more numerous and better intersections, a number of *diagonal lines* are drawn in the body plan. The positions of these lines will be given hereafter; suffice it to say, for the present, that they are the lines of the heads and heels of the timbers, and therefore of the harpins and sirmarks (see Art. 80.)

Having transferred these lines to the floor, we proceed to copy the body plan by measuring, with a scale, the distances, along the several level and diagonal lines, from the middle line to where they cut the square stations, and then setting off these distances to full size on the corresponding lines upon the floor. Battens are then "*penned*" or bent, so as to approximate as closely to these points as is consistent with absolute fairness or continuity, and the lines are marked in with thin slices of chalk. At some yards it is customary to measure these ordinates, etc., and record them upon paper in a tabulated form before proceeding to draw the body to full size on the floor; and thus the latter operation is performed without direct reference to the drawing when working on the floor. The square stations thus drawn upon the floor are ended as follows:—The lines of the half sidings of keel, stem, and sternpost, are drawn in the body and half-breadth plans from dimensions furnished by the specification or scheme of scantlings, which also states the taper, if any, which these parts of the ship should have; and if the taper is not stated, then it is set off according to the rule given at Art. 172. Next, the distance from the base line of sheer at which each square station cuts the lower or fore edge of rabbet, is set off from the base line of body upon the middle line of that plan, and from this point a line is squared out to the half siding of keel, stem, or sternpost. A circle is then swept with the point thus obtained as a centre, and a radius equal to the thickness of the bottom plank, and the square station is ended as a tangent to this circle upon the side of the latter, which is nearest to the middle line of body. It should be noticed that this ending is approximate (see Art. 132).

12. The Half-Breadth Plan.—The half-breadth plan has next to be drawn upon the floor; and here we may again note that lines now being used, which are curved in the body plan, will be straight in the half-breadth plan, and *vice versâ.* Before proceeding to copy the half-breadth plan from the body plan, it should be noticed that, owing to the new level lines which have been pencilled on the sheer drawing, the half-breadth plan to be drawn upon the floor will be totally dissimilar in appearance to that given in the design. But if the base line of the sheer draught is parallel to the water lines, and the body is therefore given in that drawing as shown by Plate II., the additional work of copying the body by new lines, and then transferring the latter to the half-breadth plan, will be unnecessary.

Having already drawn on the floor the middle line of the half-breadth plan, and the projections of the square stations in that plan, we proceed

13. To Copy the Level Lines from the Body into the Half-Breadth Plan (see Plate III.).—Straight edged battens are set to the middle lines of body and half-breadth. Then measure on a staff, whose end is kept against the former batten, the distance from the middle line to where a level line *ab* cuts each square station, 1, 2, 3, etc., in the body plan, and transfer these distances to the corresponding square stations in the half-breadth plan, by setting the end of the staff against the middle line batten of that plan, and marking the distances out on the respective square stations. A batten is then bent so as to pass fairly through as many as possible of these points, and the line a_2b_2 is chalked in, this process being performed for each level line.

To End the Level Line.—Still referring to Plate III., square down from the sheer plan to the middle line of the half-breadth plan, the point of intersection a_1 of the level line with the fore edge of rabbet of stem, and set off on this perpendicular line the half siding of stem at this height as measured from the body plan. Then end the level line by making it a tangent to a circle whose centre is the point thus found, and whose radius is equal to the thickness of the bottom plank, taking care to do so on that side of the circle nearest to the middle line of body. We must again remark that this ending is only approximate, unless the stem is square to the level line. For the fore edge of the rabbet is assumed to be the axis of a curved cylinder, the radius of which is the thickness of the bottom plank; and the surface of the timbers is supposed to be in contact with this cylinder along the line of the centre of rabbet. It is evident, then, that unless the section of the cylinder is made square to the axis it will be elliptical. Another error is, however, introduced owing to the tapered siding of the stem below the lower cheek.

A more correct ending is, therefore, obtained by making the level line end as a tangent to an ellipse of greater or less eccentricity in proportion as the stem deviates much or little from the above-mentioned condition. However, practically, these endings are sufficiently correct, being within the limits of error to which work is carried out upon the mould loft floor. For further information on this subject, see Arts. 15 and 132.

14. The Bearding Line.—It is necessary at this stage of the work to get in the *bearding line, i.e.*, the true line of the after edge of rabbet of stem or upper edge of rabbet of keel, that given in the sheer draught being not sufficiently correct to be copied from thence to the floor. The *bearding line* is the line of the intersection of the surface of keel, dead wood, stem, and stern post, with the outer surface of the frame timbers; hence a rough, and, indeed, a common way of finding this line, is by measuring in the body plan the half siding of stem at each level line, and drawing, in the half-breadth plan, a line parallel to the middle line of that plan at a distance equal to the half siding thus found. The intersection of this parallel line with the corresponding level line in the half-breadth plan will be, approximately, a point in the bearding line; and if this point be squared into the sheer plan to the corresponding level line, we shall have an approximation to a point in the bearding line in that plan. Other points in the bearding line below the level lines in the sheer are obtained by measuring in the half-breadth plan, the half siding of keel at each square station, and drawing a line in the body parallel to the middle line of that plan, and distant from it the half siding thus found; the intersection of this parallel line with the corresponding square station, when transferred to the respective square station in the sheer plan, will be an approximation to a point in the bearding line in that plan. There is an error in this method of obtaining the bearding line due to the same causes as the incorrectness of the endings of the level lines already referred to. However, it is usually sufficiently correct for all practical purposes, and if slight allowances be made in ending the lines by substituting ellipses for circles, according to the discretion of the draughtsman, no error worthy of notice will occur.

15. More Correct Mode of Drawing the Bearding Line.—At some dockyards it is usual to obtain the bearding line and middle of rabbet by the following mode, which is obviously more accurate than the preceding, although even this is not theoretically correct, as the taper of the stem is not taken into account.

At any selected points A and C on the fore edge of stem (see Plate IV.) in the sheer plan, about the same distance from each other as the level lines, draw lines AB and CD perpendicular to the stem; these will be the vertical traces of planes which are perpendicular to the stem and to the sheer plane. Where either of these lines, say CD, cuts the square stations 1, 2, 3, etc., draw lines EG, FH, and DK perpendicular to CD. Then measure the heights of these intersections E, F, and D above the base line of sheer, and set them up from the base line of body upon the middle line of that plan at E_1, F_1, and D_1. Next measure the perpendicular distances of these points E_1, F_1, D_1 from the respective square stations in the body, and set them off from the perpendicular line CD in the sheer upon the corresponding lines EG, FH, DK. Pass a curve through these points G, H, and K, and we have the form of a section of the bow made by a plane which is perpendicular to the stem and to the sheer plane, the section being rabatted upon this latter plane.

To end this section, measure the height of the point L (where the line CD cuts the fore edge of rabbet) above the base line of the sheer plan, and set it up on the middle line of body, measuring from the base line of that plan. Then take the half siding of stem at that height, and set it out from the point L perpendicular to CD; with the point S, so found, as centre, and with a radius equal to the thickness of the bottom plank, sweep a circle, and end the curve KHG as a tangent to this circle upon the side of it nearest to CD. A line SM drawn through the centre S of the circle parallel to CD, will intersect the curve KHGT in a point M, from which a line MP perpendicular to CD will determine a point P on the latter which will be a point in the bearding line. A perpendicular TO from the point of contact T of the curve with the circle upon the line CD, will give a point O in the middle of rabbet. By following a similar course with the other perpendicular lines AB, etc., points are obtained by which the bearding line and middle of rabbet may be drawn (see Art. 132). Both body and half-breadth plans are now upon the floor, the latter having been obtained from the former.

In drawing the lines of the half-breadth plan, it will be found that they do not pass through all the points determined for them from the body plan, hence, as yet, these plans do not quite agree with each other. We may now proceed to correct the body plan from the half-breadth plan by reversing the preceding process, and thus draw new square stations in the former plan, having previously rubbed out those originally drawn.

16. Further Test of Fairness.—But it is found advisable, before doing this, to institute a greater check upon the square stations in the body plan, than can be made with level lines only. This is done by projecting and rabatting upon the half-breadth plane the intersections of the diagonal planes, already drawn, with the surface; and by projecting upon the sheer plane the intersections, with the surface, of planes parallel to that plane. The two sets of lines obtained by treating the diagonal planes as described, are termed *diagonal lines* and *horizontal ribband lines* respectively; while the lines obtained by the intersections of the planes parallel to the sheer plane, are known as *bow lines* when in the fore body, and *buttock lines* when in the after body.

The *diagonal lines* and *horizontal ribband lines* are valuable as checks upon the fairness of the ship, inasmuch as, being in planes which are nearly perpendicular to her surface, they give more determinate intersections; besides which, they afford an excellent criterion of the nature of that surface.

The *bow* and *buttock lines* are valuable only at the extremities of the ship; and, there, more as a criterion by which the experienced draughtsman can decide whether or not the character of the surface is such as it should be, than as a means of fairing the body, owing to the general indeterminateness of their intersections.

Hence, some draughtsmen test the fore and after ends of the ship by bow and buttock lines, before proceeding to fair the body; as it sometimes happens when the body has been carefully faired by level lines, by "running in" a few bow and buttock lines, a radical defect in the character of the surface is discovered, which necessitates a repetition of the whole fairing process.

Before proceeding to fair the body by means of the diagonals, or lines of heads and heels of timbers, it must be remarked, that as neither of the planes of projection is parallel to the diagonal plane, in order to obtain the true form of intersection of the diagonal plane with the surface of the ship, it is necessary to rabat the plane upon either the half-breadth or sheer planes. The former is that generally chosen, and, as before stated, the line so obtained is termed *a diagonal line.*

17. To Draw a Horizontal Ribband Line.—See Plate V. Measure the distance square to the middle line of the body plan at which a diagonal line *ab* cuts each square station, 1, 2, 3, etc., and set off these distances from the middle line of the half-breadth plan upon the corresponding square stations—a line a_1b_1 drawn through these points is the horizontal ribband line.

To End the Line.—Measure the perpendicular distance from the base line of body, to where the diagonal *ab* cuts the half siding of stem, and set that distance up square to the base line of the sheer plan, to where it intersects the bearding line at e_1, from which point square a line e_1e_2 to the middle line of half-breadth, and measure from the base line upon the line e_2e_1, a distance e_2a_1 equal to half siding of stem *ef* at the height of the point *e*. The point a_1 thus found is the ending of the horizontal ribband line.

18. Rabatted Diagonal Lines.—In fairing the bodies of wall-sided ships, the horizontal ribband lines frequently coincide, or are so near each other as to be indistinguishable. In such a case it is advisable to use the rabatted instead of the projected intersection of the diagonal plane, *i.e.*, *to fair by diagonals*. Indeed, in any case it is advantageous to draw these lines in fairing, as they must be laid off at some time or another in order that the moulds may be made for the harpins.

To Draw a Diagonal Line in the Half-Breadth Plan.—See Plate V. Measure along the direction of the diagonal line *ab* in the body plan, the distance from the middle line of that plan to where the diagonal cuts each square station, 1, 2, 3, etc., and set off these distances in the half-breadth plan upon the corresponding square stations, measuring from the middle line. A curve AB passed through these points is the diagonal required.

To End the Diagonal Line.—Measure the half siding of stem *ae* in the body plan along the direction of the diagonal line, and set up this distance on the perpendicular line e_2e_1 already drawn through the ending of the horizontal ribband line—a point A is thus determined at which the diagonal is to be ended.

19. Bow and Buttock Lines.—We will now turn our attention to the *bow* and *buttock lines*. Since the sheer and half-breadth plans overlap each other on the floor, and have the base and middle line of these plans, respectively, coincident; as a matter of convenience, the level lines in the former plan may be used as bow and buttock lines for the latter. In the body plan, these lines will be drawn parallel to the middle line, and at the same distance from it as they are from the middle line of the half-breadth plan.

The bow and buttock lines are drawn only as far from the extremities towards amidships, as curvature of a peculiar character may extend.

To Draw a Bow Line in the Sheer Plan.—See Plate VI. Where the bow line *ab* in the half-breadth plan intersects with each level line, square up to the corresponding level line in the sheer plan, and the points thus determined are in the bow line.

Next, take the heights above the base line of the body plan, at which the bow line cuts each square station, and set up these heights in the sheer plan upon the corresponding square stations, measuring from the base line; the points thus obtained will also be in the bow line. Generally, a curve will not pass through all these points, owing to the indeterminateness of the intersections at some parts, as well as to an unfairness of the surface. Hence, bow and buttock lines require more judgment and discretion in their treatment than either of the other lines by which the body is faired. When discrepancies occur, the level and diagonal lines in the neighbourhood must be examined to see if the points of intersection were correctly taken, and if a modification of these lines, consistent with fairness, will give such points for the bow line as the batten will spring to. As we have already stated, bow and buttock lines are of great service to both designer and draughtsman in judging of the character of the surface at the extremities of the ship. No rules can be laid down for guidance in dealing with them, experience being required in order that they may afford a vivid conception of the form of the vessel.

The body plan may now be recopied, and the new square stations drawn in and ended as before. If these do not pass through all the points obtained for them, the half-breadth plan must again be checked by it, and so on, alternately, these operations must be repeated until the body and half-breadth plans exactly coincide, and both plans have fair or continuous lines in them.

In practically performing these operations, a great deal must be left to the judgment of the draughtsman; a practised eye will save much labour. When a batten does not spring well to the points, it is best to pass it outside some and inside others, and thus prevent great deviation from the design in either direction; observing that, as a rule, the batten should pass on the outside more frequently than on the inside of the points, in order that the volume of the ship may not be less than that given by the design.

In copying and drawing the body plan, it is advisable to draw the midship section first, and then the others in rotation, as the draughtsman is thus better enabled to see what he is doing, and exercise his judgment.

20. Fairing the After Body.—Should the preceding operations have been carefully carried out, the fore body will be fair, and work, which will be treated of in the next chapter, can be proceeded with at once. Before entering upon this, we will, however, first consider the after body. All that has been said of the fore body is true of this; a slight variation is, however, made with reference to the bearding lines. Owing to the swell allowed to house the screw shaft, and the general fineness of the after body, which would cause the heels of the timbers to run off to a thin wedge, a somewhat irregular stepping line is cut in the stern post and deadwood for the endings of the timbers (see Plate I.). Greater care is required in getting in buttock than bow lines, as owing to the great curvature at the counter, which is in a direction perpendicular to the buttock planes, the intersections are more trustworthy than by any other planes, and, hence, they are almost the only criterion of the fairness at that part. It is well, in fairing the body, to scarph or overlap the lines in the half-breadth plan, that is, to fair a few feet of the midship portion of the ship in both bodies. Perhaps, however, the best way to ensure the ship being fair when the fore and after bodies are joined amidships, is to set off in the half-breadth plan lines parallel to the middle line of that plan, and distant from it the greatest breadths at the several level lines; and take care, when penning the battens to the respective lines, to prevent them from extending beyond the parallel lines.

21. The Contracted Method of Fairing.—The body being fair, we might now proceed to lay off the cants, etc., by it; but, before doing so, we will first show how to fair the body by what is known as the *contracted method.*

The extremities of a ship are the parts which require the most care in fairing, this being due, not only to the greater curvature at those parts, but also to the fact that most of the problems in laying off occur at the bow and stern.

As we shall see further on, the midship portion of the ship, although by far the largest, is yet that most easily disposed of by the draughtsman, and, owing to its being so straight, very little fairing is required for it.

To save time and labour, as well as for the advantage derived from being able to do in a small space that which would otherwise occupy a large part of the floor, the body is often faired by the *contracted* method, which we will now describe.

To Fair the Body by the Contracted Method.—See Plate VII. First determine by an examination of the body plan how much of it shall be faired by this method, observing that it is well to leave such portions of the two bodies as may have great curvature to be faired by the method already given. A little more than that length of the extremities for which harpins are usually made, is generally sufficient to leave for fairing by the ordinary process. It must be observed, that in the figure, more than the usual portion of the body is shown as being faired by this method.

Draw upon the floor, perpendicular to any chosen base line, as many equidistant straight lines as there are sections to be faired, and number these perpendiculars to represent the square stations. These lines need not be spaced more than a sixth or seventh of the spacing of the stations apart. Next, produce each level and diagonal line (diagonal line usually) in the body plan to any point chosen at a few feet beyond the midship section, the reason for this will be seen presently. Then measure along each level and diagonal line from the termination outside the body plan just fixed upon, to where it intersects with each of the square stations to be faired; set these distances upon the corresponding perpendicular lines just drawn, measuring, of course, from the base line; and draw lines, by a batten, through these points. Treat all the level and diagonal lines in a similar manner; and at the top sides use level lines drawn in at the same places as when fairing that part of the ship by the ordinary method. Fair these lines in the same manner as if the spacing of the perpendiculars were the correct room and space. Alternate the processes by re-copying the body from these curved lines, and *vice versâ*, until the curves pass fairly through all the points obtained for them, after which this fictitious half-breadth plan may be rubbed out, the midship portion of the body being faired. Assume the two endmost of the stations so faired to be absolute and invariable; and in fairing the extremities of the ship by the ordinary method, let the batten pass through all the spots in these stations in the same manner as if it were the midship section, taking care, however, to let the batten pass through points obtained from the adjacent stations, so that there may be no discontinuity in the surface of the ship where the portion of the body faired by the contracted method joins to that faired by the ordinary method.

One of the chief advantages of the method of fairing which we have just been describing, consists in the facility with which the moulds of the square body can be sent out, and the timbers converted before the fairing of the extremities of the ship is completed.

It may be remarked, that when the square stations are not equidistant, it will be necessary to space the perpendicular lines, by which the curves are set off, at distances from each other proportional to the spacing of the square stations. There is no necessity for using the level and diagonal lines already in the body, as any lines may be used for the purpose of fairing.

It will be readily seen that not only is the contracted method correct in principle, but owing to the ordinates of the curve being placed closer together, the curvature is increased, and, therefore, the battens are more likely to spring fairly than when the curves are nearly straight.

22. Projections of Diagonals on the Sheer Plan.—We will now get in a set of lines, which, although seldom used for the purpose of fairing, yet serve to prove that fairness, when drawing upon paper. The lines referred to are the projections of the diagonal lines on the sheer plane. The chief use of these lines is to give the positions of the heads and heels of the timbers when disposed in the sheer plan, upon boards which are given to the workmen for their guidance in fairing the ship.

It has been already remarked, that diagonals are used as harpin lines; of these diagonals there are two sets, viz., *heads* or *harpins*, and *filling heads* or *sirmarks*. The former give the lines of the heads of *frame timbers*, and the latter of *filling frames*. An arrangement of diagonals in the body plan is shown by Plate II.; those marked FH, 1H, 2H, etc., being the *floor head*, 1st *head*, 2nd *head*, etc., harpins, respectively; while those marked FS, 1st S, 2nd S, etc., are the *floor sirmark*, 1st *sirmark*, 2nd *sirmark*, etc., respectively. The same names are given to the corresponding diagonals in the half-breadth and sheer plans. At some yards a different nomenclature is adopted; the sirmarks FS, 1st S, 2nd S, etc., being known as S.F.H., F.F.H., F.1st H., etc., or *short floor head*, *filling floor head*, *filling* 1st *head*, etc., while the same names, as before stated, are given to the heads of the *frame* timbers. Further particulars regarding the disposition of the timbers composing the frames and filling frames, are given in the next chapter.

The diagonals in the sheer plan are generally copied upon paper to a quarter inch scale, being laid off from the sheer draught without reference to the floor. When the frames are disposed, the drawing is copied upon a board and given to the workmen for their guidance, as before stated.

To Draw the Diagonals in the Sheer Plan.—See Plate VIII. Measure the height square from the base line of the body plan, at which a diagonal line *ab* cuts each square station, 1, 2, 3, etc., and set these distances upon the corresponding square stations in the sheer, measuring from the base line of that plan. A line a_1b_1, drawn through these points, is the diagonal in the sheer plan. Diagonal lines are generally ended at the bearding line, and the ending is obtained by measuring the height above the base line of the body plan at which the diagonal cuts the half siding of stem or stern post, and setting this height square from the base line in the sheer to cut the bearding line; the point on the bearding line, so obtained, is the ending of the diagonal.

23. Intermediate Sections.—Up to the present time we have been working with only every second, third, or, perhaps, fourth square station drawn in each plan. These were sufficient to fair the body by; and, indeed, were preferable to having the whole of these stations drawn, owing to the greater clearness resulting from fewer lines being drawn upon the floor.

The intermediate stations may now be supplied. As these stations appear straight in the sheer and half-breadth, they are first drawn in those plans by dividing the space between two consecutive square stations, as at present drawn, into the requisite number of equal parts, and drawing vertical lines through the points thus obtained. They are then easily transferred from these plans into the body plan by the methods already given. If the body is fair, the new square stations will pass through all the points set off for them.

24. Sheer Lines.—Either at this stage of the work, or before putting in the intermediate square stations, it is necessary to draw the top side line, top-breadth line, and other lines which at all conform to the sheer of the ship. These lines will appear curved in all the plans. Measure with a scale from the sheer draught the height above the base line of the sheer plan at which the top side, top-breadth, or other such line, cuts each square station, and set up these heights on the corresponding square station in the sheer, and pass a batten through as many of the points, so found, as is consistent with fairness. It will be found that this line will not differ materially from a line copied upon the floor previous to the body being faired. When the line is copied into the sheer plan, it can be transferred to the body plan, by measuring the height above the base line at which it intersects each square station, and setting up these heights upon the corresponding square stations in the body plan, measuring square from the base line of that plan. A curve passed through the points so obtained, will be the projection in the body plan of the sheer line referred to. To transfer the line to the half-breadth plan, measure the distance square from the middle line of the body plan at which the sheer line cuts each square station, and set these distances upon the corresponding square stations in the half-breadth, measuring from the middle line of that plan. A curve passed through these points will be the horizontal projection of the sheer line.

The sheer lines are ended at the bearding line similarly to the horizontal ribband lines.

25. Swell for Screw Shaft.—See Plate IX. When the after body of a screw ship has been faired, the height and direction of the centre of screw shaft are drawn in the body and sheer plans. A circle is then swept in the former plan, the centre of which is the centre of shaft, and the radius is that of the shaft plus the scantling of timber which is allowed around it. It should be remarked that, the scantling taken for the radius does not usually include the boxen wood allowed in lieu of the bottom planking. The after square stations are then bent, so that all which would otherwise intersect with this circle are made tangents to it. The bent portions of these square stations are then faired by putting additional level lines in the vicinity of the *swell*, transferring them to the half-breadth plan, and recopying the stations as before described. After this is done, the lines of the outside of the plank are drawn parallel to these, and the moulds to the stern post, etc., are made to the outer lines, thus allowing for the boxen. Plate IX. shows the outer lines.

26. Thick Garboards.—The square stations in the body plan have been ended as tangents to circles, each having a radius equal to the thickness of the bottom planks. If the centre of a circle be joined to the point where the square station touches it, and the side of keel be drawn, we shall have the shape of the rabbet of keel at the section in question, on the supposition that the garboard strakes are the same thickness as the bottom plank. Now, generally, this is not the case, for in the Royal Navy, and sometimes in the merchant navy, *thick garboards* or *Lang's safety keels* are fitted. The floors are scored down $1\frac{1}{2}$ inches into the keel, $\frac{3}{4}$ inch being taken out of each;* and the under side of the floor is snaped away in a straight line to a point termed the *angle of floor*. See A on Plate X., fig. 1. This point is given in the midship section; and, in order that the edge of the outer piece of garboard may be a fair curve, and parallel to the general run of the bottom planking at that part, the draughtsman measures with his compasses the distance between the centre of rabbet *c*, and the angle of floor in the midship section; and with the former point as a centre, sweeps a circular arc† in the body plan (see *a a*, fig. 2), to cut the square stations at points, each of which will be the angle of floor for that section. The shape of the floor for each section is then obtained, by joining a point $1\frac{1}{2}$ inches below the upper part

* This practice of scoring the floors is not universally adopted.

† Sometimes a point above the centre of rabbet is chosen as the centre of this arc, in order that the garboards may be wider at the extremities than at amidships.

of keel with the angle of floor at that section. It will be observed that, as the stations get more perpendicular forward and aft, the lines of the underside of floors, as thus drawn, merge into the curves of the frames until the angle disappears at station 7. Sometimes only the square body frames have been treated in this way; the timbers of what is termed the cant body, which we shall consider in a future chapter, being made to heel against the bearding line. Hence, below the angle of floor, these timbers have projected beyond those of the square body. Of course, this has only been the case when the cant body has commenced nearer amidships, than where the angle of floor has merged into the curvature of the frames. A fair surface has been given to the ship's bottom in such a case, either by scoring the garboard plank over this projection, or by putting the garboards in two thicknesses, the inner of which has flushed the surface before the outer was put on.

27. The Cutting Down Line, *i.e.*, the line of the upper side of the floors at the middle line in the square body, and of the upper side of the heels of the timbers in the cant body, should now be drawn.

The position of this line is governed by the shape of the body and the moulding of the timbers. It is usually obtained by setting in square to the surface at each square station in the body plan, the moulding of the timber at its ending, to where that distance cuts the half siding of either stem deadwood or stern post, according to the situation of the ending. Such a point will be the *height of cutting down* at that square station, that is, the minimum height to which the deadwood need come in order to completely house the heel of the timber in the cant body; it is also the top of the floors, at middle line, in the square body. Points such as these are obtained for each square station in the body plan, then these heights are transferred to the corresponding stations in the sheer plan; and a line drawn through the points so obtained gives the cutting down line.

We have just stated that the mouldings of the timbers are set in square to the surface of the ship. Now, at amidships, it will be sufficient if we merely set the moulding of the timber in a direction square to the curve of the station; but at the extremities, especially in a bluff ship, it is evident that the distance thus set in would be considerably less than the actual thickness of the timber; we have therefore to obtain the accurate moulding of the timber in the plane of the square station, before we can draw in a correct cutting down line at the extremities. Such mouldings are difficult to obtain perfectly accurate, and we propose to postpone the consideration of a theoretically correct method for the present, and satisfy ourselves with a mode of obtaining the cutting down line at the extremities of the ship, which is sufficiently accurate for all practical purposes.

Referring to Plate XI. (which, as will be seen, is constructed similarly to Plate IV.). Determine the moulding of the frame timbers at the height of the intersection of the line AB with each of the square stations, 1, 2, 3, etc., and set these distances inside the line GD at the respective points G, F, and D. Pass a curve, HO, through the points so obtained, to represent the inside surface of the frames at the section AB. Draw OK parallel to AB at the distance of the half siding of stem at the height of the section. From the point O, where the curve OH intersects with OK, draw OP perpendicular to AB, then P is a point in the cutting down line. Other points at the bow and stern can be obtained in a similar manner, and thus the cutting down line can be continued from the portion already drawn in at amidships by the method just referred to.

Just as the bearding line is the line of the endings of the outer sides of the timbers, so the cutting down line is that of their inner sides. They are, in fact, respectively the traces of the planes of the side of stem, stern post, and deadwood with the outer and inner surfaces of the frame timbers. In proportion, then, as the ship is full or sharp at her extremities, so will these lines be near to each other or far apart. Now, as a sufficient moulded width of stem, apron, stern post, deadwood, etc., is required to provide heeling and security to the cant frames, it is evident that the cutting down line will regulate the dimensions of the fore and after ends of the backbone of the ship. The deadwood usually projects about one inch beyond the cutting down line, but in some instances, when the ships have been very sharp, it has been found necessary to reduce the moulded width of the deadwood in order to save weight, by allowing the cutting down line to run along the keelson, and thus partially heeling the cants against the latter; this, however, should be avoided when possible, as the keelson is considerably weakened by receiving the bolts from the heels of the timbers.

Even before we have arrived at this stage of the work, the drawing on the floor is sufficiently advanced for moulds to be made for the frames of the square body, and other information to be supplied from it, by means of which the workmen can begin to prepare many of the timbers of the ship.

Certain other data, however, are required, which will be considered in the next chapter.

CHAPTER III.

28. Besides the sheer draught, other instructions are furnished to the draughtsman to enable him to supply a correct account for the various parts of the hull. The principal of these are the *midship section* and *scheme of scantlings* or *specification.*

The Midship Section, as its name implies, is a drawing of a vertical transverse section of the ship amidships, showing the dimensions and shapes of the various parts of the hull which are cut by the section, together with the positions of the heads and heels of the timbers at amidships, and other data.

It is by the positions of the heads and heels of the timbers, thus given in the midship section, that the draughtsman determines the positions of the diagonals at the midship square station in the body plan. These diagonal lines are inclined at such angles to the middle line of that plan as will best aid conversion of timber, their intersections with that middle line being raised above the base line in proportion as the ship is fine at the extremities (see Plate II.).

Plate XII. shows the midship section of the ship whose sheer draught is given in Plate I. With the *midship section* an elevation is usually provided, showing the disposition of frames and riders amidships; these, together with a developed plan of the former, are given by figs. 2 and 3 on the same plate.

29. **The Specification** or **Scheme of Scantlings** gives complete information concerning the dimensions, material, and modes of combination of the several parts of the hull.

30. **Disposition of Stem, Keel, etc.**—Shortly after the lines are copied from the sheer draught, and before the body is entirely faired, the pieces of keel, stem, stern post, etc., are disposed or arranged upon paper to a quarter inch scale.

Upon a sketch of the outlines of the sheer plan, to the above-mentioned scale, the edges of keel, stem, stern post, apron, deadwood, keelson, stemson, and sternson are drawn. The bounding lines of these timbers are taken from the floor, and for this purpose the bearding and cutting down lines are usually obtained simultaneously, at an early stage of the work, to enable the moulds to be sent out for converting the timbers.

31. The Keel is disposed in pieces of as great length as can be obtained, subject to a good disposition of scarphs. The length of each of the scarphs is equal to twice the room and space, and they are placed so as to avoid the mast steps and the junctions of the square and cant bodies, also to make a good shift with the deadwood. It has been already stated that the square stations are the projections of the joints of the frames in the square body. Two of the keelson bolts pass through each keel scarph, the one through a frame floor, and the other through the filling floor on the same side of the joint as the frame floor is of its joint, both being clenched on the underside of the keel. Hence, in fixing upon the exact positions of the keel scarphs, the lines of these bolt fastenings are drawn, after which one-half of the room and space is set off on the fore and after sides of the fore and after of these bolts respectively, and these distances give the extremities of the scarphs. The directions of the lips of the scarphs in the fore and after bodies are given on Plate XIII., which shows the disposition of keel, keelson, deadwood, stem, stern post, etc., of a line-of-battle ship. The fore and after pieces of keel, especially the former, are usually curved to suit the form of the ship at the junction with the stem and stern post.

32. Keel Battens.—When the positions of the scarphs of the several pieces of keel are arranged, either sketches showing the arrangement or boards cut to the lengths of the pieces are sent to the timber converters, in order that they may determine whether there is suitable material in store; and if there is not, the arrangement is modified to suit the timber in stock. *Keel battens* or *room and space battens* are then provided (see fig. 1, Plate XIV.). The positions of the square stations are set off upon these battens, and sometimes those of the keel scarphs; the marks are so arranged that, when setting off the stations on the keel, it is not necessary to turn the staff end for end upon reaching *dead flat.* It is not customary at some yards to furnish any particulars to the workmen regarding the lengths, etc., of the scarphs, as the latter are always made by one rule : at other yards, however, a mould is made to the scarph, which serves for all the pieces of the keel. Moulds are always made to the fore and after pieces, having the square stations, scarphs, perpendicular line, lower edge and middle of rabbet, and other such marks upon them for setting the stem and stern post in position; also the siding and taper of the keel.

33. Disposition of Stem.—The pieces of *stem* and *apron* are next disposed, in doing which the draughtsman is governed, within certain limits, by the curvature and dimensions of the timber in store. The scarphs of these two sets of timbers are arranged so as to give good shift to each other, and at the same time aid good conversion. The arrangement given on Plate XIII. is an ordinary case.

34. Stem and Apron Moulds — Plate XV.—Separate moulds are made to the pieces of *stem* and *apron*, and a perpendicular line is marked upon them as a guide by which to set these timbers in place; also the fore edge of rabbet, bearding line, harpins, sirmarks, and the sidings of the timber at the extremities of each piece. It is also usually found advisable to mark the level lines on the stem, as they are frequently used in laying off, trimming, and erecting the *stem pieces* and *knight heads.*

35. Disposition of Stern Post—Plate XIII.—No difficulty is found in disposing the parts of the stern post of a sailing or paddle wheel ship, as the pieces being straight and generally in one length, only the lines of the edges have to be marked.

36. Stern Post Mould.—The information for trimming such a stern post as that just referred to, consists of an ordinary batten mould, in which the battens are so arranged that the joints of the pieces of post can be marked upon them. Besides these marks, the positions and directions of the harpins and sirmarks, the after edge of rabbet, the bearding line, the sidings, and a perpendicular as a guide by which to set the post in place. It is also advisable to draw in the level lines, as upon the stem mould.

For the mould to the body post of a screw ship (Plate XVI.), certain modifications are required, owing principally to the *swell* or the body of wood which is required in the after part of the ship in order to house the screw shaft. Before the mould can be made to such a body post, it is necessary to obtain the shape of transverse vertical sections of it. To get these, the joints of the sections are drawn in the half-breadth plan, and then, by the aid of the additional level lines which were used in fairing the swell, these sections can be transferred to the body plan, where their shape will be seen. The positions of the sections are drawn upon an ordinary batten mould of the body post; and, in addition thereto, moulds are made to the curves of the sections just obtained, and by means of these the post is trimmed. The manner of disposing the pieces composing such a body post is shown by the same Plate.

The bearding line, after edge of rabbet, a perpendicular, and the heads and sirmarks, are marked upon the batten mould similarly to the body post mould of a sailing ship; and besides these, the line of centre of shaft must also be given. A simple batten mould marked with the joints of the pieces (if made of more than one), their sidings, the bearding and perpendicular lines, are all the data required for trimming the rudder post.

37. The Deadwood, Keelson, etc.—In disposing the pieces composing the deadwood, keelson, stemson, and sternson, the aim should be to get as good a shift of butts as possible, and not to have a greater number of pieces of timber than are absolutely necessary (see Plates XIII. and XXII).

38. Deadwood Mould (see Plate XV.).—An ordinary batten mould is provided for trimming the deadwood, of which mould the lower batten fits against the upper part of keel and inside of apron or stern post, the upper batten is made to about one inch above the cutting down line, and that at the midship end fits against the last timber crossing the keel. The intermediate battens composing the framing of the mould are made to the edges of the pieces which are to form the deadwood, and the whole is stiffened by vertical battens, which are usually made to the half section of the deadwood at different positions, generally at the square stations, these being placed in such positions that the middle line of the half sections shall be coincident with the positions of the lines on the mould giving the places where the sections are made. The rabbet is generally cut in these sections, but it is not essential. The following marks are given upon the deadwood mould:—the positions of the square stations, the cant sections (these are marked upon it subsequently), the joints of the various pieces composing the deadwood, the bearding line, and sometimes certain level lines, are marked upon it, these levels being useful as guides in pitching the frame timbers, and as auxiliary bevelling spots for the cants.

Generally, the deadwood does not conform to the taper of the keel, stem, and stern post, but is made parallel; in such a case there are, evidently, different bearding lines on these timbers, as the ship's surface, being cut by more than one plane, gives more than one intersection. A separate bearding has therefore to be found for the deadwood, by using its half siding (see Arts. 14 and 15) instead of that of the stem and stern post, and this line is marked upon the deadwood mould in order to get a fair surface to the ship when the cant timbers are in place.

39. Disposition of Frames in Square Body.—The abovementioned moulds could have been all sent out before the body was faired; while, however, the latter operation is being performed, the frames of the square body can be arranged.

In order to do this, a drawing of the outline of sheer plan is made, showing the bearding line, ports, side scuttles, diagonals, and square stations; and then, by the aid of the dimensions and instructions given in the specification and midship section, the square body frames are disposed in a manner similar to that shown by fig. 2 on Plate XII., and between the letters *M* and *X* on Plate XVII. The general character of the disposition there shown is the same as that now adopted in H. M. service, and is known as the *frame and filling frame* arrangement. The timbers of the *filling* *frames* butt at the sirmarks or filling heads, and those of the *frames* at the various heads.

It should be remarked with reference to Plate XVII., that in some yards it was the practice, until recent years, to keep the first futtocks of the frames on the midship side of the joint in both the fore and after bodies; but this is now frequently discontinued, and instead of changing sides either in the manner just mentioned, or as shown by Plate XII., fig. 2, the timbers are usually kept in the same relative position right fore and aft the ship; besides this, the single timber frame at *dead flat* is now discontinued. With these slight exceptions the disposition there shown is that now adopted in the Royal dockyards.

The room and space is generally constant throughout the length of the ship; but, as already stated, some wooden sloops of war have been recently built in the Royal dockyards, having the spacing of frames at their extremities greater than at amidships, in order to reduce the weight and unnecessary transverse strength at those parts.

In the merchant navy, ships are frequently built of all *frames;* such a shift is very simple, and requires no explanation, as an idea of it can be gathered by reference to Plate XII., considering the filling frames replaced by frames. Further particulars on framing are given in Art. 178, Part II., of this book.

When a port is so situated that a timber carried straight up will not form its side, it is necessary to joggle the timber until it does so (see A, Plate XVII.). Timbers are similarly moved to form bollards, etc.

In disposing the frames, the aim should be to get the openings between the timbers as nearly as possible of one size, and the *moulding edge,* or joint of the frame, in the middle of the opening. The disposition given in Plate XII. is termed *open jointed,* as there is an opening between the two sets of timbers composing each frame. Of late years, however, the small wooden vessels built in the Royal dockyards have been framed on the *close-jointed* system, and thus the number of openings have been reduced, while the breadths of the remaining openings have been increased. The same arrangement of butts is carried out in either case.

The square body is continued as far forward and aft as is possible without having timbers of excessive bevelling; when the latter becomes so great as to render conversion difficult, the timbers are *canted,* a term and process to be described in the next chapter. It may be remarked that the fore-cant body usually commences about two frame spaces before the foremast step.

The square body being thus disposed upon paper, we will return to the mould loft floor. After fairing the body, the inside of the timbers at *dead flat* is drawn, the mouldings being obtained from the midship section. This inside line is *rased* or scratched in; it being more particularly required when making the beam mould, as the midship beam terminates against it. This mould will be considered presently.

When the square body is disposed upon paper, a copy of it is drawn upon a chalked board, and given to the building officers for their guidance, together with a sketch of the disposition of keel, deadwood, etc., upon a similar board.

40. Moulding Book.—Besides the preceding, at some yards a manuscript book, termed the moulding book, is prepared, giving information to the timber converters regarding the mouldings of the timbers, their sidings, the lengths of scarphs of joggled timbers, the heights at which the several futtocks stop, the character of their bevellings (whether *standing* or *under*), and any other information which may be useful to them in providing the timbers. A copy of this book is also kept by the draughtsman for his own reference.

41. Moulds to Frames of Square Body.—We now send out the moulds for the frames of the square body, commencing forward according to the usual practice. It will be assumed that the arragement of timbers is on the *frame and filling frame* system, as that is the most complicated combination, and the method followed with others can readily be deduced from it.

The square stations are situated, as before stated, at the joints of the square body frames, as far as the latter extend. The projections of these stations in the body plan are assumed to be the same as the curves of the moulding edges of the timbers composing the frames. Hence moulds made to these curves will give the shapes of the moulding edges of the timbers; and so by these moulds, and the bevellings which we shall obtain presently, the frames can be trimmed. This statement is strictly true only when the frames are close-jointed; but when such is not the case, this is a sufficient approximation for as far forward and aft as the square body extends.

The sections in the body plan having been numbered or lettered, if the midship section is made a *frame*, every odd section will also be a *frame*, and the even sections will be *filling frames;* thus we can see at a glance, especially when numerals are used, which are *frames* and which *filling frames.*

Moulds are first made to frame floors. These extend on each side of the ship as high as the floor head, and are formed of battens, one of which is made to the curve of the midship floor, and another to that of the foremost or aftermost floor, according to the body under consideration. These boundary battens are united by other battens placed with their edges at the lines of floor head, floor sirmark, angle of floor, and side of keel, these lines being marked upon the mould.

The mould is made first to one side of the middle line only, and then the other half is made a duplicate of it. Upon this mould are marked all that portion of the square body *frame* sections from the keel to as high as the floor head, these lines being copied on one half from the mould-loft floor, and then reversed upon the other half of the mould. Besides the above-mentioned lines, the seating and throating of the floors are also drawn upon it (see Plates XVIII. and XVIII. A).

The moulds to *filling floors* are next made, the process being similar to that for the *floor* mould. One arm of the mould reaches to the floor sirmark, while the other is continued to the first sirmark. The boundary battens of the mould are made to the midship and foremost or aftermost *filling* floors, and the connecting battens are placed at the first sirmark, floor head, floor sirmark, angle of floor, and side of keel, these being marked upon the mould. Upon the mould are also marked all the filling frame sections as high as the first sirmark, together with the seating and throating of floors.

After this the moulds to first futtock frames are made, then to first futtock filling frames, and so on.

As we proceed to make the moulds to the upper futtocks, we find that owing to the frame sections being so far apart, a mould made large enough for all the frame or filling futtocks in either body would be inconveniently large. Hence two or more moulds are made for these. Upon the moulds to the upper futtocks and top timbers, the beam end, port sill, top side, and other such lines are subsequently marked (see Arts. 51 and 52).

The moulds for the timbers of the fore body being made on the floor to the port side of the ship, and those for the after body to the starboard side, in order to make these moulds serve for both sides of the ship, it is customary to mark the *frame* moulds on both their sides, in order that they may be reversed for timbers on the opposite side of the ship; while those of the *filling frames* have to be marked on one side only, as corresponding futtocks of the same frame are on opposite sides of the joint or square station.

42. Bevellings of Square Body Frames.—After the moulds are made to the timbers of the square body, their bevellings must be determined and marked upon boards, in order that the workmen may trim these timbers. The heads and sirmarks are usually chosen as bevelling spots; in such case the bevellings are taken at these lines upon the floor.

The perpendicular distance between two consecutive square stations at any diagonal in the body plan, is, approximately, the perpendicular opposite the angle of deviation from a right angle of the bevelling of the timbers at that diagonal, the room and space being the base. This may be expressed as "the perpendicular opposite the complement of the angle of bevelling," etc.

Referring to Plate XIX., let fig. 1 be a portion of the body plan, and fig. 2 a corresponding portion of the half-breadth plan, the adjacent square stations AB and CD in the latter corresponding with A_1B_1 and C_1D_1 in the former; also the diagonal line E_1F_1 being represented by EF. From D draw DN perpendicular to AB, and join AD, then MF_1 is equal to AN. Now AN is the perpendicular opposite the angle ADN, the base being the room and space DN. Draw sections of the frames on each side of the joint AB, and produce AD both ways to any points L and K; then it is evident that the bevelling GAN of the timber on the fore side of the frame whose joint is AB, is a little greater than the angle LAN, while the bevelling PAN of the timber on the aft side of the joint is a little less than the angle KAN. But the angle NAD is a right angle minus the angle ADN. Hence the perpendicular distance between two consecutive square stations at any diagonal in the body plan is, approximately, the perpendicular opposite the angle of deviation from a right angle of the bevelling of the timbers at that diagonal. It is clear that the error is caused by the convexity of the surface; so that at amidships, where the ship's side is nearly flat, the error is inappreciable, while the square body terminates before reaching the extremities, where the error would be of importance. We shall presently proceed to show that, by a simple artifice, the measurements from the body plan are so taken as to materially reduce the error which would result by taking the bevellings in the way just referred to. It is also necessary to state that, at the extremities of the square body the bevellings are taken by a method which will be described hereafter (see Art. 45).

Before dismissing Plate XIX., it should be remarked that the diagonal E_1F_1 in the figure, is assumed to be perpendicular to the square stations C_1D_1, A_1B_1; but, should the diagonal be not so inclined, then, in order that the bevellings taken may be such that they can be applied by the workman in the usual manner, viz.—square to the curve of the moulding edge of the timber, it will be necessary still to measure the distance between A_1B_1, C_1D_1 in a direction perpendicular to the former curve at the point M.

Referring to Plate II., it is seen that the distances between consecutive square stations increase continuously from midships towards forward and aft. Hence, if we examine the bevellings at any section, say No. 19, we shall see that in the fore body the timbers on the fore side of the joint have greater bevelling than those on the aft side of that joint; and *vice versâ* in the after body.

Now, as it is customary to trim the square body futtocks on both sides of a joint with the same set of bevellings (by merely reversing the latter), it is necessary that the bevellings so given should be a mean of the actual bevellings of the timbers on the two sides of the joint. Accordingly, this is done on the floor in the following manner:—Still referring to the section shown by Plate II. For the bevellings of No. 19 at 3 *H*: set the point of one leg of a pair of compasses at *A*, and the other at *B*, in a direction perpendicular to No. 19; then swing the compasses about *A*, so as to sweep the arc cutting the diagonal at B_1, bisect the perpendicular distance between this arc and the section 10 (which at present assume to be section 18), and measure the distance *AP* from the leg *A* of the compasses to this point of bisection; the distance so found will be the foot of a perpendicular opposite the mean angle of deviation from a right angle of the bevellings of the two sets of futtocks of the frame 19 at that harpin, the room and space being the base of the triangle. The preceding is the mode of obtaining the approximate bevelling at some yards; it has certain advantages which will be referred to presently. At other yards, however, it is customary to measure the perpendicular distance between two alternate sections, and set up this as the perpendicular, with double the room and space as the base of the triangle. It is evident that this gives the same angle as before. We need hardly remark that the bevelling so found is for the intermediate station between the alternate ones whose distance apart was measured.

43. Bevelling Frame.—We will now proceed to show the mode of marking the *Bevelling Boards*, to do which we must construct a *bevelling frame*. See Plate XX., which represents a board about 2 feet 6 inches wide and 4 feet long, having its edges straight and parallel. To one of these edges is fastened a parallel-edged straight batten, about 1¼ inches wide and ⅝ inch thick; another straight batten, of similar dimensions, has a plain clamp at one end, and a screw clamp at the other, the latter being so fitted that the batten may be tightened to, or loosened from, the board at pleasure. We will suppose this latter batten to be screwed tightly in place, so that its edge is parallel to the fixed batten. Parallel lines, about ¾ inch apart, are then drawn square across the two battens, throughout the length of the board. The *bevelling frame* is now complete.

44. Bevelling Board.—Next, a *bevelling board* has to be prepared, that is, a board upon which the bevellings are to be marked. This is usually a straight and parallel-edged piece of $\frac{1}{2}$ inch board, about a foot wide, and sufficiently long to receive the number of bevellings that are to be marked upon it, giving a $\frac{3}{4}$ inch space between the bevelling lines, and making sufficient allowance for the obliquity of the latter. A straight line is drawn upon the board parallel to the left hand edge, and about 1 inch from it.

Two boards are generally sufficient to receive all the bevellings; one being for those of the fore body, and the other for those of the after body. The bevellings are marked in groups (see Plate XX. A), those at the heads forming one set of groups, and those at the sirmarks another set. Each group is marked with the name of either the head or sirmark, as the case may be; and each bevelling has marked upon it, within the one inch space, the alphabetical or numerical position of the section.

Both sides of the board are usually occupied by the bevellings, especially in the case of a large ship. The boards shown on Plate XX. A, are supposed to have the bevellings at *FS* on the back of those at *FH*, and so with the others.

In trimming a timber the workman copies from this large bevelling board the bevellings of the timber he has to trim, and transfers them to a small board of his own.

It has already been shown how the feet of perpendiculars opposite the mean angle of deviation from a right angle of the bevellings of the two sets of futtocks at any section are obtained—the base of the triangle being the room and space by one method, and twice the room and space by another. We will now proceed to show how the bevellings are marked in when their data are known. Again referring to Plate XX., set the movable batten of the bevelling frame parallel to the fixed one, and at a distance from it equal to the room and space plus the breadth of margin on the bevelling board, which is 1 inch in this case. If the double room and space method is adopted, then the battens must be set apart twice the room and space plus the margin on the board; but as the bevelling frame must be inconveniently wide in order to do this, the other method is preferred, as the trouble saved by working with a narrower frame more than compensates for the extra labour involved in taking the mean distances, as illustrated by Plate II.

Having drawn square across the bevelling board a number of lines $\frac{3}{4}$ inch apart (or whatever may be the spacing of the lines squared across the bevelling frame), next put the bevelling board upon the latter with its edge against the fixed batten, and with the square lines on the bevelling board exactly in a straight line with those on the frame. If preferred, the square lines on the board can be drawn across it by joining the lines on the two battens of the frame, when the board is in place against the edge of the latter. These square lines are then consecutively numbered (either alphabetically or numerically) to represent the stations that are being bevelled. Next set down, on the movable batten, below each square line, the distance aa_1, bb_1, cc_1, etc., at the corresponding stations taken off the floor. These distances, as we have shown, are the feet of perpendiculars opposite the complements of the angles of bevelling. Then join each of these points, say p_1, with the intersection P on the bevelling board which the margin line makes with the corresponding square line to that from which the distance has been set down. The angles between these lines, such as Pp_1, and the side of the bevelling board, are the bevellings of the several timbers at the head or sirmark under consideration. Plate XX. illustrates the mode of marking a bevelling board as just described; the angle pPp_1 corresponding to ADN on Plate XIX.

It is evident from the preceding, that by applying the bevel in the workman's usual manner, viz., with the stock against the left hand side of the board and directed towards his body, all the bevellings will be *under*, that is, less than a right angle. Hence they can only be applied, as they now appear, in trimming the futtocks on that side of the joint which is farthest from amidships; and in order to trim the timbers on the other side of the joint, the bevellings must be reversed, that is, the supplements of their angles must be taken. This is done either by holding the stock of the bevel so that it is pointed from the body of the individual, or by holding it against the right hand side of a parallel-edged bevelling board, with the stock pointed in the usual direction, viz., towards the body.

We thus find that when the first futtock frames are on the amidship side of the joint, their bevellings are always *standing*, or greater than a right angle, as also will be those of the third, fifth, and all other odd futtocks. The bevellings of these are therefore taken from the board as just described; whereas those of the floors, second, fourth, and all the even futtocks, will be *under*, and the latter can be taken from the board in the ordinary manner.

As we shall see when treating of "actual building," the workman in copying the bevellings from the bevelling board given from the floor to his own board, when about to trim any futtock, first determines upon which side of the joint the timber he is to trim will be situated, and so decides whether the bevellings he requires are *under* or *standing;* when this point is settled, he copies the bevellings upon his board, so that in taking them from the latter when trimming the timber he can hold his bevel in the ordinary manner.

45. Frames at the Extremities of the Square Body.—At the extremities of the square body, and where it merges into the cant body, the timbers have greater bevelling than those more nearly amidships, and the bevellings of the futtocks on the fore side of the joint become much greater than those on the aft side. These are generally bevelled in the following manner, which has the advantage of accuracy:—In the half-breadth plan lines are drawn on either side of the frame to be bevelled, and distant from it the siding of the floors (see Plate XXI.). Then, if the harpin is square to the curve of the section, or nearly so, the bevellings are taken by applying an ordinary bevel to the diagonal lines in the half-breadth plan on the floor, and transferring the angles *RQT*, *SQT* to the bevelling board for trimming the futtocks on the fore and after sides, respectively, of the joint of No. 1 square body frame at floor head, and similarly for the bevellings at the other harpins. If, however, the harpins are not normals to the sections in question, it will be necessary to draw the bevelling edges in the body plan, and then measure the perpendicular distances between the moulding and bevelling edges at the several harpins, and set these distances off on the bevelling frame as before, taking care, however, to set the movable batten at a distance from the fixed one equal to the siding of the floor plus the 1 inch for the margin on the board.

Having thus obtained the two sets of bevellings for the timbers on the two sides of the joint, it is not necessary for us to reverse the bevellings as for the more midship portion of the ship.

46. Angle of Seating.—When the frames are perpendicular to the keel, the bevelling of the *seating* of the floors, *i.e.*, the angle between the plane of the side of timber and the keel is a right angle, so that a line squared across the bevelling board gives the *seating* of the floors throughout the whole length of the ship wherein the keel is straight. Should the frames be not perpendicular to the keel, the angle between the square stations and the upper side of keel gives the bevelling for the seating of the floors at the straight part of the keel. In all cases the angle of seating is given with the frame bevellings, and is taken with a bevel from the floor, in the manner shown by Plate XXII., fig. 2.

47. Moulding of Frames.—We have already drawn the inside of the timbers of the midship section upon the floor. The thicknesses of the timbers measured square to the surface of the ship are termed the *mouldings*. The *mouldings* are usually kept uniform throughout the ship at each head and sirmark. In some dockyards, it is the practice to mark the mouldings of the timbers at each head and sirmark upon the frame moulds, and as these mouldings are square to the surface, the workman has to discover the thickness he must set off in the plane of the side of the timber, in order that the latter may be to its true moulding.

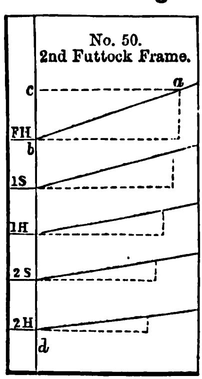


Fig. 4.

This is done by setting out the true moulding *ca*, fig. 4, square from the margin line *dc* on the bevelling board to intersect the bevelling of the timber at the head or sirmark in question at *a*; then the distance *ab*, measured from this point to the margin, along the line of the bevelling, gives the moulding of the timber in the plane of its side.

At other yards, however, a stick is provided for each head and sirmark, and upon this stick are marked the mouldings of all the square body frames measured square to the surface at that head or sirmark. These sticks are known as *scantling* or *moulding sticks*. The actual mouldings in the planes of the timbers are obtained from those given on the sticks in the same manner as already explained.

48. Half Breadth Staffs.—To correct the frames when they are in place, and keep the ship to the true form, *half breadth staffs* are made, upon which are marked the half breadths of the ship at the several heads, sirmarks, port sills, etc., as taken from the body plan upon the floor (see fig. 3, Plate XIV.). At some yards it is the practice to give the *full* breadths (and not the *half* breadths) on staffs, termed *spread staffs*, which have the middle line marked upon them. In both cases, the heights at which the staffs are to be held are given on separate staffs, such as is shown by fig. 4, Plate XIV.

49. Cutting Down Staffs.—The height of the insides of the floors at the middle line are given by what are termed *cutting down staffs*, which show the distances between the under and upper sides of keel and the cutting down line at the square stations (see fig. 5, Plate XIV.).

50. Ribband Battens, sometimes known as *station staffs*, are provided as a check upon the relative positions of the frames. These are battens which have been bent to the curvature of the portion of the harpin lines in the half-breadth plan of the square body, and then the intersection of the square stations are marked upon them and numbered. The *ribbands*, *i.e.*, the harpins of the square body, are marked by these battens, and when they are temporarily secured to the timbers, the latter are set so that the joints of the frames shall coincide with the positions marked for them on the ribbands (see fig. 2, Plate XIV.).

The preceding is all the data that is usually required in trimming the frames of the square body. In some small vessels, however, which have been recently constructed in H.M. dockyards, instead of the mouldings being uniform along the lines of the heads and sirmarks, they have been kept constant at each level line. In such a case, in order to give an account for trimming the timber to its moulding, it is necessary to draw level lines through the points where the planes of the heads and sirmarks cut the midship section; these levels are marked upon the moulds; and the mouldings furnished to the workman, either on the mould or by means of scantling sticks, are then set off by him at the positions so given. The sidings in these cases alter at the heads and sirmarks as usual.

51. Beam Moulds and Beam End Line.—Now that the moulds to the square frames are issued, those for the beams may next be considered.

The lines of *beam at middle, beam at side,* and *deck at middle,* are given on the sheer draught, as was explained in Chap. I. The former is rased or scratched in on the floor in the body plan, being copied into that plan from the sheer plan by measuring square to the base line the height at which the *beam at middle line* in sheer cuts each square station, and transferring these heights to the body plan, square to the base line, upon the corresponding stations.

The midship beam itself is also drawn in the body plan, being copied from the midship section. We have now to determine the curves and lengths of the beams, in doing which we will also show, as an exercise, how to obtain the *beam at side line* from the *beam at middle line.* Not that this line is required in actual practice, as all we have to do on the floor is to determine the beam mould, the mode of doing which is included in the following.

Although the beam end line is given on the sheer draught, it is not fixed like the beam middle line, which has simply to be copied from the sheer plan, subject only to the amount of correction which a fair batten will give when bent to pass through the points marked upon the floor. The distance between the beam end and beam middle line at any square station in the sheer plan, is evidently the *round up* in the length of the beam at that section. Hence, having given the latter line, together with the curve of the longest beam and the lengths of the beams in the deck under consideration, the former line is at once determined by setting below the latter the amount of round up for the beam at each square station, and passing a curve through the points so obtained. The curve or *round up* of the beam must therefore first be drawn.

The curve of a beam is that of an arc of a circle. This circle being necessarily of very large radius, the portion of it that is required is conveniently constructed by certain simple methods well known to geometricians, a few of the more practicable of which we now proceed to give. The versed sine of the arc, or *round up of the beam*, as it is usually termed, is given in the midship section.

The chord of the arc is the straight line drawn from end to end of the beam, and its length is accordingly found by measuring on the floor the breadth of the ship on the inside of the timbers at the height of the deck amidships.

52. To Get in the Round up of a Beam.—See Plate XXIII., fig. 1. Draw a straight line AB equal to half the length of the beam; from the point *A* draw *AC* perpendicular to *AB*, and in length equal to the given round up of the beam. Join *BC*, and from the point *B* draw *BH* perpendicular to *BC*; also through *C* draw *CH* parallel to *AB*. Divide *AB* and *CH* into any number of equal parts the same number in each, and join those opposite each other, as *DF*, *EG*. Through *B* draw *BO* perpendicular to *AB* cutting *CH* at *O*, divide *BO* into the same number of equal parts as *AB* or *CH*, and join *C* with each of the divisions. Then through the point *C*, the point *a* where *DF* cuts *CK*, the point *b* where *EG* cuts *CL*, and the point *B*, draw the curve *CabB*: this will be an arc of a circle whose semichord is *AB* and versed sine is *AC*. If *AB* be produced to *M*, *AM* made equal to *AB*, and a similar construction be made, then *BCM* is the curve of the beam.

When the round up is very small compared with the length of the beam, as is the case in a ship, it is sufficient for all practical purposes to draw *BH*, and therefore *DF* and *EG*, perpendicular to *AB*. This is the method usually practised on the mould loft floor, and, as drawn in the figure, it is mathematically correct.

Fig. 2 on Plate XXIII. shows another method of getting the curve of a beam. Let *AB* be the half length of the beam, and *AC* the round up, drawn perpendicular to *AB* at the point *A*. Join *BC*, and from the point *C* draw *CE*, making, with *BC*, an angle *BCE*, equal to *BCA*, and take *CE* equal to *CA*. This latter operation is usually performed, in practice, by drawing *AQ* perpendicular to *BC*, and producing it to *E*, making *QE* equal to *AQ*, and joining *CE*. Join *BE*, and from the point *B* draw *BD* perpendicular to *AB*, and in length equal to twice the round up *AC*. Then divide the lines *AC*, *CE*, and *BD* each into the same number of equal parts at the points *K*, *L*, *M*, *N*, *G*, and *H*. Join *BM* and *BN*, also *LG* and *KH*, cutting the two former at the points *O* and *P* respectively. A curve passed through the points *C*, *O*, *P*, *B* is the arc of a circle, and the required curve of the beam. Make a similar construction on the other side of *AC*, upon the line *AB*, produced to *F*, *AF* being equal to *AB*; then *BCF* is the whole curve of the beam. This method is also mathematically correct.

The following method gives a very good approximation to the curve (see fig. 3, Plate XXIII.):—Draw a quadrant *DBC* of a circle with a radius equal to the round up of the beam. Divide *CB* into any number of equal parts, *CA*, *AE*, and *EB*; also divide the arc *DB* into the same number of equal parts, *DF*, *FG*, and *GB*. Join *AF*, *EG*. Then draw a straight line HB_1 equal in length to the beam; bisect it at *C*, and draw *CD* perpendicular to it and equal to the round up. Divide CB_1 into the same number of equal parts that *CB* was divided into, and let A_1 and E_1 be the points of division. From these points draw A_1F_1 and E_1G_1 perpendicular to CB_1, and equal to *AF* and *EG* respectively. Make a similar construction on the other side of *CD*, and a line passed through the points B_1, G_1, F_1, *D*, *L*, *K*, *H* is approximately the curve of the beam. It is hardly necessary to state that in each of these methods of determining the curve of the beam, the greater the number of divisions made, the more dependence can be placed in the curve being that of a true circle. Of the three methods we have just given, the first is much to be preferred, on account of its combined simplicity and accuracy.

We will suppose the midship beam drawn, and then rased on the floor in the body plan. We next draw a level line in that plan to touch the top of the beam; then the distance measured down from the level line upon the beam line at any distance from the middle line, is termed the *round down* of a beam of that length.

We have already rased in the beam middle line in the body plan. Now, before we can tell the round down of a beam at any station, its length must be measured; and as the beam bears against the inside of the timbers, the scantling of the frame in the plane of the station, at the height of the beam line, must be set inside the square station in the body plan. Therefore, where the beam middle cuts each square station in the body plan, draw a horizontal line whose length is equal to the said scantling, measured in a level plane. The inner extremities of these lines will give the ends of the beams. For the length of the square body, the scantling to be set in will be as nearly as possible equal to that given in the moulding book, or marked on the frame moulds at the height of beam line. But, at the extremities of the ship, the scantling to be used is obtained by setting in the half-breadth plan, at the nearest level or harpin line to the beam line (or, in the absence of these, to a level line drawn at the beam line), the scantling of the frame, square to the curve, to intersect each square station. The distance from this point to where the station cuts the level or other line, measured in the direction of the station, is the scantling to be set in on the corresponding horizontal lines we have just drawn in the body plan, and the points so obtained will be in the line of beam ends against the inside of the timbers.

We have now the lengths of the beams at each square station, and so the round down for each beam can be obtained from the beam mould, by measuring the length of the beam in question along the beam mould, and finding the height of the level line touching the top of the beam above the curve of the beam at that point. These distances are set below the beam middle line on the corresponding square stations in the sheer plan; a curve passed through these points is the beam end line. It is evident that right forward and aft, at the cutting down lines, the beam end and beam middle lines unite.

In a wooden ship, the lengths of the beams when of wood are taken at the ship, so that all the workman requires in trimming the beams is the beam mould, the latter having the middle line marked upon it. The lengths of iron beams are measured upon the mould loft floor.

A straight line is struck upon the beam mould, and a spiling is marked in order to check the curvature; also, the siding and moulding of the beam are marked upon it.

CHAPTER IV.

53. The Cant Body.—Hitherto we have been treating of those frames, the planes of whose sides coincide with, or are parallel to, the planes of the square stations. But if the frames at the extremities were arranged in this manner, a ship of no very considerable bluffness would require timber of greater scantling than could possibly be obtained. This difficulty is overcome by, what is termed, canting the frames; that is, by disposing the plane of each frame at such an angle to the sheer plane as shall make it as nearly square to the surface as possible. Fig. 5 illustrates what is here meant: *ABCD* is a horizontal section of a timber of the frame, when the plane of its side is square to both the half-breadth and sheer planes; and *EFGH* is a similar section of a timber, having the same siding and moulding, when the plane of its side is canted to the sheer plane, but still kept square to the half-breadth plane. The difference in the sizes of the pieces of timber required in order to convert the frames in the two cases is evident.

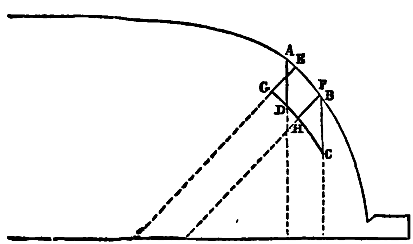


Fig. 5.

Besides assisting conversion, the cant timbers have the advantage of giving better fastening for the plank; and being in planes so nearly perpendicular to the surface of the ship, they afford better means of combining the several parts of the hull, at such important parts as the bow and stern.

54. Disposition of Cant Frames.—Having thus shown the necessity for canted frames, we will proceed to dispose or arrange them. This operation is entirely left to the judgment of the draughtsman, and it is, to a great extent, a tentative process.

The square body ends, and the cant body commences just where the angles between the level lines and square stations in the half-breadth plan begin to deviate greatly from right angles, or where a difficulty is found in obtaining suitable timber owing to the bevelling required. It is desirable to continue the cross floors to about two frame spaces before the heel of the foremast. If the floors are placed on the fore side of the moulding edge, or joint of the frame, in the fore body, and on the aft side in the after body, it is advisable to terminate the square body with a frame, as the deadwood has then an unbroken piece of timber to tenon into.

Before disposing the fore cant body, the half siding of stem and deadwood are drawn in the half-breadth plan, and the beardings of these in the sheer plan. As the trace of the cant in the half-breadth plan is a straight line—the plane of cant being square to the half-breadth plane—the cant frames are disposed in that plan. Unlike the frames of the square body, there are no openings between the heels of the cants, neither is the siding of their heels the same as that of the floors, but generally a little less. The height to which the close joints are continued increases towards the extremities of the ship, and right forward they are close for at least half the height of the ship, and sometimes to the whole height. It is thus seen that between the endings of consecutive cant joints, there is a space nearly equal to twice the siding of an ordinary floor. Sometimes when the longitudinal girth of the bow at the topside is much in excess of the space on the deadwood to receive the heels of the cants, it is necessary to snape the heels, one against the other, in order to end the necessary number of cant frames required to fill the space at the upper part of the frames. It is only in full bowed ships, however, that such expedients are necessary. Formerly, when bluff ships were much more common than at the present day, it was customary to dispose some of the foremost of the cant timbers in planes either parallel, or nearly so, to the sheer plane, their heels being secured against an ordinary cant (see Plate XXIV.).

55. Knight Head and Stem Piece. — Before disposing the ordinary cant frames, we must first arrange the *knight head, stem piece,* and *hawse timbers.* The *knight head,* as shown in Plates XVII. and XXIV., is the next timber to the stem in a small vessel, and in larger vessels it is (if a cant) separated from the stem by a small wedge-shaped timber, termed the stem piece. Before the knight head can be drawn, the bowsprit must be marked in, and then, in a large ship, the fore side of knight head will be placed just sufficiently far from the middle line that it may not be wounded in cutting the bowsprit hole, except a little on the inside of the ship. The space between the fore side of knight head and stem is then occupied by the stem piece already referred to. In small vessels a piece of timber is easily obtained sufficiently large to fit close against the stem, and still to leave sufficient wood uninjured by the bowsprit hole to provide the required siding of knight head at its upper part.

56. Hawse Timbers.—The timbers of the fore cant body, next abaft the knight head, are known as *hawse pieces,* these being close jointed for a great portion of their length, and forming a compact and strong framing around the hawse holes. Care is taken in arranging these timbers that no more of them may be wounded in cutting the hawse holes, than is actually necessary.

These timbers being arranged, the remainder of the cant joints can be disposed in the half-breadth plan. To do this we divide up the curve of the top breadth, or fullest line, and determine how many timbers having the required siding, together with the corresponding number of openings of the required width, will fill up this space.

We next determine the number of timbers of the required siding that can be heeled against the deadwood. If the number of timbers thus determined agrees with the number which are required to fill up the longitudinal girth at the topside, all difficulty is at end, and our disposition of cants can be readily drawn. But if it be found that these do not coincide, then we must try if the difficulty may be overcome by slightly reducing or enlarging the openings, slightly increasing or diminishing the scantlings, making certain foremost joints close, or else by snaping the heels, so that one cant may partially or wholly step against another.

When we have approximated somewhat to our disposition, the joints of the cant frames are drawn in the half-breadth plan on the mould loft floor, and then a series of corrections are made in the following manner:—Nails are driven at the intersections of the sides of the timbers with the half siding of deadwood, and the sides of the timbers with the top breadth line. A chalk line is fastened to the last nail, and the line is then wound around the other nails, so that it indicates the sides of all the timbers of the cant body. The sizes of the timbers at their heads and heels are then equalized, as also are the openings, by shifting the nails and tightening the cord around them. When the arrangement is satisfactory, the joints of the frames are chalked or rased in. Plate XXIV. shows plans of two dispositions of cants in the fore body. It should be observed that care must be taken to arrange these frames, so that, if possible, timbers may form the sides of ports without joggling them.

57. The Stern Framing.—The stern framing, even of our most recent ships of the line and frigates, is the most complicated portion of their structure, this being due to the peculiar form given to the stern, both to suit the eye and to meet other, and more practical requirements.

The stern framing of the small wooden ships of war at present being built is of a far more simple character, and conforms very closely to that of the bow.

As different periods have produced their particular forms of land architecture, so there have been a variety of styles of naval architecture, each of which has grown out of that preceding it, and to which it has been preferred for a time as being more beautiful and useful; in turn to give place to other styles of building, which have been considered superior to it. In no part of a wooden ship has these differences in style been more marked than at the stern, and the problems in laying off have been similarly influenced. What have been termed *square sterns* have given place to *round sterns*, and these again to *elliptical sterns*, until, in the present utilitarian age, it would be a difficult question to decide what is the prevailing type. This is more particularly true of the ships of the Royal Navy, the sterns of which, as at present built, should, with accuracy, be termed *parabolic*. In the merchant navy, so few wooden ships are being built of any considerable size, that no law can be deduced from the few examples at hand. The largest wooden ships are built in North America, and there the *square stern* still prevails.

In all the styles of stern the combinations of frames are uniform as far aft as the fore stern post, being an ordinary *cant* arrangement. In the *elliptical* stern, the last of these cants is termed the *fashion timber*. As this is the form of stern which was most recently adopted for large war ships, we purpose, in the present small treatise, to devote a short space to a consideration of the elliptical stern, and the style at present in vogue in H.M. service.

58. Fashion Timber—(See Plates XXV., XXVI., and XXVII.).—Before disposing our after cant body, the *fashion timber* must first be drawn in the half-breadth plan, in which plan we will suppose the stern post and deadwood already delineated. If a ship be propelled by a single screw-propeller, the following considerations will govern the position and direction of this timber: It will heel close against the after side of the body-post, so that the aft side of the fashion timber will be coincident with the bearding line at the upper part of the post. It will also be placed at such a *cant* that it will pass close to the side of the screw aperture, and also be near to the fore end of the *knuckle line*, so that the *quarter timber* shall heel against the fashion timber, and leave only the breadth of an ordinary opening between the two timbers at the knuckle line. It should be stated that the termination of the knuckle line is found from the sheer draught. By the preceding arrangement the space above the knuckle, between the quarter timber and the fashion timber, can be filled up by a number of short cants stepping upon the latter timber. If these filling timbers stepped on the fashion timber below the knuckle, it would be found necessary to cant them in two directions, similarly to the ordinary stern timbers, of which we shall say more hereafter. Sometimes, in order to fulfil all these conditions, it is necessary to fit several fashion timbers, as shown by the above-mentioned Plates. This will occur more frequently in a screw than in a sailing or paddle-wheel ship, in consequence of the greater overhang of the stern in the former case. By using these additional fashion timbers, shorter stern timbers are required. These after fashion timbers necessarily heel against the lower stern timbers that are nearest the middle line; the other stern timbers, including the quarter timber, heel upon the after fashion piece.

In a sailing ship the fashion piece heels against the stern post just sufficiently far from its after edge as to leave room for the bolt fastenings of the post timber to the post. It stands out as nearly square to the surface of the ship as possible, and is arranged, as before, with regard to the heel of the quarter timber, the position of the latter being governed by the termination of the knuckle line. Having thus fixed upon the fashion timber, which is the termination of the after cant body, we can proceed to dispose the cant frames in that body by the method already described when considering the fore body. We will, however, leave the remainder of the stern framing for treatment in Chap. VI.

59. To Dispose the Cant Frames in the Sheer Plan.—Supposing that the joints of the cant bodies are arranged, we have next to dispose their butts. This can best be done upon paper, and, in fact, may be made part of the same drawing which shows the sheer view of the disposition of the square body (see Plates XVII. and XXVIII.).

A drawing of the half-breadth plan, with the cant disposition in it, is copied from the floor upon paper, to the same scale as the disposition of square body in sheer plan just referred to. In this plan (Plate XXVIII.) are drawn the horizontal ribband lines, level lines, etc., and when ready it is placed immediately below and parallel to the drawing of the sheer plan, to the same scale, which shows corresponding level and diagonal lines. Then the intersections of a cant joint with the several lines in the half-breadth plan are squared up to the corresponding lines in the sheer plan; a curve drawn through these points is the disposition of the cant joint in the sheer plan. It is ended on the bearding line, at a point obtained by squaring up to the latter line, from the intersection of the joint of the cant with the half siding of deadwood in the half-breadth plan.

Before proceeding further, it should be stated that the cants are all *frames*, and hence their butts are in the lines of the *heads*. Having the cant joint disposed in the sheer plan, we are the better enabled to arrange the butts, seeing that we can judge of the lengths of the timbers in it better than in the half-breadth plan. Owing to the decrease in the girth of the ship at her extremities, and to the flatness of the surface at those parts, the timbers of the cant bodies can frequently be disposed so as to embrace three or more harpins.

When the positions of the butts are arranged, the two moulding edges of the timbers can be drawn in the sketch of the sheer plan; if the cants are close-jointed, only the bevelling edges remain to be so drawn. These edges are copied from the half-breadth plan in the same manner as just described when referring to the cant joint. Attention is again called to Plate XVII., which shows a fore body disposition.

It should be observed that a disposition drawn upon a model to a quarter inch scale, is of great value in giving the draughtsman a more correct idea of the timbers required for special parts of the hull, than can be obtained from a drawing.

60. To Lay off a Cant.—While the dispositions of frames are preparing, the draughtsman can be *laying off* the cants. That is to say, he may be determining the curves of the joints or moulding edges of those timbers, and drawing them upon the mould loft floor in such a manner that moulds may be made by which the timbers can be trimmed. It should be stated that moulds are generally made to the joints, or lines through the middle of openings, and these are usually considered sufficiently correct for the sides of the timbers themselves. Sometimes, however, when the openings are large, or the bevelling excessive, it is considered advisable to lay off the edge, near the joint, of each of the sets of timbers composing a cant frame; each of these being then termed a moulding edge.

To lay off a cant, the plane containing it is rabatted upon the body plane, that is, the plane of the cant is hinged about the middle line of the body plan until the former coincides with the plane of the latter plan. In practice this is usually performed with horizontal ribband lines in the following manner:—

1*st*, *By horizontal ribband lines* (see Plate XXIX.) In the half-breadth plan measure, on a staff, the distance square to the middle line to where the cant joint *ab* intersects each horizontal ribband line as at *d*, and set off a line parallel to the middle line of body, at the distance so found, to intersect the corresponding diagonal line in that plan at d_1. This intersection is a point in the projection of the cant in the body plan. Draw a line through this point parallel to the base line. Then measure in the half-breadth plan, along the cant joint *ab*, the distance from the middle line to where the cant joint cuts the before-mentioned horizontal ribband line. Set this distance off from the middle line of body upon the line d_1p parallel to the base line already drawn, and the point *p* so found will be in the moulding edge of the cant when rabatted. By obtaining points from the other horizontal ribband lines, in a similar manner, the curve of the moulding edge can be drawn.

61. To End the Moulding Edge (still referring to Plate XXIX.).—At *c* where the joint of the cant cuts the half-siding of deadwood in the half-breadth plan, square up to the bearding line in the sheer plan at c_2. Measure the height of this point above the base line, and set it up on the middle line of body plan at *e*, measuring from the base line of that plan. Through this point *e* draw a line ec_1 square to the middle line, and set off on it the half-siding of deadwood measured in the direction of the cant joint in the half-breadth plan: the point c_1 thus found, is the ending of the moulding edge.

As we have already stated, the curve thus found is usually, for all practical purposes, a sufficiently good approximation to the curves of the actual moulding edges of the timbers, which are situated on either side of this joint. When, however, it is necessary to lay off both these edges, the operation is performed in a similar manner to that already described, using the lines obtained by continuing the *joint* side of the lowest futtock on each side out to the top breadth, or fullest line, instead of the line of the cant joint.

62. Bevelling the Cants.—We have next to obtain the bevellings, and as we are now dealing with a surface of a more twisted character than at amidships, greater nicety is necessary in obtaining these bevellings than for those of the square body.

The mode adopted is to draw in the half-breadth plan the traces of planes parallel to the plane of the cant joint or moulding edge, and at a distance from it on each side, equal to, at least, the siding of the lowest futtocks in the cant frame. The curves made by the intersection of these planes with the surface are projected upon the plane of the moulding edge, which is then rabatted about its trace with the longitudinal vertical plane, or, which is the same thing, the middle line of body, in the same way as before. In this manner we get, in the body plan, the curves of the moulding and two bevelling edges (as they are termed) situated relatively to each other, just as the square body sections are in the body plan; so that the square distance between the curve of the moulding edge, and that of either of the bevelling edges at any point, is the perpendicular opposite to the angle of deviation of the bevelling of the cant futtock in question from a right angle at that point.

When the two moulding edges of the cant are laid off, instead of assuming the cant joint to represent them both, it is necessary to draw the traces of the planes of the bevelling edges parallel to their respective moulding edges, instead of both being parallel to one line, as in the above description.

In this case the *modus operandi* remains the same as before.

63. We now proceed to lay off the bevelling edge, having the traces of its plane drawn in the half-breadth plan.

To Lay off the Bevelling Edge of a Cant (see Plate XXIX.)—Draw a line fag perpendicular to the moulding edge through a, its point of intersection with the middle line of the half-breadth plan, to cut the bevelling edges fh and gk, produced, if necessary, at f and g.

Then measure, in a direction perpendicular to the middle line of half-breadth plan, the distance from the latter to where the bevelling edge *gk* cuts each horizontal ribband line, as at *l*, and draw a line parallel to the middle line of body, at the distance so found, to intersect the corresponding diagonal line in that plan as at l_1. Draw through this point l_1 a line l_1p_1 parallel to the base line. Then measure from the point *g*—where the perpendicular at the end of the trace of moulding edge cuts the bevelling edge—the distance in the direction of the trace of bevelling edge to the point *l*, where the latter intersects with the before-mentioned horizontal ribband line, and set this distance *lg* off upon the line l_1p_1, already drawn parallel to the base line of body, measuring from the middle line of that plan. If other points be obtained in a similar manner by means of the remaining horizontal ribband lines, a curve drawn through them is the bevelling edge of the cant. Both the bevelling edges are obtained in this manner.

64. To End the Bevelling Edge.—Square up the intersection *m* of the bevelling edge with the half-siding of deadwood in the half-breadth plan to the bearding line in the sheer plan at m_2; and measure the height of the point m_2 above the base line, and set up the distance thus found upon the middle line of body, measuring from the base line of that plan. Draw from this point a line square to the middle line, and measure on it from the latter the length *gm** of the bevelling edge included between the side of deadwood and where the perpendicular from moulding edge cuts the bevelling edge; the point m_1 so found will be the ending of the bevelling edge.

65. To Take the Bevellings of a Cant Frame.—It was remarked, when describing the mode of obtaining the bevellings of the square body frames, that the bevellings as taken from the floor are always *under*, this being due to the fact that the angle between the joint and the portion of the surface farthest away from amidships is alone obtained; the other angle of the frame on the midship side of the joint, being the supplement of this angle of bevelling, is found

* Or *fm* in the case of the other bevelling edge; observing that in this latter case the distance em_1, equal to *fm*, is measured off on the other side of the middle line of the body plan.

by reversing the bevel. Now, in taking the bevellings of a cant frame, since two bevelling edges are laid off, and hence a separate set of bevellings obtained for the portion of the frame on each side of the joint, the bevellings will thus be sometimes *standing* and sometimes *under*. This is due not only to the fact of the bevellings of the two sets of frames being found, but also to the usual twisted character of the ship's surface at her extremities, whereby there are often obtuse and acute angles of bevelling for timbers on the same side of the cant joint. If, in the fore body, the bevelling edge on the fore side of the cant joint in the half-breadth plan is, when rabatted, farther from the middle line of body than the moulding edge, it shows that the deviation of the bevelling from a right angle is in excess, and hence the bevelling is *standing*, and *vice versâ*. The same is true of the bevellings of the timbers on the aft side of the joint. The contrary, of course, holds good for the after body.

To take the bevellings of a cant.—Measure at the horizontal lines, such as d_1p drawn when constructing the moulding edge, the distance square to the curve of the latter between it and the bevelling edge. Then, having set the movable batten of the bevelling frame at a distance from the fixed batten equal to the distance between the moulding and bevelling edges in the half-breadth plan, set the square distances just found *above* the horizontal lines drawn on the bevelling frame to represent the several heads and sirmarks, when the bevellings are standing, and *vice versâ*. The bevellings are then marked as shown in Plate XX., and as already described.

66. Cant Bevelling Board.—See fig. 2, Plate XXX. The cant bevellings are not grouped upon the bevelling board similarly to those of the square body; but the bevellings for each frame are collected together, and marked with the names of the heads and sirmarks at which they are to be applied.

There are, of course, two sets of bevellings for each frame, one for either side of the joint; these sets are each marked with the names of the futtocks which are to be trimmed by them.

To the preceding must be added the bevelling at the cutting down, and that of the heel against deadwood. The former is obtained in the sheer plan, being the angle between a perpendicular through the ending of the disposition of the cant and the cutting down line, while the latter is the angle between the cant joint and the half-siding of deadwood in the half-breadth plan. The snape of the heel of the cant against the deadwood is given by a line drawn through the ending of the moulding edge of the cant in the body plan parallel to the middle line; this line is therefore marked upon the cant mould.

67. Cants with Snaped Heels.—When disposing the cants in the half-breadth plan, it was remarked that sometimes, as shown by fig. 2, Plate XXIV., it is necessary to snape the heel of one cant against another. To give an account to the workman for trimming such a timber, the siding of the heel of the cant and the length of the taper are marked upon the mould. The bevelling of the heel in a horizontal direction, is obtained by taking the angle between the moulding edges in the half-breadth plan of the stepping timber and that stepped upon, as shown in the figure at A. In trimming the timber this bevelling is applied in the direction of a level line at the ending of the moulding edge, for which purpose the level line should be marked upon the mould. To obtain this ending, we have simply to rabat the point of intersection of the bevelling edge of the timber stepped upon, with the moulding edge of the stepping timber in the same way as if the point were the intersection of the moulding edge with the half-siding of deadwood.

For the angle of heeling in a vertical plane, we have simply to draw a line parallel to the middle line of the body plan through this ending; which line should be marked upon the cant mould in the same way as if it were the snape of the heel against deadwood.

68. Cant Moulds.—Separate moulds are usually made to every two adjacent cants, one edge of the board being made to the curve of each cant. For a small ship, one mould will serve for all the futtocks of a frame, and thus one board will be sufficient for all the futtocks of two adjacent cant frames.

Upon the cant mould (see Plate XXX.) we mark the position of the heads, sirmarks, etc., the height of cutting down, the direction of heel against deadwood, together with the distinguishing numbers or letters of the frames to be trimmed by them. The ends of the lines, parallel to the base of body plan, used in rabatting the cant, give the positions of the corresponding heads and sirmarks on the cant mould. To obtain the height of cutting down for the cant, the moulding of the cant at its heel is set in square to its curve to cut the line drawn upon the cant mould for the vertical direction of the heel against deadwood. A level line is drawn, through the point thus obtained, across the cant mould when the latter is in position on the floor. At some yards the mouldings of the cant are marked upon the mould.

Owing to the two edges of a piece of board being made to the curves of two cant frames, it is necessary in marking the latter, to lay the mould *upon* the timber in one case, and hold it *off* the timber in the other.

At some yards it is customary to mark these edges *on* and *off* respectively, for the guidance of the workmen. The moulds have simply to be reversed for trimming the timbers on the opposite side of the ship, for which purpose both the sides are marked and lettered.

We have now shown how all the information required for trimming a cant frame may be furnished to the workmen, the said frame being laid off by horizontal ribband lines. Although, for the sake of convenience, these lines are selected by the draughtsman, yet the cants can also be laid off by level or bow lines. By the term "*bow*" line is included both bow lines and buttock lines.

69. To Lay off a Cant by Level Lines (see Plate XXXI.).—In practice level lines alone are rarely used in laying off cants; and, if they are, it is merely either as a check to the horizontal ribband lines, or to give points at places where the diagonals do not cross the cant, except at wide intervals.

Measure in the direction of the cant joint *ab* in the half-breadth plan, the distance from the middle line to where the line *ab* cuts each level line, and set these distances off on the several level lines in the body plan at b_1, c_1, and d_1, measuring from the middle line of that plan. A curve passed through these points, b_1, c_1, and d_1, is the cant edge required.

It is ended, as was described when showing how to lay off the cant, by horizontal ribband lines.

The bevelling edges are laid off similarly to the moulding edge, the distances of the intersections with the level lines being measured in the half-breadth plan from the same point, *g*, as when laying off the bevelling edges by horizontal ribband lines (see Art. 61).

The bevellings are taken by measuring the square distances between the moulding and bevelling edges at b_1, c_1, d_1, etc., where the level lines cut the former, and the positions of these level lines must therefore be marked upon the mould in order to give bevelling spots. The curves drawn in the sheer plan on Plate XXXI. will be referred to presently.

70. To Lay off a Cant by Bow or Buttock Lines (Plate XXXII.).—Square up the intersection of the cant joint *ab* in the half-breadth plan, with each bow line,* to the corresponding bow line in the sheer plan; a curve passed through the points so obtained gives the *disposition* of the cant in that plan. To obtain the ending: square up to the bearding line of deadwood in the sheer plan, the intersection of the cant joint with the half-siding of deadwood in the half-breadth plan.

Then for the true shape of the cant, measure the height above base line of sheer plan at which the disposition of the cant, already drawn, intersects each bow line, and draw lines in the body, square to the middle line of that plan, at heights above its base equal to those just found. Then measure in the half-breadth plan, along the cant joint, the distance from the middle line to where the cant joint cuts each bow line, and set these distances off from the middle line of body plan upon the corresponding square lines already drawn. A curve passed through the points so obtained will be the true shape of the cant required.

To end the curve, proceed as when laying off the cant by horizontal ribband lines (see Art. 61).

The bevelling edges are laid off similarly to the moulding edge or joint, with the same modifications as were

* It is assumed we are laying off a fore body cant; if the cant is in the after body, *buttock* must be substituted for *bow.*

required when laying off the bevelling edge by the previous methods.

The bevellings are taken at the lines squared out from the middle line of body, and the positions of these lines must be marked upon the cant mould in order that the workman may know where to apply the bevellings when trimming the timber.

The preceding methods of laying off a cant by level lines and bow or buttock lines, are given chiefly as exercises, although they are sometimes useful to correct the method by horizontal ribband lines, as well as to give additional spots for the curve of the cant.

In conjunction with the horizontal ribband lines, points for the cants above the highest head or sirmark are obtained by means of such lines as the top side, top breadth, and port sill lines. In using these lines to lay off the cant, a method is employed similar to that when laying off by bow lines. Their positions are marked upon the cant moulds, and are given, as in the case of the diagonals, by the intersections of the curve and the horizontal lines upon which the breadths are set out from the middle line of body plan. Bevellings are taken at these points.

Harpins are usually made to these top side, etc., lines; but of these more will be said in the next chapter.

71. Rationalé of Methods.—Having thus considered some of the principal problems connected with the cant timber which are met with in actual work on the floor, we now proceed to examine the *rationalé* of the processes employed.

The manner of obtaining the disposition of the cant in the sheer plan is evidently based upon the simplest principles of projection, and therefore needs no explanation. But the manner of rabatting the cant plane upon the body or sheer plane, so as to obtain the true form of the cant in those plans, is not quite so obvious to the beginner.

It has already been said that the plane of the cant is perpendicular to the half-breadth plane, but inclined to the sheer plane; and to get the true form of the cant joint the plane containing the latter is hinged about its trace with the sheer plane until it is parallel to the body plane, in which position all lines in the cant plane when projected upon the body plane, will appear in their actual form.

The trace just referred to will, of course, be coincident with the middle line of body plan when it is projected on that plan. When, therefore, in laying off a cant by horizontal ribband lines, the distances of the intersection of the cant joint with these lines is measured square to the middle line of half-breadth, and set off parallel to the middle line of body to intersect the corresponding diagonal in that plan, we are determining the height of that intersection above the base line of the body plan. Now, when hinging the cant plane about its trace with the sheer plane, all points in the former plane will remain at a constant height above the half-breadth plane; so that by drawing a line through the intersection, square to the middle line of body plan, or parallel to the base line of that plan, we are drawing the direction in which the point moves while the plane is being hinged or rabatted. Again, when setting out on this horizontal line (measuring from the middle line) the distance along the cant joint of the same intersection in the half-breadth plan, we are determining the distance from the axis of rabatment at which the point will be when the plane of the cant is parallel to the body plane.

The bevelling edges could be laid off similarly to the moulding edges, only in that case we would have that which we do not require, as our aim is not to get the curve of the bevelling edge for the purpose of making a mould, but to get the curve of the bevelling edge in such a position with regard to the moulding edge, that the square distance between the two curves at any point shall be the perpendicular opposite the angle of deviation of the bevelling from a right angle.

To do this, we, in effect, project points in the plane of the bevelling edge upon the plane of the moulding edge, and then rabat the latter in the manner already described. This will be evident by reference to Plate XXIX., bearing in mind that in so projecting points in one plane upon the other plane, the projecting lines are perpendicular to the plane of the moulding edge.

This explanation of the process of laying off by horizontal ribband lines, will sufficiently explain the modes by level and bow lines also.

72. We will now consider certain problems connected with the cant timber, which, although rarely, if ever, involved in actual work on the mould loft floor, will yet repay an examination, being useful as exercises. The first of these which we will notice is that of obtaining the true form of the cant in the sheer plan.

To Lay off a Cant in the Sheer Plan (see Plates XXXI. and XXXII.).—We will suppose the cant to be disposed in the half-breadth and sheer plans, and now proceed to rabat the plane of the cant about its trace with the plane of the latter plan. This trace is found by drawing a perpendicular line a_2h_2 through the intersection of the cant joint with the middle line of the half-breadth plan.

Then through the intersections of the cant projection in the sheer plan with the several diagonals, levels, port sill, bow, or other lines, draw horizontal lines (these will, of course, be unnecessary in the case of level lines), and set out on these horizontal lines, measuring from the trace a_2h_2, the distances from the middle line along the cant joint to where the latter cuts the corresponding lines in the half-breadth plan. A curve drawn through the points so obtained is the true form of the cant joint or moulding edge.

It is ended at a point on a line drawn through the ending of the disposition, and square to the trace a_2h_2, which point is at a distance from the trace equal to the half-siding of deadwood measured in the direction of the cant joint.

To lay off the bevelling edges.—They are first drawn in the half-breadth plan as by the other methods. Then treat the bevelling edges as the moulding edges, measuring the distances of the intersections from the line *ag* drawn square to the moulding edge in the half-breadth plan as before, ending each bevelling edge on a horizontal line drawn through the ending of the disposition of bevelling edge, and at a distance on this line, measured from the trace a_2h_2 of moulding edge plane, equal to the distance between the half-siding of deadwood and the line *ag* drawn perpendicular to the joint at its end.

The bevellings are taken at the horizontal lines just drawn in the sheer, and in the same manner as when laid off by other methods.

73. Cant Mould in Sheer Plan.—If a mould be made to the cant timber when so laid off, the positions of the harpins, etc., on the mould are given by the points where the horizontal lines, drawn out when rabatting, intersect the curve. These are the bevelling points for trimming the timber. The height of cutting down is obtained by drawing a horizontal line across the mould, through the intersection with the cutting down line made by a perpendicular through the point where the cant joint cuts the half-siding of deadwood. The direction of the heel of the cant against the deadwood is given by drawing a line across the mould parallel to the trace a_2h_2, and at a distance from it equal to the half-siding of deadwood, measured in the direction of the cant joint. The bevelling of the heel against deadwood is taken, as before, from the half-breadth plan.

74. To Lay off a Cant in the Half-breadth Plan.—We will now show how to lay off a cant in the half-breadth plan. In this case the cant plane is rabatted about its trace with the half-breadth plane, until the former plane is coincident with the latter (see Plate XXXIII.).

From where the cant joint ab in the half-breadth plan cuts each horizontal ribband,* level, bow, or other such line, draw a line perpendicular to the joint. Then, having drawn the disposition b_1c_1 of the cant in the sheer plan by the method previously given, measure the height above the base line at which the disposition of cant b_1c_1 cuts the corresponding horizontal ribband, level, or bow line in that plan, and set off all such distances on the respective lines perpendicular to the cant joint which have already been drawn, measuring from the joint. A curve passed through these points is the true curve of the moulding edge of the cant.

It is ended on a line drawn perpendicular to the cant joint at its intersection with the half-siding of deadwood, and at a distance from the joint equal to the height of the ending of the disposition of cant in the sheer above the base line of that plan.

To lay off the bevelling edge.—Draw the bevelling edge

* Horizontal ribband lines only are used in Plate XXXIII.

in the half-breadth plan as before, and from its intersection with each of the horizontal ribband, level, and bow lines, draw a line perpendicular to the joint; then set out on these perpendicular lines, *measuring from the moulding edge*, the heights at which the disposition of bevelling edge in the sheer plan cuts the corresponding diagonals, etc.; a curve passed through these points is the bevelling edge required. It will be observed that this bevelling edge is so laid off with respect to the moulding edge, that the square distance between the curves at any point is the amount to be set off when obtaining the bevellings in the usual manner.

The bevelling edge is ended on a line drawn perpendicular to the intersection of the bevelling edge in the half-breadth plan with the half-siding of deadwood, and at a distance on this line, *measuring from the moulding edge*, equal to the height of the ending of the disposition of the bevelling edge above the base line of the sheer plan.

75. Cant Mould in the Half-Breadth Plan.—If a mould is made to the cant as thus laid off, the positions of the harpins and other bevelling spots are given by the intersections of the perpendicular lines with the curve of the cant. The bevellings are taken at these places, and in the same manner as when the cant is laid off by the preceding methods.

The bevelling of the heel against the deadwood in a level plane is obtained, as before, from the half-breadth plan. The heel against deadwood is given by a line *cp* drawn across the mould perpendicular to the cant joint, from its intersection with the half-siding of deadwood; and to determine the height of cutting down, proceed as stated in Art. 68. The same principles are involved in Arts. 72 to 75, as were given at Art. 71, in explanation of the method of laying off the cant in the body plan by the ordinary method, and if this be understood, no further explanation will be needed than has already been given.

76. We will conclude this chapter with the solution of a problem, which, although of no practical utility, is yet a valuable exercise on the cant timber; viz.—

To Lay off the Moulding Edge of a Cant by Rabatted Diagonals only, that is, without the aid of the horizontal projections of these lines, but using only their true curves as rabatted in the half-breadth plan, and the traces of the diagonal planes in the body plan.

Let *ab*, Plate XXXIV., be the trace of the plane of the moulding edge of the cant in the half-breadth plan, and *cd* be the trace of the diagonal plane in the body plan, c_1d_1 being its rabatted form in the half-breadth plan. Take any point *g* in the trace *ab*; then it is evident that this is the horizontal projection of a certain point in the intersection of the diagonal plane with the cant plane; for the line *ab*, besides being the horizontal trace of the cant plane, is also the horizontal projection of the intersection of the cant plane with the diagonal plane. From *g* draw *gh* perpendicular to the middle line *xy* of the half-breadth plan, and find a point g_2 in *cd* at a perpendicular distance h_2g_2, equal to *hg*, from the middle line of the body plan. In the half-breadth plan, continue *hg* to *k*, making *hk* equal to cg_2; then *k* is the projection of the point *g*, when it is rabatted in the diagonal plane, about the axis *xy*, upon a plane through *c* parallel to the half-breadth plane. Join *ak*, and produce the line to *l*. Then, since *a* and *k* are two points in the intersection of the diagonal plane with the cant plane when that intersection is rabatted parallel to the half-breadth plane, therefore the line *al* is the intersection of the two former planes when so rabatted. From the point *l* draw *lm* perpendicular to *xy*, cutting *ab* at *r*, and from the point *c*, in the middle line of the body plan, measure along *cd* the distance *cP* equal to *lm*. Then *P* is a point in the projection of the moulding edge of the cant in the body plan.* By obtaining points from the other diagonals in a similar manner, the projection of the curve can be drawn. This line is ended in the ordinary way by projecting the intersection of the cant trace with the half-siding of deadwood at *n*, to the bearding line of the sheer plan at *T*; then measuring the distance of this point above the base line of sheer, and setting it upon the middle line of body plan (measuring from its base) to the point *W*; the projection ends at a point *R*, upon a perpendicular to the middle line

* The point *P* may also be found by drawing a line parallel to x_1y_1, and at a distance from it equal to *mr*; this line will cut *cd* at the point *P*, for *r* is a point in the horizontal ribband line corresponding to *cd*.

through the point W, the distance WR being equal to the half-siding of deadwood at n.

Next, to obtain the true curve of the cant by rabatting its plane on the body plane. Proceed in the usual manner as when laying off by horizontal ribband lines. Draw through P a line QPp perpendicular to the middle line of body, and set off on this line a distance Qp equal to ar, then p is a point in the curve when rabatted. On obtaining similar points by means of the other diagonal lines, the true curve of the moulding edge of the cant can be drawn. The line is ended upon the line WR at a point S, such that WS is equal to an.

77. To Lay off the Bevelling Edge of a Cant by Rabatted Diagonals.—Proceed at first in a similar manner to that already described. Let a_1b_1 be the trace of the cant plane with the half-breadth plane. Take any point g_1 in this trace, say a point at the same distance as g is from xy, this being done for the sake of convenience. Obtain a line a_1l_1 in a similar manner to that by which al was found; it can also be drawn through a_1 parallel to al. Draw l_1m_1 perpendicular to xy, and set off along cd the distance cP_1 equal to l_1m_1; then P_1 is a point in the projection of the bevelling edge. Other points are obtained in a similar manner, and the line is ended similarly to the projection of the moulding edge.

Next, draw through a the line az perpendicular to ab, cutting a_1b_1 at z. Then through the point P_1 draw $Q_1P_1p_1$ perpendicular to x_1y_1, and set off on this line the distance Q_1p_1, equal to zr_1; p_1 is a point in the true curve of the bevelling edge of the cant, the latter being so laid off, that the bevellings can be taken in the usual manner by measuring the square distance between the curves at the points, such as p. The bevelling edge is ended on the same line as its projection, and at a distance from the middle line equal to zn_1. The line al is the direction of the cant joint across the harpin mould, which we shall refer to in the next chapter.

CHAPTER V.

78. When the timbers of both the cant and square body frames are trimmed, it is requisite, before putting them together, that we should have some means of keeping them to the required form of the ship when they are in place. This is done by means of *harpins* and *ribbands*, which are placed at or near the lines of the heads and heels of the timbers.

79. Ribbands are usually made of stout fir quartering, and are employed at the comparatively straight parts of the ship, consequently no moulds are made for them, their curvature being so slight that they can be easily bent into the forms indicated by the half-breadth or spread staffs, shown on Plate XIV.

The positions of the square stations are marked upon them by means of station staffs or ribband battens, shown on Plate XIV. Ribbands are made not only to the diagonal, but also to the top side, port sill, and other such lines above the highest diagonal line. The ribbands are placed about six inches below the lines of the heads and heels of the frames, and the latter are temporarily secured to them by means of Blake's screws.

80. Harpins are the ribbands at the extremities of the ship. They are made of oak or elm plank, and are trimmed to moulds and bevellings supplied from the mould loft floor. These are obtained with great accuracy, and marks are put upon the moulds, with which the sides of the frames must coincide when the latter are erected. The harpins extend as far towards amidships as there is any curvature of importance, generally to three or four square stations beyond the cant body.

As has already been said, the *rabatted diagonal lines* used in fairing the body, being the lines of the heads and heels of the timbers, are the curves to which the harpin moulds are made, and to which the harpins are trimmed. The diagonal line is the moulding edge of the harpin, and the mode of laying it off was given at Art. 18, and illustrated by Plate V. The harpin is generally made of several pieces, each of which is as long as possible; the several pieces are connected by hook scarphs, wood-keyed. The section of the harpin is about six inches each way, and as it overlaps the ribband on the upper side of the latter, the upper edge of the harpin is just at the line of the heads and heels. Sometimes, however, harpins are made at the lines of the sirmarks only; and as all the cant futtocks are combined on the "*frame*" system, the harpins are thus quite clear of the heads and heels, consequently allowing the workmen full scope in faying the timbers at their butts.

81. To Obtain the Bevellings of a Harpin, the bevelling edge has to be laid off, to do which it must first be drawn in the body plan, where it is straight. In Plate V., draw a line *cd* parallel to and below the moulding edge, being distant from it the siding of the harpin. This line is the bevelling edge of the harpin in the body plan. The harpin shown on Plate V. is drawn disproportionately large for the sake of clearness.

To lay off the bevelling edge.—Draw a line *ac* perpendicular to the moulding edge, at its intersection with the middle line of the body plan, and rabat the plane of the bevelling edge upon a plane parallel to the half-breadth plane about the trace represented by the point *c*. To do this, measure from the line *ac*, just drawn, the distance along the diagonal line *cd* to where the latter cuts each square station, and set off this distance from the middle line of half-breadth upon the corresponding square station: a curve CD passed through the points so obtained is the bevelling required.

82. To End the Bevelling Edge.—Measure the height from the base line of body to the point *g*, where the bevelling edge cuts the half siding of stem; set this height up in the sheer plan, and find f_1, its intersection with the bearding line. Square down this intersection upon the middle line of the half-breadth at f_2, from which draw a perpendicular f_2C, in length equal to the distance *cg*, measured along the bevelling edge from tne perpendicular *ac* to the half siding of stem or stern post. The bevelling edge ends at the extremity of this perpendicular.

83. To Take the Bevellings.—We must first get the directions of the joints of the frames across the harpin mould, in order to know where to obtain the bevellings, the latter being applied at these points on the harpin.

In the case of the square body frames these directions are the intersections of the square stations with the diagonal in the half-breadth plan. For instance, in Plate V., the line marked 6 drawn across the mould gives the direction of the square body frame at square station No. 6. To find the bevellings at that point, it is seen that if, in the body plan, *ck* be measured equal to *ab*, or, which is the same thing, *bk* be drawn perpendicular to *ab*, then the distance *dk* is equal to the perpendicular distance *lk* between the moulding and bevelling edges of the harpin at square station 6. Hence *lk* is the perpendicular opposite the angle of deviation from a right angle of the bevelling of the harpin at station 6; and is therefore the amount to set off in the usual manner when marking the bevellings at such square body frames as the harpin is fitted against.

To determine where a cant joint crosses the harpin mould (see Plate XXXV.), we must draw a line square to the middle line of half-breadth, from the intersection *d* of the cant joint with the horizontal ribband line, to the corresponding diagonal or harpin line at d_1; this intersection is the bevelling point required. By joining this point d_1 with the intersection *c* of the cant joint with the middle line, we obtain the direction cd_1 of the cant joint across the harpin mould. To obtain the sides of the cants on the harpin mould, treat the sides of the timbers in the half-breadth plan in the same way as just stated for the cant joint. These lines thus serve for bevelling points, and to show the positions that the timbers should occupy when in place.

The bevellings of the harpins are now obtained by measuring the distance square to the curve, at each of the above spots, between the bevelling and moulding edges of the harpin; the distance so found is the perpendicular opposite the deviation of the bevelling from a right angle; observing that, when the bevelling edge is nearer the middle line of half-breadth than the moulding edge, the bevelling is standing, and *vice versâ*. The bevelling edge is shown on Plate VI., it being omitted on Plate XXXV. to avoid confusion.

84. Bevelling Boards are provided for the harpins at some yards, these being made in the manner already described; the battens of the bevelling frames are set apart one inch more than the siding of the harpin (being one inch for margin), and the boards are marked, as shown at fig. 2, Plate XXXVI.

The bevellings are applied, as in the case of the frames, by holding the stock of the bevel square to the curve.

85. Harpin Moulds (see Plate XXXVI., figs. 1 and 3).—The former figure shows the manner of marking the harpin at Devonport yard, and the latter that at Chatham and some other yards; the only difference being, that in the Devonport system the bevellings are given on a separate board, whereas by the other the bevellings are marked upon the mould. In each case, the following marks are placed upon the mould: Sides and joints of square and cant body frames; a straight line, and spilings for checking the curvature of the harpin when in place; also, spilings from the middle line and the under side of keel, for checking the position of the harpin when erecting it.

86. To Lay off a Harpin in the Sheer Plan. — In practice the harpin is always laid off in the half-breadth plan, this being done for convenience sake, as the rabatted diagonals are used in fairing the body. But we may also obtain its true form in the sheer plan in the following manner, observing that the plane of the harpin is rabatted about the same line as before, viz., its trace with the sheer plane (Plate XXXVII.): Draw in the sheer plan a straight line ml parallel to the base line of that plan, and at the height above it at which the intersection a of the diagonal ab with the middle line of body is above the base line of that plan. This line ml, being the trace of the diagonal line with the sheer plane, coincides with the middle line of half-breadth when projected on that plane, and is the line about which we rabatted the diagonal plane when laying off the harpin in the half-breadth plan. In the body plan, measure, from the middle line, along the diagonal line *ab* to where it cuts each square station, and set off these distances in the sheer, on one side of the trace *ml*, upon the corresponding square stations; a curve *AB* passed through the points so obtained is the line required.

87. To End the Line.—Through the ending of the projection a_1b_1 of the diagonal line in the sheer plan (see Art. 22), draw a line b_1B perpendicular to the trace *ml*, and set off on this perpendicular the half siding *ae* of stem or stern post measured in the direction of the diagonal line, and end the curve at the point *B* so found.

88. To Mark the Direction of the Cant Joint across the Mould.—Square up from the intersection *g* of the cant joint *gh* with the middle line of the half-breadth plan to the trace, about which we are rabatting, at g_1. Then from h_1, where the disposition of cant in the sheer cuts the projection of diagonal, draw a line h_1H perpendicular to the trace *ml*, to cut the rabatted diagonal in that plan at *H*. Join this point with the point g_1, and the line g_1H is the direction of cant across the harpin mould, *H* being a point for taking the bevellings. The other marks upon the mould are the same as before.

89. To Lay off the Bevelling Edge and Take the Bevellings.—The bevelling edge *cd* is drawn as usual in the body plan; and the trace with the body plane of the line about which its plane is rabatted, is determined as before, by the intersection *c* with the bevelling edge of a line *ac* perpendicular to the moulding edge, at its intersection with the middle line of the body plan. The intersections of the bevelling edge with the several square stations are measured from this point, and set off from the diagonal trace *ml* in the sheer plan upon the corresponding square stations in that plan; a curve *CD* passed through these points is the bevelling edge required.

To end the bevelling edge: through the ending of its projection in the sheer plan draw a line perpendicular to *ml*, and set off on this perpendicular a distance equal to *cf*; the bevelling edge is then ended at the point *D* so found.

The bevelling edge is now so situated with reference to the moulding edge, that the square distance between the curves at any point is the amount to be set off when marking the bevellings in the ordinary manner, as described when referring to the mode of laying off the harpin in the half-breadth plan. If the moulding edge is rabatted below the bevelling edge, the bevelling is standing, and *vice versâ*.

90. The Sheer Harpin.—It has already been remarked that harpins and ribbands are placed at the lines of the top side, port sill, etc., besides those of the heads and heels of the timbers; but while the latter are in diagonal planes, the former are in level planes in the case of a ship with no *sheer* or *spring up* at the extremities. This very rarely occurs, as, in order to give the ship a more graceful appearance, and, as far as possible, to keep head or following seas from breaking over her, a rise is given to the extremities, especially the bow, and the amount of rise which gives the curvilinear form of the top side, decks, etc., is termed the *sheer* of these lines. The surface containing these sheer lines is perpendicular to the sheer plane, and as the amount of sheer is usually comparatively inconsiderable, a projection on the half-breadth plane of the top side, port sill, and other such lines, is usually sufficiently correct to enable the moulds for the sheer harpins to be made to these projections without any practical inaccuracy. As these lines are necessarily *foreshortened* to some extent in the half-breadth plan, the draughtsman sometimes deems it expedient to make the mould a little longer than the distance, measured on the curve, between the endings at the bow and stern and the square station at which the midship end of the harpin is to be fixed. Of course a corresponding elongation of the distances, measured on the curve, between successive square stations and joints of the cants is necessary, in order that the positions of these stations and joints may correspond with the joints of the frames when the harpins are in place.

Although a correct line for the moulds to the sheer harpins is rarely laid off in practice, yet as such a line may sometimes be required, and as the problem is one of those with which the draughtsman should be conversant, we now proceed to

91. Lay Off a Sheer Harpin in the Half-breadth Plan,

that being the plan in which the true form of the line should be obtained, in consequence of the greater facility with which the directions of the joints of the cants may be drawn across the harpin mould, than if the line were laid off in the sheer plan,—another form of the problem which will be afterwards considered.

In Plate XXXVIII., which is purposely exaggerated in order to render the figure clear, let AB and A_1B_1 be projections of the moulding edge of the sheer harpin in the sheer and half-breadth plans respectively, and let 1, 2 be two square stations in these plans. Bend a batten to the line AB in the sheer, and mark upon it the ending A at the bearding line, and the intersections of the square stations 1 and 2 with the projection of the harpin in that plan. Then fix the point of the batten which was at A to the point P at the foot of a perpendicular on the middle line from A; let the batten spring straight along the middle line of half-breadth, and set off on that line the positions of the intersections taken from the sheer. At the points a and b, draw perpendiculars ac, bd, and from the intersections of the square stations 1, 2, with the horizontal projection of the harpin, draw horizontal lines to intersect these perpendiculars at c and d. Then c, d will be points in the developed curve of the sheer harpin, and a batten bent to pass through the ending A and all such points as c, d, will give the true length of the moulding edge of the sheer harpin.

92. To Lay off the Bevelling Edge, of which CD and C_1D_1 are the projections, a similar course is pursued, the construction for which is shown in the figure.

93. To Obtain the Bevellings.—Measure the distances square to the moulding edge at the points c and d between the moulding and bevelling edges, and these distances will be the perpendiculars to set off in marking the bevelling board by the ordinary method, observing that when the curve of the bevelling edge falls nearer to the middle line of the half-breadth plan than the curve of the moulding edge, the bevellings are *standing*, and *vice versâ*. It should be remarked that these bevellings are not exactly correct, as no allowance has been made for the sheer of the harpin in its siding, the latter being measured square to its edge; but as the sheer in a length of 6 inches measured square to the edge of the harpin is exceedingly small, it may be disregarded.

The directions of the square stations across the harpin will be given by the lines *ac* and *bd*; but to obtain the directions of the cant joints across the harpin, let *ef*, e_1f_1 be the projections of the cant joint in the sheer and half-breadth plans respectively. Then measure along the curve of the harpin in the sheer the distance between *A* and *e*, and set off this distance from P along the middle line to *g*, from which point draw the perpendicular *gh*, intersecting the curve of the harpin at *h*; through *h* draw *hk* parallel to e_1f_1, then this line is the direction of the cant joint on the harpin mould. The points, such as *h*, will be the bevelling spots for the harpin in the wake of the cant body.

94. To Lay off the Sheer Harpin in the Sheer Plan.—We will now lay off the sheer harpin in the sheer plan. In Plate XXXIX., let *AB* and A_1B_1 be the projections of the moulding edge of the sheer harpin, as before; through the point *A*, where the harpin ends on the bearding line, draw a line *Aab* parallel to the base line of the sheer plan. Bend a batten to the curve of the line *AB*, and mark on it the intersections with the square stations 1 and 2, as by the preceding method. Then, still keeping the point *A* fixed, let the batten spring out straight along the line *Ab*, and mark upon the latter at *a* and *b* the points taken on the batten. Through the points *a*, *b*, draw *ac* and *bd* perpendicular to the line *Ab*. Then measure the breadths 1 c_1, 2 d_1, and set them off upon these perpendicular lines; the points *c*, *d* so found will be in the developed curve of the moulding edge of the sheer harpin.

The ending *g* is obtained by drawing *Ag* perpendicular to *Ab*, and equal to the half siding of stem A_1g_1

95. To Lay off the Bevelling Edge, of which *CD*, C_1D_1, are the projections, as before. Measure the breadths 1 e_1 and 2 f_1, and set them off from *Ab* on the lines *ac* and *bd*, thus giving the points *e* and *f*, which will be in the curve of the bevelling edge. The latter is ended at a point on the perpendicular *Ag* equal to the half siding of stem, measured at where the projection of the bevelling edge ends on the bearding line.

The bevellings are obtained by measuring the square distances between the moulding and bevelling edges at such points as *c* and *d*, and using these distances when marking the bevelling board in the same manner as before, observing that, when the curve of the bevelling edge is nearer the line *Ab* than the curve of the moulding *edge*, the bevelling is *standing*, and *vice versâ*.

It is unnecessary to give further particulars regarding the sheer harpin when laid off in the sheer plan, as it would never be so determined in actual practice.

Moulds for the harpins are made at about the same stage of the work as those for the cants, so that both the harpins and the cants being trimmed simultaneously, the former are first put into place and then the latter; the marks on the harpins serving as guides and checks when getting the cants into position.

96. Special Timbers of Fore Body.—The description already given of the mode of laying off the cant frames did not include certain special timbers, for which additional and different data have to be given to the workmen. The timbers referred to are the *knight head* and *stem piece.*

In the preceding chapter, mention was made of the considerations which govern the dimensions of the stem pieces, and, as was there stated, these timbers are only required for large ships, in which the knight heads would have to be very large, if they were fitted close against the stem; this being due to the hole which is cut for the bowsprit.

The siding of the knight head is sometimes fixed by the specification, and at others it is left to the decision of the practical officer.

97. To Lay off a Knight Head (Plate XL.).—The after edge *ab* of the knight head is usually chosen as the moulding edge, and this line is laid off as an ordinary cant. The knight head being larger at the head than at the heel, the actual bevelling edge *ed* of the timber is not parallel to the moulding edge. For convenience in taking the bevellings, we lay off the curve produced by the intersection with the ship's surface of a plane parallel to the plane of the moulding edge, and distant from it the siding of the knight head at its upper end. The horizontal trace of this plane is a line *cd* drawn through the outer extremity of the bevelling edge in the half-breadth plan, and parallel to the moulding edge in that plan. This line *cd* we will now term the bevelling edge. Through the intersection *a* of the moulding edge *ab* with the middle line, draw a line *ac* perpendicular to *ab*, to cut the bevelling edge produced. This bevelling edge is laid off in the same manner as the other bevelling edges of the cant body, and the bevellings are marked by setting apart the battens of the bevelling frame, a distance equal to that between the moulding and bevelling edges in the half-breadth plan (plus the breadth of the margin on the bevelling board).

The principal difference between the modes of treating an ordinary cant and a knight head, consists in the data furnished for trimming the latter. This is due both to the fact that the siding of the timber tapers considerably, as well as on account of the *boxen* wood allowed for housing the plank in the wake of the bowsprit hole, and receiving certain bolts required for the bowsprit rigging. At the *boxen* the inner and outer surfaces of the timber are flush with the surface of the plank.

98. The Knight Head Mould (fig. 2, Plate XL., and fig. 1, Plate XLI.) is made to the exact shape of the moulding side of the timber; that is to say, the lines of both the inside and outside of the timber, including the boxen wood, are drawn upon the floor, and the mould is made to the space enclosed by these lines. This is done by taking from the moulding book the mouldings in the plane of the side of timber at the several heads and sirmarks, and setting them off inside the curve of the moulding edge at their proper heights, and passing a curved line through these points. At the head of the timber, the lines of the inside and outside planks are set off to the depth at which boxen wood is to be carried. The height of cutting down is drawn across the mould, the heel of which is cut to the direction of the heel of the knight head against the deadwood, so that the shape of the moulding side is thus entirely given. When the mould is made as in Plate XLI., the following lines are drawn across it: the position of heads and sirmarks, and sometimes the direction of certain level lines at which bevellings are given; also the sidings of the timber at the several heads and sirmarks.

Thus the data furnished to the workmen to trim the timber consist of a mould to the shape of the after side of the timber, having sidings, etc., marked upon it, and a board with the bevellings at the several bevelling spots marked upon it, as shown by fig. 2, Plate XLI.

It is sometimes considered preferable to give section moulds of the timber at certain level lines, as shown by Plate XL., and in this case the bevelling edge need not be laid off nor bevellings furnished. This method is superior to that already described, as the section moulds give not only the bevellings, but the exact shape and size of the timber at the horizontal sections indicated by the level lines marked upon the mould. These section moulds are readily made to the shapes of the spaces in the half-breadth plan enclosed by the moulding and bevelling edges, the several level lines, and the lines drawn parallel to them, representing the inside surface of the timbers at the sections (see Plate XL., fig. 1). In the wake of the heeling of the knight head, the side of stem or deadwood will take the place of these parallel lines, as in the case of the sections at $1L$ and $2L$ in the figure.

99. To Lay off a Stem Piece (Plate XLII.).—We will now direct our attention to the mode of laying off the stem piece, which differs materially from the other timbers of the cant frame, inasmuch as it is always laid off in the sheer plan.

The fore edge of the stem piece being that to which the mould is given, the latter has evidently to be made to the shape of the bearding line. This will not be quite correct, for, owing to the taper of the stem, the plane of its side is not quite parallel to the sheer plane. However, for all practical purposes the projection of the bearding line in the sheer plan is the curve of the moulding edge of the stem piece.

Similarly, the cutting down line is the curve of the after edge of the fore side of the timber. It is customary to make a mould to the shape of that side of the stem piece, that is, to the space on the stem enclosed by the bearding line, cutting down line, and a perpendicular from the ending of the disposition of the after edge of stem piece on the bearding line to the cutting down line (see fig. 2, Plate XLII.). In addition to this mould, the bevellings and sidings of the timber at the several diagonals are sometimes given, the sidings being measured from the floor. These are sometimes supplemented by bevellings at level lines which cross the timber at places where bevellings would be useful as a guide to the workman, these bevellings being taken with a bevel from the floor. The direction of the level lines have to be drawn upon the mould, in order that the workman may apply his bevel in a level plane instead of square to the surface of the timber, as is the usual practice.

But it is generally admitted that section moulds to the stem piece at the several level lines, as just described for the knight head, are far preferable to bevellings and sidings. The manner of obtaining such section moulds for a knight head is shown by fig. 1, Plate XL.

When section moulds are provided in lieu of bevellings for trimming the stem piece, the level lines at which the sections are taken must be marked upon the mould.

Should, however, it be considered necessary to provide bevellings, the latter are obtained in the following manner: The bevelling edge must first be drawn, to do which, draw in the half-breadth plan a line *bc* parallel to the half siding of stem, and distant from the latter the siding of stem piece at its head. Project this line into the sheer plan by squaring up its intersections with the level, horizontal ribband, and bow lines in the half-breadth plan to the corresponding lines in the former plan, and pass a curve b_1c_1 through these points. Then the distances between the line b_1c_1 and the bearding line at the several diagonals are measured square to the former curve, and these distances are set off in the usual manner in marking the bevellings, the battens of the bevelling frame being set apart one inch (for the margin on the board) more than the distance between the moulding and bevelling edges in the half-breadth plan.*

* In strict accuracy the line *bc* should be curved, owing to the taper of the stem which is shown in the half-breadth plan. However, it is usually drawn straight, as very little inaccuracy is involved thereby, whereas some labour is saved.

In the case of small ships, already alluded to, when the knight head can be provided in one piece of sufficient siding without resorting to the use of a stem piece, the knight head is laid off similarly to the stem piece just described.

In this case, again, it is quite optional whether bevellings and sidings or section moulds shall be given to the workmen, in addition to the mould of the fore side of the timber, to enable him to trim the latter.

100. Timbers whose Sides are Parallel to the Sheer Plane.—Allusion was made in the preceding chapter to the disposition of cants, which it was found necessary to adopt in the bluff bowed ships of the early part of the present century. Fig. 2, on Plate XXIV., shows such an arrangement, which is contrasted with that of a more recent date, shown by Fig. 1. It will be seen that, in order to avoid excessive bevelling, it was necessary to dispose them in this manner, and even in the case shown the bevelling of the knight head at the *first head* harpin is very great. It should be observed that these figures are somewhat exaggerated in their proportions, in order to show clearly the principles intended to be explained.

The sides of the knight head and hawse timbers in Fig. 2 are in planes parallel to the sheer plane, therefore to lay off such timbers the curves of their edges are projected upon that plane. It will be at once seen that the curves are simply *bow lines*, hence they are obtained in a similar manner to that already explained when treating of those lines. The fore edge of the knight head is the bearding line, and this is chosen as the moulding edge of the timber, as before stated, when referring to the case in which no stem piece is fitted.

A mould is made to the fore side of the knight head, the after edge of the mould being the cutting down line. The bevelling edge is laid off, and the bevellings taken in the manner described for the bevelling edge of the stem piece. The athwartship angle of the heel against No. 1 cant is measured in the half-breadth plan as if the cant were the deadwood; the vertical direction of the heel against the cant being marked upon the mould, when in place on the floor, by drawing a perpendicular line through the intersection of the moulding edge of the timber with the disposition of the fore edge of the cant against which it heels.

101. Each of the frames *a*, *b*, *c*, and *d* (Fig. 2, Plate XXIV.), can be laid off as an ordinary cant in the body plan, by rabatting it about an axis through the intersection of the plane of its side with the middle line. It is obvious, however, that this is a very unsatisfactory way of performing the operation in actual practice, especially in such a case as that of the second hawse timber, the plane of whose side is inclined so obliquely to the longitudinal vertical plane, that its horizontal trace would not intersect with the middle line of the half-breadth plan within the limits of an ordinary mould loft floor. A more practicable, and therefore better way, is to lay off these cants in the sheer plan by rabatting each of them upon a plane, parallel to the sheer plane, about a vertical axis through the intersection of the projection of the moulding edge of the cant with the projection of the fore edge of the cant, against which the former heels.

In Plate XLIII., let ab be the horizontal trace of the fore edge of the cant against which the timbers in question heel, and let a_1b_1 be the projection of this edge in the sheer plan. Also let cd be the horizontal trace of the cant to be laid off, c_1d_1 being its projection in the sheer plan, ef and e_1f_1 are the horizontal and vertical projections of a diagonal line. Through the point c_1 draw c_1x perpendicular to the base line of sheer plan, then c_1x is the vertical projection of the trace about which we are to rabat the plane of the cant, upon the plane whose horizontal trace is given by cy, drawn through c, parallel to the middle line of the half-breadth plan. When the cant is rabatted upon this plane, it will evidently be projected in its true form in the sheer plan.

Through the point g_1, where the disposition c_1d_1 cuts a diagonal line, draw g_1c_2 perpendicular to c_1x; produce this line to p, making c_2p equal to cg, then p is a point in the moulding edge of the cant when laid off. The moulding edge is ended at c_1.

102. To lay off the bevelling edge whose horizontal and vertical projections are given by Tr and T_1r_1 respectively. Produce rT to o, and through c draw co perpendicular to cd. Then through the point s_1, where the vertical projection of the bevelling edge of the cant cuts a diagonal line, draw s_1o_2 perpendicular to c_1x, and produce it to p_1, making o_2p_1 equal to os, p_1 is a point in the bevelling edge of the cant.

To end the bevelling edge: project T to T_1, and through T_1 draw o_1T_2 perpendicular to c_1x, making its length equal to oT, then T_2 is the ending of the bevelling edge. The bevellings are measured in the usual manner, and the points, such as p, give the positions where they are to be applied. The angle gcT is the bevelling of the heel against the cant, whose trace is ab, and a level line must be drawn across the mould near c_1, to show the direction in which this bevelling is to be applied. The vertical direction of the heel against the timber ab is marked on the mould by drawing on it the line c_1x.

This cant can also be laid off in the body plan in the ordinary way, by treating cy, drawn parallel to the middle line, as the middle line of half-breadth plan, and a line corresponding to cy as the middle line of the body plan.

103. The Head Rail.—Although in modern shipbuilding, as carried out in H.M. dockyards, the knee of head and its appurtenances have been discarded, yet a treatise on the laying off of wood ships would be incomplete without some reference being made to the problems in connection therewith.

The chief of these is the *head rail*, which, like most of the other features neglected in recent designs, served more as a work of ornament than of utility, although, as will be stated hereafter, it performed an office in the economy of the ship which is now dispensed with in favour of other considerations of greater importance in a vessel suited to the requirements of modern naval warfare. A description of the functions of the *head rail* (or rather *rails*, for there are several) is given in Chap. XV., so that for the present we have only to notice the method of laying it off, and providing the workmen with the necessary information to enable them to fashion it.

As will be seen by referring to Plate I., the positions of the head rails are given on the sheer draught, and they are curved in such a manner as to conform to the contour of the *knee of head*, so that the rails, figure, scrolls, etc., may form an assemblage of graceful lines uniform in character; which, while they remove the appearance of abruptness at the extremity of the ship, shall also convey the impression of speed. The upper rail was termed the *berthing rail,* and the two others, the *main* and *middle rails* respectively. Below these are the continuations of the *cheeks,* the number of which varied according to the class of the ship. For further particulars of these and the *head timbers,* see Art. 232.

The berthing and main rails were usually ended against the fore side of the cathead, the fore ends being of course secured close to the figurehead. It will, however, be seen that such is not the case in the ship drawn on Plate I. The horizontal projections of all the rails are straight lines: hence in the half-breadth plan the edges of these rails are straight lines, those of the berthing and main rails ending against the cathead, and that of the middle rail at some part of the bow on the fore side of the cathead. The exact position of the middle rail is obtained by first drawing a section of the framing of the head, as shown in fig. 2 of Plate XLV., —the shape of this section being governed by the position of the scroll continuation of the upper cheek (termed the "hair bracket"), and by the spread of the main rail. As will be seen by reference to this figure, the under side of this section is hollowed, in order to improve its appearance; and when the extent of this hollow is decided upon, and the section of the middle rail placed upon it so as to please the eye, then the distance of this rail from the middle line of the half-breadth plan at any section in its length can be measured, and a line joining this point and the ending on the figure will, when continued to the bow of the ship, be the horizontal projection of the middle rail.

The sectional form of these rails, the hair bracket, and of the other ornamentations of the *head,* are purely a question of taste, although a great deal of conservatism was displayed in these matters. We will suppose the general outline of the rails to be decided upon, and their projections drawn in the sheer and half-breadth plans, and will now proceed to the general problem of *laying off a head rail.*

104. To Lay off a Head Rail in the Half-breadth Plan. —Let ab, Plate XLIV., be the horizontal, and a_1b_1 the vertical projections of the moulding edge of the ***head rail;*** through the point b_1 draw a horizontal line b_1a_2, and divide this line into any number of parts at the points c_1, d_1, and e_1, from which and the point a_2 draw the vertical lines a_2a, e_1e, d_1d, c_1c to the line ab. At the points a, e, d, c, where these verticals cut the line ab, draw aA, eE, dD, cC perpendicular to ab, and equal to a_2a_1, e_2e_1, etc., respectively. A curve passed through the points A, E, D, C, b is the true form of the head rail.

105. To Lay off a Head Rail in the Sheer Plan.—In Plate XLV., let ab in the half-breadth plan and a_1b_1 in the sheer plan be the horizontal and vertical projections respectively of the head rail. In the line ab take any number of points c, d, e, whose vertical projections are the points c_2, d_2, e_2. Rabat the plane of the side of the rail parallel to the sheer plane about an axis through b, so that the points c, d, e, a will now be at c_1, d_1, e_1, a_2. Through the points c_2, d_2, e_2, a_1, draw short horizontal lines, and project the points c_1, d_1, e_1, a_2 upon these horizontal lines, giving the points C, D, E, A; through these and the point b_1 draw a curved line, which will be the true form of the head rail.

It should be remarked that there is a slight inaccuracy in the above, caused by the taper of the half siding of the knee of head being neglected, it being assumed that bf is parallel to the middle line xy. The error, however, is inappreciable.

106. Knee of Head.—Very little remains to be said concerning the knee of head. Sections of it show a tapered siding, which taper is obtained as follows: Pen a batten to the outline of the knee of head, and draw lines on the latter square to its curvature. Mark the position of these lines upon the batten, and let it spring straight; then set off on a perpendicular drawn from the end of the batten nearest the keel, a distance which is a little less than the half siding of the stem at that place, and set off on a perpendicular at the other end the half siding of the knee at its upper end, this being about two inches in a frigate. Join these two points, and the distance between this line and the batten, when straight, at any of the points marked on it, is the half siding of the front of the knee of head at that point. The line of the half siding of a section of the knee at that point is obtained by joining the half siding of stem at the fore edge of rabbet with the half siding just found. Moulds made to these half sections are given to the workmen with the mould to the knee of head, as shown by Plate XV., the half sections being nailed to the mould with their middle lines touching the lines of the sections on the mould.

The manner of disposing the pieces of the knee is shown by Plate XIII., and their names and purposes are referred to at Art. 232.

As will be gathered from the preceding remarks, the portion of the stem on the fore side of the rabbet is trimmed to the taper of the knee.

CHAPTER VI.

107. The Stern.—Before the recent introduction of heavy rifled guns into the armament of ships of war, when there were consequently fewer restrictions laid upon the dimensions and form of such ships than at the present time, a great deal of the skill of the naval architect, when preparing his designs, was devoted to considerations of beauty of outline, and at no part of the hull was more attention paid to this feature than at the stern. Allusion has already been made to the several styles of stern which have been in vogue, and reference has been made in detail to that portion of the stern framing, common to all the styles, which consists of an assemblage of ordinary cants. It is, however, with the timbers abaft these, and which constitute the *specialité* of the *elliptical stern*, that we have now to deal.

The upper aftermost portion of the continuation of the contour of the ship's bottom is termed the *buttock*. It is usually so flat and nearly horizontal, that the only planes giving a definite intersection with it, are the vertical longitudinal or buttock planes. Hence the buttock lines are of considerable service, and are largely employed in fairing this portion of the ship, especially as they afford a very accurate conception of the nature of the surface.

As a great number of timbers, each of independent character, are employed in the construction of the stern, it is found necessary to draw many additional level and buttock lines and square stations at this part. The first thing to be done, when proceeding to lay off the stern, is to draw in the three plans a number of these lines, corresponding with each other, and then carry out very carefully another such a tentative process as has already been described under the heading of "Fairing the Body" (see Art. 10).

The stern, when viewed in the sheer plan, rakes aft, the bounding line being straight, and making an obtuse angle with the line forming the boundary of the buttock. This angle, which is continued around the stern until the curvature of the buttock breaks continuously into the inward inclination of the ship's side, is termed the *knuckle*, and its projection in the three plans is termed the *knuckle line*.

Now, in consequence of the inward inclination or "fall home" of the ship's side, and the rake of the stern right aft, the surface of the ship's side between those limits must necessarily be twisted. But there are certain ports to be cut in this part of the stern in order to fight guns and admit light to the cabins; hence, if these port holes be cut square, they will appear very unsightly in connection with such a twisted surface as we have referred to. In order, then, to please the eye, the line of the rake right aft is produced upward, and a line is drawn from the end of the knuckle line in the direction of the "fall home" of the side; the point of intersection of these lines is chosen as the apex of a cone containing the knuckle line and enveloping the stern. The sides of the ports and stern timbers are then inclined so as to be straight lines on this cone, which lines, if produced, will pass through the apex. The character of the cone is governed by the rake of the stern right aft, the fall home of the side, and the curvature of the knuckle line. The after extremities of the top side or rail and top breadth lines in the sheer draught, are curves approximating to those of ellipses; hence the name *elliptical* stern given to this style of construction. These lines, or, more correctly, level lines very near them, when projected into the half-breadth plan, are the directrices of the surface, and thus the latter becomes invariable.

The surface of the stern above the knuckle being approximately an elliptical cone, and the surface of the stern below the knuckle a continuation of the contour of the ship's bottom, it remains to be decided what kind of line the knuckle shall be; for it is evident that although the former surface may be invariable, it is yet possible to modify the surface of the bottom consistent with fairness, so that the position of the knuckle may be varied slightly to suit certain other requirements which we shall now allude to.

It is customary to place the knuckle line in the surface containing the upper sides of the beams of a deck, both for the sake of beauty and to suit the internal arrangements of the ship. Hence, the knuckle line conforms to the round of the beam and the sheer of the deck.

108. Cone of Stern.—Before getting in the knuckle line, we will show how to draw in the cone of the stern. Referring to Plate XLVI., a line C_1P_1 is drawn to touch the curves of the rail line and a level line passing through the point B at the aftermost end of the knuckle line given on the sheer draught; in other words, the line C_1P_1 is a tangent to these curves. It should be premised that this level line at knuckle, generally termed the "knuckle level," can be copied from the faired body plan as far aft as where the knuckle commences, say at No. 50 square station, shown on the figure. Beyond this point some little latitude is allowed to the draughtsman, when drawing it, to enable him to construct a fair curve; at the same time the character of the line must conform, as nearly as possible, to the curve given by the top breadth or deck line, when such a line is provided for his guidance on the sheer draught. The line C_1P_1 intersects the middle line of the half-breadth plan at the point P_1, which is therefore the horizontal projection of the apex of the cone. Produce the margin line BA upwards, and from the point P_1, draw the perpendicular line P_1P to intersect BA produced at P; then P is the vertical projection of the apex. The square station, No. 50, is drawn through the touching point C_1, therefore the point C in the sheer plan is the vertical projection of C_1. Join PC; the line PC will be the foremost generatrix of the cone, the horizontal projection of the same being, of course, P_1C_1. Level over P to P_2 on the middle line of the body plan; B_2C_2 on the knuckle level in that plan is equal to C_1D, and the line P_2C_2 is the projection on the body plane of the line PC or P_1C_1.

Having, then, the level line at knuckle as a directrix of the cone, and the two generatrices P_1B_1 and P_1C_1, we may draw as many intermediate generatrices as we please, by dividing the knuckle level between B_1 and C_1 into the required number of parts, and joining the points of division with the point P_1; as, for instance, a_1P_1, b_1P_1, etc. These may be either equidistant, leaving the actual line of the edges of the stern timbers to be drawn at a future stage; or, if thought necessary, the lines of the principal timbers can be drawn in at once, as shown in the figure, for they will be situated between the ports or cabin lights, which are given upon the sheer draught and the other drawings of the ship.

109. The Knuckle Line.—Sometimes the half-breadth plan on the sheer draught gives the correct horizontal projection of the knuckle line, in which case it has to be drawn in the other plans by a mode to be stated presently (Art. 111).

We will now assume that the only line of a fixed character which we can use is that of the beam at middle. The ordinary mode of getting the knuckle line from this data corresponds so closely with that of getting in the beam end line, that we will pass over it with a brief description.

Where the beam at middle line intersects each of the straight lines on the cone surface in the sheer plan, level over to the body upon each of the corresponding lines in that plan. Then construct a *round of beam* line (Art. 52), the chord of which is horizontal, with its middle point coincident with the middle line of the body plan. Square down the points of intersection to this *round of beam* line, and measure the amount of *round down* at that point, which *round down* set vertically below the intersection of the corresponding line on the cone, in the sheer plan, with the deck middle line. The point so obtained will be in the *knuckle line.*

It is evident that by neglecting the variation of breadth, etc., in the cone at different heights, and therefore of the round of the beam in the short distance between the sheer line and the true position of the knuckle line, the point thus found is but an approximation to the true line of the knuckle.

It is, however, sufficiently correct for all practical purposes, and we would not recommend in preference to it any theoretically correct mode which could not be so readily carried out on the mould loft floor.

110. Correct Method of Drawing the Knuckle Line.—As an exercise, we now purpose stating a correct solution of the problem. In Plate XLVII., CD is the vertical, and C_1D_1

the horizontal, projection of the edge of a stern timber, or of any other straight line on the surface of the cone. *BL* is the beam at middle line given in the sheer draught. Construct a round of beam line B_1E in the position shown by the figure, so that the distance measured between the perpendicular line BB_1 and the curve B_1E at any point, is the round up of the beam at the distance of that point from the middle line. Take any point *a* in the line *CD*, and let a_1 be its horizontal projection.

Now, disregarding the beam at middle line *BL* for a moment, suppose a beam mould is held horizontally across the ship from the line *CD*, C_1D_1, on one side, to the corresponding line on the other side of the ship, and let the point *a* be the intersection of its curve with the line *CD*; then by squaring over a_1a_2 to the line BB_1, the distance a_3a_2 between that line and the curve B_1E is the round down of the beam between the point *a* on one side and the corresponding point on the other side of the ship. From the point *a* draw a vertical line aa_4 equal in length to a_3a_2, then a_4 is the vertical projection of the middle of the beam mould so held across the ship. Similarly, let the beam mould be raised, still keeping its curved edge to the line *CD*, and holding it in a horizontal position, we get successively for the points *b* and *c* of the beam end the corresponding points b_4 and c_4 of the beam middle. Hence, a curve passed through the points a_4, b_4, c_4, etc., is the locus of the beams at middle produced by moving the mould upwards against the line *CD*. This curve $a_4b_4c_4$ will evidently intersect with *CD* at the intersection of the latter with the line *AB* produced. But *BL* is the true curve of the beams at middle; hence the intersection of *BL* with the line $a_4b_4c_4$ gives a point *P* common to both, and therefore the middle of the curve of the beam mould when its end is at a certain point on the line *CD*. Draw PP_1 perpendicular to base of sheer plan, and P_1, where it intersects with *CD*, is a point in the beam at side line, of which beam *P* is a point in its middle. But *P* is a point in the actual beam at middle line given by the sheer draught, therefore P_1 is a point in the knuckle line. By levelling this point over into the body plan, or projecting it down into the half-breadth plan upon the corresponding line or timber, a point is determined in the projection of the knuckle line in those plans. Other points may be obtained in a similar manner, and the knuckle line drawn.

111. When the Knuckle Line is Given in the Half-breadth Plan.—If the projection of the knuckle line is given in the half-breadth plan of the designed sheer draught, the following method may be adopted: In Plate XLVIII., B_1D and A_1C are the projections of the knuckle and rail lines respectively, as given on the sheer draught.

These sometimes represent the outside of the timbers, and at others the outside of the plank. Some draughtsmen prefer working all the lines of the stern to the outside of the plank, in which case the plank must be removed before moulds can be made to the outside of the timbers (Art. 130).

In the following description it matters not whether the plank be assumed *on* or *off*, as in the former case it can afterwards be removed, and in the latter case the thickness of plank can always be put on to obtain any lines on its surface. The lines 1, 2, 3, and 4 in the half-breadth plan are equidistant buttock lines, and through their intersections with B_1D, straight lines, as aP, hP, etc., are drawn upon the cone (Art. 108). Project the points a, h, etc., upon the beam at middle line BE at r, s, etc. Level over the point B to the middle line of body plan at B_2, and through this point draw the curve B_2d of the round of beam of the deck represented by the line BE, the chord of the curve being horizontal and its middle point at B_2 (Art. 52). Let 1, 2, 3, and 4 in the body plan be the buttock lines shown in the half-breadth plan, d, m, etc., being their points of intersection with the beam mould. Then project m and d upon the line BB_1 at c and l respectively. Through c and l draw cb and lk parallel to the line BE, and through a and h draw perpendiculars ab and hk to cut lk and cb at k and b respectively. A curve passed through B, and all such points as k and b, will be the knuckle line in the sheer plan. Next project the points b and k upon the corresponding buttock lines 4 and 3 at e and n respectively, when a curve passed through the points B_2, n, and e will be the knuckle line in the body plan.

We have thus found the intersection of the surface of the deck beams with that of the cone; we have now to end the buttock lines at that intersection. It will be found that very little correction is necessary, and by copying and recopying the several plans, as is usual in fairing, the surface of the bottom will be made to intersect with the cone surface in the same line as is given by the intersection of the latter with the surface of the deck beams.

112. Disposition of Elliptical Stern Framing.—We have now to dispose the timbers of the elliptical stern, and then proceed to lay them off. Plates XXV., XXVI., and XXVII. show the stern framing of a screw frigate. As will be seen, the quarter timbers are so placed that their edges are straight lines on the cone surface just where the latter blends into the surfaces of the top sides. The spaces between these and the aftermost fashion timbers are filled up by a number of short cants, which, like the quarter timbers, are heeled upon the fashion timbers. The quarter timbers, and those abaft them, are known by the generic name of stern timbers; these, however, are variously disposed, as we shall now proceed to show.

In disposing the stern timbers, it is necessary that their sides should be canted into such positions as to avoid excessive bevelling; at the same time, it is requisite that all the timbers required to fill up the stern should heel on the fashion timbers, or upon a short cant which itself heels on another stern timber (see Plate XXV.).

In consequence of the greatest horizontal girth of the stern being at the knuckle line, it is sometimes necessary to make the joints close at the heeling, while an ordinary amount of opening is allowed at the knuckle line. In attending, then, to these considerations, it will be seen that right aft, where the ship's surface is almost parallel to the body plane, the sides of the timbers must be square to that plane, in order to get the minimum bevelling. Hence we see that the *post timber* and the three timbers adjacent thereto below the knuckle, are in planes parallel to the sheer plane, while the planes of the sides of the timbers which extend above the knuckle line, as far aft as No. 5 on each side, are likewise square to the body plane, at the same time they are necessarily canted so that their edges may be generatrices of the cone. After getting beyond No. 5 stern timber on each side, the curvature becomes too great to allow of the planes of the timbers being any longer square to the body plane. Hence they are treated as ordinary cants, in addition to their edges conforming to the direction of the lines on the cone, like the other stern timbers. Thus we see that the quarter timber and stern timbers, Nos. 6 to 9 inclusive, are canted in two directions, one direction being to make their edges generatrices of the cone, and the other to avoid excessive bevelling. It is with these latter timbers that we have principally to deal in the remainder of this chapter. We will first, however, show how to obtain the true shape of the other timbers of the stern, viz., those which are either not canted at all, or only in one direction.

113. To Lay off the Post Timbers.—The timbers on each side of the after post are tabled to the latter, and their sides are in planes parallel to the sheer plane, as also are those of the lower stern timbers 1, 2, and 3, shown on the plates. Hence, to obtain their true shape, we have simply to project the curves of their moulding edges in the sheer plan similarly to buttock lines.

As these timbers are so near the middle line, the line of the margin of the after part, when the plank is taken off, will be a very close approximation to their actual shape; they will also have very little bevelling Should it be necessary to lay these timbers off, the moulding and bevelling edges are transferred from the half-breadth plan to the sheer plan similarly to buttock lines; and the square distance between those lines at any point is the distance to be set off when marking the bevelling board.

114. To Lay off a Stern Timber when Canted in one Direction only.—We have now to consider the second case, viz., that in which the planes of the timbers are canted in one direction only, so that their edges may be in the direction of straight lines on the surface of the cone, but the horizontal traces of the planes of their sides parallel to the middle line of half-breadth plan. It is evident that all the timbers which extend above the knuckle line, as far out towards the quarter timber as No. 5 stern timber inclusive, are comprehended in this class, as up to this point it is possible to work single-canted timbers without excessive bevelling.

We will lay off these timbers in the sheer plan, for which reason we must first determine their projections on that plane (see Plate XLIX.). As the sides of the timbers are perpendicular to the body plane, their projections in that plan will be straight lines determined by joining the vertex of the cone with the points on the knuckle line where it is intended their edges shall pass through. By continuing these lines to the line at which they must end, the projections of the timbers in the body plan is determined. Next, to obtain them in the sheer and half-breadth plans: The portion of the edge of the timber above the knuckle will be straight, and is easily drawn; but the projection of the portion below the knuckle is obtained by measuring the distance, from the middle line of the body plan, at which the disposition of the stern timber in that plan cuts each level line, and measuring off these distances from the middle line of the half-breadth upon the corresponding lines in that plan; a curve drawn through the points so obtained is the projection in the half-breadth plan of the portion of the stern timber below the knuckle. The projection of the timber in the sheer plan is found by squaring up these points to the corresponding level lines in that plan, and passing a curve through the points so found.

Next, to lay off the timber (Plate XLIX.).—We suppose the plane containing the moulding edge to be swung round until it is parallel to the sheer plane, at the same time keeping the plane of the moulding edge fixed at its intersection with the knuckle line. In this position the true shape of the timber is projected upon the sheer plane. During the revolution, every point in the moulding edge will move in a vertical plane; those above the knuckle moving upwards, and those below the knuckle downwards.

Hence, where the disposition of the stern timber in the sheer plan cuts each level line, draw a perpendicular line (upwards above the knuckle, and downwards below it). Then measure in the body plan, along the direction of the projection of the moulding edge, the distance from the knuckle line to where the edge cuts each level line, and set these distances in the sheer plan upon the corresponding perpendiculars just drawn, measuring from a level line drawn through the intersection of the moulding edge with the knuckle line, and in the proper direction, *up* or *down*; a straight line drawn through these points above the knuckle, and a curved line through the points below the knuckle, will give the true shape of the stern timber.

The vertical angle of heel against the after cant or fashion timber is obtained as follows (see Plate XLIX.): Draw a line *ga* through the knuckle of the timber in the half-breadth plan, parallel to the middle line, to cut the edge of the fashion timber at *a*, and project this point to a_2 on the level line, which is drawn through the knuckle of the timber in the sheer plan. A line joining this point a_2 with *h*, the ending of the moulding edge, will be the direction of the heel against the fashion timber.

To obtain the horizontal bevelling of the heel against the fashion timber (see Plate XLIX.).—From any point *a* on the fashion timber, draw *ab* perpendicular to the middle line of the half-breadth plan, and take any point *b* in this line, through which draw *ef* parallel to the middle line, cutting the after cant at the point *c*. At any point a_1 on the moulding edge of the stern timber in the body plan, draw a_1b_1 perpendicular to the middle line of that plan, making a_1b_1 equal to *ab*. From the point a_1 draw a_1d_1 perpendicular to the moulding edge, cutting a line b_1d_1 (drawn through b_1 parallel to the middle line) at d_1. Produce *ba* in the half-breadth plan to *d*, making *bd* equal to a_1d_1, and join *dc*. Then the angle *bcd* is the bevelling of the heel against the fashion timber; observing that this bevelling must be applied when trimming the stern timber by holding the stock of the bevel along a level line, which must therefore be marked upon the mould.

The bevelling edge is projected and laid off similarly to the moulding edge; but the distances of the intersections of the bevelling edge with the level lines in the body plan are measured from a line *pr* perpendicular to the moulding edge in body, through its intersection with the knuckle line, and set off in the sheer plan by measuring from the same level line as before. The square distance between the moulding and bevelling edges at any point, is the amount to be set off for bevelling at that point when marking the bevelling board; observing that, as the timber has a tapered siding, it is necessary to shift the portable batten of the bevelling frame to the siding at each bevelling spot. This can be avoided, if thought necessary, by drawing the bevelling edge parallel to the moulding edge, notwithstanding that by so doing a slight error is introduced, inasmuch as two parallel straight lines cannot be drawn upon a cone. So that, if they be drawn parallel, the portion of the bevelling edge above the knuckle should, in strict accuracy, be constructed to a certain curvature. However, no error worth noticing is admitted by considering a bevelling edge parallel to the moulding edge to be straight, and then the bevellings can be set off in the same way as for any other timber of uniform siding. It is questionable whether there is any advantage in drawing the bevelling and moulding edges parallel, for, after all, an account giving the siding of the timber at the several bevelling spots must be provided for the workman who trims the timber.

115. To Lay off a Stern Timber when Canted in Two Directions.—We have finally to consider the case of a stern timber having a double cant, such as is shown by stern timbers Nos. 8, 9, and the quarter timber in Plates XXV., XXVI., and XXVII.

In Plate L., let ab in the body plan, and a_1b_1 in the half-breadth plan, represent the disposition or projection of the moulding edge of the timber between the knuckle and rail lines. Having decided that the heel of the stern timber shall end against the after cant or fashion timber at d and d_1 in the body and half-breadth plans respectively, draw a level line cd through the point d, cutting the line ab produced below the knuckle at c, which point is therefore in the plane of the moulding side of the timber, but outside the surface of the stern. Produce the line a_1b_1, in the half-breadth plan beyond the knuckle; and having measured the perpendicular distance of the point c from the middle line of the body plan, set it off from the middle line of the half-breadth plan to cut the line a_1b_1 produced at c_1, which point is therefore the horizontal projection of the point c. Join c_1d_1; this is the trace of the plane of the moulding edge with the level plane cd. Through d_1 draw a line perpendicular to c_1d_1. this is the intersection with the level plane cd made by a vertical plane perpendicular to the plane of the moulding side of the timber. We purpose rabatting the plane of the moulding edge upon this vertical plane.

Now, since this vertical plane is perpendicular to the line (cd, c_1d_1), it is also perpendicular to the intersection of every other level plane with the plane of the moulding edge of the timber. Next measure the perpendicular distance of d_1 from the middle line of the half-breadth plan, and set it off from d_1 on the line drawn through that point perpendicular to c_1d_1. Through e, the point so found, draw ew perpendicular to d_1e; then ew will represent the middle line for our future measurements, as, by so doing, we shall, in effect, hinge round the vertical plane, whose trace is d_1e, about a vertical axis through d_1, until it is parallel to the body plane, in which position the rabatted moulding edge will appear as if rabatted upon the body plane. What we have next to do, then, is to rabat the plane of the cant upon the vertical plane d_1e about its intersection with that plane. We must therefore first determine the intersection about which the moulding edge plane is to be rabatted.

From the point a_1 in the half-breadth plan, draw a_1f_1 parallel to c_1d_1, and cutting d_1e at f_1. Then through the point a in the body plan, draw a horizontal line af, upon which set off from the middle line a distance vf equal to ef_1, or, what is the same thing, equal to a_1w. Proceed in a similar manner with regard to the point b_1 on the knuckle in the half-breadth, by setting off a distance, upon a level line drawn through the point b in the body plan, equal to eg_1, measuring as before from the middle line of that plan. Let g be the point so obtained, then f and g being two points in the trace required, therefore the line fg, joining them, is the trace itself. This line fg, if produced, will evidently pass through the point d, as f, g, and d, are three points in the intersection of two planes.

Before proceeding further, it is necessary that the projection of the portion of the moulding edge below the knuckle should be drawn in the half-breadth plan. In the body plan take the distance from the middle line to where the trace *fd* cuts each level line, and set off the distances so found along the line ed_1 in the half-breadth plan, measuring from the point *e*. Let *l*, *m*, and *o*, be the points so determined. Through these points draw lines, parallel to the line c_1d_1, to cut the corresponding level lines at h_1, i_1, and k_1. A curve passed through the points d_1, k_1, i_1, h_1, b_1, will be the projection of that portion of the moulding edge which is below the knuckle line.

Then to proceed with laying off the timber. Through the points *f*, *g*, *h*, etc., in the body plan, draw the lines *fp*, *gq*, *hr*, etc., perpendicular to *fd*; and set off on these the distances *fp* equal to a_1f_1, *gq* equal to b_1g_1, *hr* equal to h_1l_1, etc. Join *pq*, and pass a curve through the points *q*, *r*, *s*, *t*, *d*, then the line *pqrstd* is the exact shape of the moulding edge of the stern timber.

The direction of the heel of the moulding edge against the after cant or fashion timber is obtained as follows:—In the half-breadth plan, take the distance g_1z_1, and set it off in the body plan upon the line *gq* produced to *z*, measuring from *g*. Join *zd*, then this line marked upon the mould gives the up and down angle of the heel of the stern timber against the after cant.

To obtain the athwartship bevelling of the heel against the fashion timber, proceed as in the case of the single canted stern timber (Plate XLIX.), using the line *fd*, in Plate L., instead of the edge of the stern timber in body plan, as shown in the former Plate.

Perhaps, however, the better plan is to mark the ending of the bevelling edge, when laid off, upon the mould for the timber, and so determine the angle of bevelling by measuring the length of the snape of the heel.

To lay off the bevelling edge and obtain the bevellings.—Draw in the body plan a line *xy* parallel to *fd*, and at a distance equal to the mean siding of the timber, say one foot. This line will be a trace bearing the relation to the bevelling edge that the line *fd* does to the moulding edge. It should, however, in strict accuracy, be stated that the bevelling edge of a stern timber cannot be parallel to the moulding edge for the reasons already given (Art. 114);

but, as before mentioned, the inaccuracy which results from the assumption that the bevelling edge is parallel to the moulding edge is inappreciable. At some yards the bevelling edge is drawn correctly, and so, in marking the bevellings, the bevelling frame has to be shifted to the variable sidings of the timber.

We first obtain the disposition of the bevelling edge in the half-breadth plan; to do which, draw level lines through the intersections of the rail and knuckle lines in the body plan with the projection of the bevelling edge. Then measure in the body plan the distances from the middle line of that plan, to where the line xy cuts the several level lines; and set these distances along the line d_1e, measuring from the point e. Then draw lines through these points parallel to c_1d_1 to cut the corresponding knuckle, level, etc., lines, in the half-breadth plan. Let G, H, I, K, L, be these points. Join GH; pass a curve through the points H, I, K, L, and the line $GHIKL$ is the projection of the bevelling edge in the half-breadth plan.

To end the disposition of the bevelling edge: Produce xy in the body plan to v on the first level line below the after cant od—viz., to No. 4 level. The horizontal projection of v is the point M in the half-breadth plan, through which pass the curve $HIKL$; the point O_1, where this line intersects the edge of the after cant, is the ending of the disposition of the bevelling edge. The point o in the body plan is the vertical projection of O_1.

Next draw in the body plan lines perpendicular to xy at its intersection with the several level lines, and set off, upon these, measuring from fd, the square distances from ed_1 to the intersections of the disposition of the bevelling edge with the corresponding level lines in the half-breadth plan. A straight line drawn through the points so found, from the knuckle upwards, and a curved line through the points below the knuckle, is the true shape of the bevelling edge; observing that the latter is laid off in such a position, with regard to the moulding edge, that the square distance between the two lines at any of the points p, q, r, etc., is the perpendicular to set off when marking the bevellings. When the bevelling edge falls beyond the moulding edge, the bevelling is *standing*, and *vice versâ*.

116. Rail and Knuckle Harpins.—Before concluding our description of the stern framing, it is necessary that some reference should be made to the harpins which are made for that part of the ship. Only two harpins are required in order to check the positions of the timbers, and keep the stern to its correct form before the plank is brought on; these harpins being at the rail and knuckle. Elsewhere the timbers are connected by ordinary ribbands and cleats, which are supported by shores and the adjacent timbers of the frames.

Some shipbuilders trim these harpins to the sheer of the rail and the combined sheer and round down of the knuckle.

In the former case no great error is introduced by treating the harpin in the manner already described for an ordinary sheer harpin (Art. 90); but with regard to the knuckle it is not advisable to attempt to lay it off or develop it on the mould loft floor, as the mould made to the curve will only give the length of the harpin and the position of the timbers, without affording any information regarding the curvature of the knuckle.

When a harpin is made to the knuckle line, it is sometimes trimmed by the aid of a beam mould and a sheer line on the timbers; but more frequently the sheer is neglected, being very small in the fore and aft length of the knuckle, and the harpin is then trimmed by a mould giving the curvature of the stern at a level line passing through the after part of the knuckle, together with the stations of the timbers; and by a beam mould.

Perhaps the better plan is to provide only the mould and bevellings for a harpin at a level line about a foot above the knuckle, and mark upon this mould the stations of the stern timbers, a straight line, and a spiling. By marking the position of this level line upon the moulds to the stern timbers, the latter can then be fixed in their true position by bringing them to the mark given on the rail and knuckle level harpins, and to the positions marked for their heels on the after cant. If the work be carefully performed, a perfect coincidence will result, and the knuckles of all the timbers will be situated at a fair and correct knuckle line. But if, as frequently happens, the siding of the after cant or fashion timber should be a little less or more than was intended, the heels of the timbers, being thus out of their true position, will cause an irregular knuckle line. This is rectified by the workman in the following manner, and it may be here observed, that such a process as we are about to describe is at all times advisable, seeing that the true knuckle line of the ship is on the outside of the plank and not of the timbers. At certain intervals, pieces of board are fixed against the stern timbers, so that the outer edges of the boards may represent the surface of the plank. A beam mould is then fixed horizontally across the stern, square to the longitudinal middle line of the ship, and with its edge level with the upper side of the beam of the deck opposite which the knuckle is situated. A straight-edged batten is then fixed on the upper edge of the beam mould in a fore and aft direction and level; although, if great nicety be desired, it should be fixed in the line of the sheer of the deck. By holding another straight-edged batten with its edge against the edge of the beam mould at certain intervals, keeping the batten "out of winding," or in the same plane as the right aft batten, points may be found on the outer edges of the boards fixed against the stern, and by penning a batten through these points, we have the line of the knuckle of the ship. Spots on the timbers obtained by drawing lines square to the surface of the stern through the line so found, will be in the knuckle of the timbers, or, as it is termed, "the working" (or inner) "edge of the plank." This line should be rased on the timber surface, and the superfluous wood dubbed off.

In the preceding remarks only the elliptical stern has been considered. In the small amount of space at our disposal, it is impossible to refer to the timbers of the square or *transom* stern, although we purpose giving a brief description of the mode of combining the timbers in this style, which is now rapidly becoming a thing of the past (Art. 190). We will conclude this chapter with a few remarks on the style of stern which has lately been brought into being in Her Majesty's service.

117. Parabolic Stern.—Plate LI., fig. 2, shows this style of stern, which is contrasted with the style that immediately preceded it, shown by fig. 1. Plate LII. shows a plan of the framework of the stern (fig. 2, Plate LI.), which, in the absence of any other name, we will term the *parabolic stern.* The chief feature of this system is the absence of a knuckle or other form of base for the stern, which thus becomes a continuation of the buttock, the *post timbers* forming the back-bone, as it were, of the ship abaft the body post. When the screw propellor is not intended to be lifted, these timbers are close jointed from the gunwale to the body post, as in fig. 1, Plate LII.; but where a lifting screw is fitted, then the timbers separate and form the base of a screw well, as in fig. 2, Plate LII. In each case, boxen wood is left on the post timbers to house the aftermost ends of the side and bottom planks.

Instead of the complicated arrangement of timbers which is required by the preceding systems, the framing of this stern consists of ordinary cants; those before the screw aperture heeling against the deadwood, and those abaft it heeling against the sides of the post timbers.

No special description of the modes of laying off these timbers is necessary. The post timbers are laid off in the sheer plan similarly to those timbers of the elliptical stern which are parallel to the sheer plane. The remaining timbers of the stern are ordinary cants.

CHAPTER VII.

118. The Double Cant.—In the preceding chapter it was shown that certain of the stern timbers are canted in two directions for the reasons therein stated, hence these timbers are included under the above head. There are, however, certain features in the problem of the stern timber which will not allow of it being taken as a typical case of the *double cant* timber. The plane of the stern timber is governed by its traces with the ship's surface, as the latter are first drawn, and then the traces on the planes of reference determined from them. Again, the planes of reference are those of the body and half-breadth, instead of the sheer and half-breadth, for, unlike the more general case, only a very few of the timbers of a ship's frame can be disposed in the body plan. Besides this, the peculiar form of the surface of the stern compared with that of the remainder of the ship, likewise tends to render the stern timber a singular case of the double cant.

Notwithstanding, however, that the stern timber is not a general form of the problem about to be considered, it is the only form in which that problem occurs in actual practice. We are not aware whether any other double canted timber was ever incorporated with a ship's frame. Indeed, the *double cant* appears to be an abstract problem useful only as an exercise, and for that purpose we now propose to consider it under the various forms in which it may serve to illustrate the application of some of the more difficult problems of "Plane Descriptive Geometry" to ship laying off.

The plane of an ordinary cant is inclined to the sheer plane only, such an inclination being all that is necessary for the purpose of reducing the bevelling of the timber to within practicable limits. It is, however, possible to conceive a ship, the surface of which is such, that timbers canted in only the one direction would still have very considerable bevelling; and although such a case rarely, if ever, occurs in practice, yet it is for the purpose of still further reducing the bevelling that the plane of the timber is supposed to be also canted to the half-breadth plane, and then we have a general form of the double cant.

The simplest mode of laying off this timber is by level lines, and therefore we will now proceed

119. To Lay off a Double Cant by Level Lines.—In fig. 1, Plate LIII., let *ab*, a_1b_1 be the traces of the plane of the moulding edge of the double cant with the sheer and half-breadth planes respectively; also let XY be the base line of the former, and X_1Y_1 the middle line of the latter plan. In order to prevent confusion in the figure, we will determine one point only in the cant, also its ending, as any number of other points can be obtained in a similar manner. Let *cd* and c_1d_1 be a level line in the sheer and half-breadth plans respectively. Project the point *e*, where the trace *ab* cuts the level line *cd*, upon the middle line of the half-breadth at e_1, and through this point draw e_1f_1 parallel to a_1b_1, then e_1f_1 is the horizontal projection of the intersection of the cant plane with the level plane, and therefore f_1 will be the horizontal projection of a point in the curve of the cant edge. Project f_1 upon the level line *cd* at *f*, then *f* is the vertical projection of the said point in the curve of the cant edge, and therefore is a point in the disposition of the latter. We will now rabat the plane of the moulding edge of the cant upon the sheer plane about the trace *ab* as an axis; then any point *f* in the process of rabatting will move in a circle the plane of which is perpendicular to the trace *ab*. Wherefore, through *f* draw *fg* perpendicular to *ab*, and produce it in the direction of *P*.

Now the distance of the point *f* from the axis of rabatment, measured in the plane of the level line *cd*, is evidently the distance e_1f_1. Hence, with centre *e* and radius equal to e_1f_1, sweep an arc of a circle, cutting the line *gf* produced in the point P; then P is a point in the curve of the moulding edge of the double cant when the plane of the latter is rabatted upon the sheer plane. Any number of other points in the curve may be obtained in a similar manner by the aid of additional level lines.

120. To End the Moulding Edge of the Double Cant on a Parallel Deadwood.—Still referring to fig. 1, Plate LIII., let n_1o_1 be the half siding, and no the bearding of the deadwood. Project the point h_1, where the trace a_1b_1 cuts the half siding of deadwood, to the point h on the base line of the sheer plan, and through this point draw hm parallel to ab. Then the line hm is the vertical projection of the intersection of the plane of the cant with the plane of the side of the deadwood, and therefore the point k, where this intersection cuts the bearding line, is the ending of the disposition of the cant. Through k draw kl perpendicular to ab, and produce it in the direction of Q; the point k, when rabatted, will fall on this line. Through k draw kr parallel to XY, so as to cut the trace ab at r; then with centre r and radius equal to a_1h_1, sweep an arc of a circle, cutting lk produced in the point Q. Then Q is the ending of the double cant, and a curve PQ drawn through all the points, such as P and the ending Q, is the true shape of the moulding edge of the timber.

121. To End the Moulding Edge of the Double Cant on a Tapering Deadwood.—Turning now to fig. 2 on Plate LIII., let P be a point in the moulding edge laid off as before. Draw any level plane to cut the deadwood, and let no be the vertical trace of this plane, and n_1o_1 the horizontal projection of its intersection with the deadwood. At the point s, where ab cuts no, let fall a perpendicular to s_1 on the middle line of half-breadth; and through s_1 draw s_1t_1 parallel to a_1b_1, then s_1t_1 is the horizontal projection of the intersection of the plane of the level line with that of the cant. Project t_1 to t, and from the point h_1 where a_1b_1 cuts n_1o_1 draw a perpendicular to h on the base line of the sheer plan. Join ht, then this line is the vertical projection of the intersection of the plane of the cant with that of the side of the deadwood. Hence the point k, where this line cuts the bearding line, is the ending of the disposition of the moulding edge in the sheer plan. Through k draw kl perpendicular to ab, also kr parallel to XY, cutting ab in r. From the point r draw rr_1 perpendicular to X_1Y_1, and draw r_1k_1 parallel to a_1b_1, cutting the side of deadwood at k_1; then with centre r and radius equal to r_1k_1, sweep an arc of a circle cutting kl produced at the point Q, then Q is the ending of the moulding edge of the double cant against a tapering deadwood.

It is hardly necessary to add, that if a case similar to that just considered ever occurred in actual practice, the amount of taper would be so small as to make no appreciable error in the result if it be neglected altogether.

122. To Lay off the Bevelling Edge of a Double Cant by Level Lines.—Before proceeding to lay off the bevelling edge of a double cant, it is necessary that we should first show how to draw the traces of the plane of the bevelling edge with the sheer and half-breadth planes. The plane of the bevelling edge being parallel to that of the moulding edge, its traces will evidently be parallel to the traces of the latter plane. It is, however, necessary that the planes should be a certain known distance apart, as that distance will be the base of the triangle when setting off the angles of bevelling. Having decided upon this amount, we have next to construct the traces of a plane which is parallel to the plane of the moulding edge, and at this fixed distance from it. It is evident that this distance set off square from the trace of the moulding edge plane in either of the plans will not give a point in the required trace. The latter is obtained as follows:—

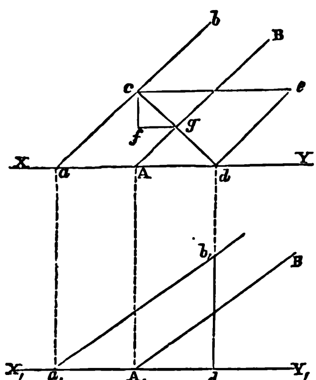


Fig. 6.

To Construct the Traces of the Plane of the Bevelling Edge.—In fig. 6, let ab and a_1b_1 be the vertical and horizontal traces, respectively, of the plane of the moulding edge. Take any point c in ab, and draw cd perpendicular to that line; cd will represent the vertical trace of a plane which is perpendicular to that of the cant and to the sheer plane. Drop a perpendicular dd_1 from d, then this line will be the horizontal trace of the perpendicular plane. We will rabat this plane and its trace with the cant plane upon the sheer plan about the trace *cd*, to do which draw *de* parallel to *ab*, and make *de* equal to d_1b_1, and join *ce*. Then *ce* is the rabatment of the intersection of the perpendicular plane with the plane of the cant, and *ecd* is the angle at which the cant plane is inclined to the sheer plane. From the point *c* draw *cf* perpendicular to *ce*, and make *cf* equal to the siding of the cant. Through *f* draw *fg* parallel to *ce*, cutting *cd* at *g*, then *g* is a point in the vertical trace of the bevelling edge. Hence the vertical trace is the line *AB* drawn through the point *g* parallel to *ab*, and the horizontal trace is found by projecting *A* to A_1 on the middle line of the half-breadth, and drawing A_1B_1 parallel to a_1b_1.

There would be no difference in the modes of laying off the moulding and bevelling edges of a single canted timber, were it not that it is found convenient to have the latter edge so laid off with reference to the former, that the square distance between them at any point shall be the perpendicular opposite the angle of the deviation of the bevelling from a right angle. With respect to the double cant, it is questionable whether there is any advantage in so laying off the bevelling edge, as the extra labour involved is not compensated for by greater facility in taking the bevellings. Hence, if it were ever required to lay off a double cant on the mould loft floor, it is highly probable that it would be found advisable to have recourse to some such a method as the following:—In Plate LIV., fig. 1, let *ab* be the vertical trace of the moulding edge of a double cant, and *pq* the curve of the cant when laid off in the manner already described. Construct the angle *lgk*, which the plane of the cant makes with the sheer plane, by the mode just given; and, for the convenience of illustration, we will make *lg* pass through one of the points *p*, at which the bevellings have to be taken. We thus obtain a point *h*, through which is drawn the vertical trace *AB* of the plane of the bevelling edge of the cant, the said plane being at a distance from the plane of the moulding edge equal to *gm*. Lay off the bevelling edge, of which *AB* is a trace, in the same manner as the moulding edge, and let *PQ* be its curve. Now, in the present situation of the bevelling edge with regard to the moulding edge, we cannot measure the bevellings without making some corrections; this we now proceed to do.

Produce *gp* to cut the curve *PQ* at *s*; then turning to fig. 2, draw a straight line Wp_1, and at a point *W* in it make the angle p_1WV equal to the angle *kgl*, in fig. 1. Take *WV* equal to *gh*, and through *V* draw Vs_1 parallel to Wp_1. Set off Vs_1 equal to *hs*, and Wp_1 equal to *gp*; join p_1s_1. It will be readily seen that fig. 2 represents a section of the volume of the ship enclosed by the planes of the moulding and bevelling edges, the said section being made by the plane whose vertical trace is *gs*. Now produce *WV* both ways, and call the extended line X_1Y_1, then X_1Y_1 represents the trace of the perpendicular plane with the sheer plane. Take *WR* equal to *mh*, or (what is the same thing) through *V* draw *VR* perpendicular to Wp_1. With centre *W* and radii *WR*, Wp_1, sweep arcs of circles cutting X_1Y_1 at *Z* and p_2; also with centre *V* and radius Vs_1, sweep a circular arc cutting X_1Y_1 at s_2. Then p_2s_2 is equal to *ps*; for we have now rabatted the planes of the moulding and bevelling edges upon the sheer plan in just the same way as in fig. 1. Now it is evident that s_2 is too far away from p_2 to allow of the bevellings being measured in the usual manner, the excess of distance being equal to *ZV*. Hence make s_2t_1 equal to *ZV*, and in the sheer plan set off *gt* equal to Wt_1; then t_1 will be a point in the bevelling edge when laid off so as to enable the bevellings to be measured in the ordinary manner. Other spots are obtained for the other level lines, and the bevelling edge can then be drawn in this position.

In practice these operations would be performed in a very simple manner. The triangle *gmh must* be constructed in order to draw the trace of the bevelling edge; hence all the additional work, after the bevelling edge is laid off, is to set off *hf* equal to *hm*, and then to mark a distance *st* equal to *gf* at *every* bevelling point; for the value *gf* is invariable for each double cant timber. A curve is drawn through all such points as *t*, when the distance perpendicular to the curve of the moulding edge between it and the former curve at every point, such as *p*, is measured, and then used in the ordinary manner for marking the bevellings. Of course the latter are applied, as usual, square to the curve of the timber.

123. To Obtain the Bevelling of the Heel of the Double Cant against a Parallel Deadwood.—When the latter is of parallel siding, the bevelling of the heel against it is the same as that between the plane of the cant and the sheer plane. Hence the angle *kgl* in fig. 1, on Plate LIV. (which corresponds with the angle *ecd* in fig. 6), is the bevelling required.

124. To Obtain the Bevelling of the Heel of the Double Cant against a Tapering Deadwood.—But if the deadwood tapers, then referring to fig. 7, construct *hm*, the vertical projection of the intersection of the cant plane with the plane of the side of deadwood, in the manner already described (see Plate LIII., fig. 2). Now, as the bevel is always held square to the intersection of the moulding side of the timber and the surface to be bevelled, we have therefore, as before, to determine the angle between two planes,

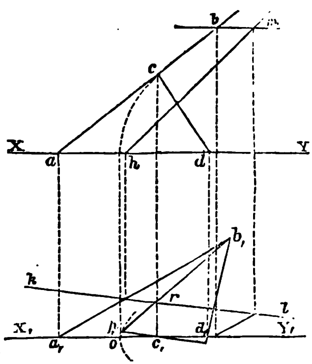


Fig. 7.

viz., those of the cant and the side of the deadwood. In other words, we have to determine the angle between the intersections with these planes of a plane perpendicular to both of them. In any convenient position draw *cd* perpendicular to *hm*, this will be the vertical trace of the perpendicular plane. Project the point *c* where the line *cd* cuts *ab*, and *d* where it cuts the base line *XY*, to the middle line of half-breadth at c_1 and d_1 respectively. Through d_1 draw d_1b_1 perpendicular to the half siding of deadwood *kl*, and intersecting a_1b_1 at b_1. Then d_1b_1 is the horizontal trace of the same perpendicular plane. We will now rabat this plane about its trace b_1d_1 upon the horizontal plane, and, with it, the intersections, the angle between which is the required bevelling. With centre d_1, and radius equal to *dc*, describe an arc of a circle op_1. In the process of rabatment the point c_1 will fall upon a line c_1p_1 perpendicular to b_1d_1, it will also be at a distance *cd* from the point d_1; hence the point p_1, where the line c_1p_1 cuts the arc of the circle, is the point *c* when rabatted on the horizontal plane in the manner stated. Join b_1p_1, cutting *kl* at *r*; this line will be the intersection of the perpendicular plane with the cant plane when rabatted. But *rl* is the intersection of the perpendicular plane with the plane of the side of deadwood, for it is unaltered by rabatment; hence the angle b_1rl is the bevelling required.

125. To Lay off the Bevelling Edge by another Method.—As we have stated, the mode already given of laying off the bevelling edge is that which causes the minimum of trouble, and is therefore the best for practical purposes. We will now give a method which accords with that of determining the bevelling edge of an ordinary cant, that is to say, such a method as will allow of the bevellings being measured at once without making any corrections.

It will be remembered that the course pursued with reference to the bevelling edge of an ordinary cant, in order to obtain it in the required position for taking the bevellings, consisted, in effect, of first projecting the plane of the bevelling edge upon that of the moulding edge, and then rabatting the latter about its vertical trace. This was done by drawing the horizontal trace of a plane perpendicular to the plane of the moulding edge, through the intersection of the moulding edge with the middle line of the half-breadth plan, and then, having produced the trace of the bevelling edge plane to cut the former trace, the distances along the bevelling edge to the several diagonal lines, etc., were taken from the intersection of these two traces, and set off from the trace of the moulding edge in the sheer plan. We have recapitulated these processes in order to explain the motives for the following construction:

In Plate LV., *ab* and a_1b_1 are the vertical and horizontal traces respectively of the plane of the moulding edge. Suppose *AB* to be the vertical trace of the plane of the bevelling edge constructed by the method already explained (Art. 122), *cd*, c_1d_1, is a level line, as before. We will now obtain the horizontal trace of a plane which is perpendicular to the plane of the cant, and whose vertical trace coincides with the vertical trace ab of the plane of the moulding edge. Draw any line gl in the sheer plan perpendicular to ab; this will be the vertical projection of a line in the plane whose horizontal trace is required. Project g upon the middle line X_1Y_1 of the half-breadth plan, and through g_1 draw kg_1l_1 perpendicular to a_1b_1; then kg_1l_1 is the horizontal projection of the line gl. From the point l where gl cuts the base line of the sheer plan, drop a perpendicular ll_1 to cut the line kl_1 at l_1. Now, since ab is the vertical trace of the required plane, therefore the point a_1 will be a point in its horizontal trace. But as the point l_1 is the horizontal trace of the line kl_1, which is in the required plane, therefore l_1 is also a point in the horizontal trace of that plane. Hence the line a_1l_1 joining these two points is that horizontal trace.

Again, project the points e and h where the vertical traces of the planes of the moulding and bevelling edges cut the line cd to e_1 and h_1 on the middle line of the half-breadth plan, and through these points draw e_1f_1, h_1F_1 parallel to a_1b_1. These lines e_1f_1, h_1F_1 are the horizontal projections of the traces of the level plane with the planes of the moulding and bevelling edges respectively. Through e_1 draw e_1E_1 parallel to a_1l_1 to cut F_1h_1 produced in E_1; then e_1E_1 is the horizontal projection of the trace of the plane ab, a_1b_1, with the level plane cd, and from this trace we have to measure the distance to the intersection of the level line used in laying off the cant, in order that by setting off this distance from the vertical trace of the moulding edge, the bevelling edge may be rabatted in the required position. We will now rabat the bevelling edge. Project F_1 to F, and E_1 to E, both on the level line cd. Through F draw FG perpendicular to AB, and through E draw Eo perpendicular to ab. Then with centre o and radius equal to E_1F_1, sweep an arc of a circle to cut GF produced in the point P; then P is a point in the bevelling edge, the latter being laid off in the required position for taking the bevellings.

126. To End the Bevelling Edge of a Double Cant on a Parallel Deadwood.—In Plate LVI., fig. 1, ab, a_1b_1 are the traces of the plane of the moulding edge, and AB, A_1B_1 are those of the plane of bevelling edge, cd is the bearding line, and c_1d_1 the half siding of deadwood in the half-breadth plan. Project the point e_1, where the trace A_1B_1 cuts the line c_1d_1, to the base line of the sheer plan at e, through which draw ef parallel to AB, cutting the bearding line at f. Then f is the projection of the ending of the bevelling edge; and, therefore, the ending of that line, when laid off, will be somewhere on the line fp drawn perpendicular to either ab or AB. Through the point f draw a level line fg; the horizontal projection of the intersection of this level plane with the plane of the side of the deadwood, is evidently the line c_1d_1. Construct a_1z, the horizontal trace of a plane perpendicular to the plane of the moulding edge, and whose trace coincides with the vertical trace ab (see preceding problem). Project the point g where the level line cuts the trace ab upon the middle line of the half-breadth plan at g_1, through which draw g_1h_1 parallel to a_1z. Also, project the point k where the level line cuts the trace AB upon the middle line at k_1, through which draw k_1l parallel to a_1b_1 or A_1B_1, cutting c_1d_1 in l. This line k_1l is the horizontal projection of the trace of the level plane with the plane of the bevelling edge, and g_1 is also a point in the trace of the same level plane with that of the moulding edge. Produce lk_1 to cut g_1h_1 at h_1. Project h_1 to the level line at h, through which draw ho perpendicular to ab. Then, with centre o and radius equal to h_1l, sweep an arc of a circle to cut fp at p. The point p is the ending of the bevelling edge. It will be observed that the ending of the bevelling edge is obtained in a manner similar to that of obtaining other points in the curve; it being, indeed, but a modification of the general mode of procedure in obtaining points in that line.

127. To End the Bevelling Edge of a Double Cant on a Tapering Deadwood.—A description of the method of laying off a double cant would not be complete without showing how to end the bevelling edge on a *tapering* deadwood. And here we must again call to mind our previous statement, that there is no practical utility in what we are about to do, our reasons for inserting it being to complete the discussion of a problem which is valuable as an exercise in the more intricate questions of the geometry of shipbuilding (see Plate LVI., fig. 2). In this case the traces of the moulding and bevelling edges are lettered as before: c_1d_1 shows the tapering deadwood, and *cd* is the bearding line. Draw *ef*, a level line to cut the plane of the side of the deadwood. At the point *f*, where *ef* cuts *AB*, drop a perpendicular to the middle line of half-breadth at f_1, through which draw f_1g_1 parallel to A_1B_1; then f_1g_1 is the horizontal projection of the trace of the level plane with the plane of the bevelling edge. Now since c_1d_1 is the horizontal projection of the intersection of the level plane *ef* with the deadwood, therefore g_1 is a point in the intersection of the plane of the bevelling edge with that of the deadwood. Project g_1 to *g* on the level line *ef*, then *g* is a point in the vertical trace of the two planes just referred to. Project h_1, where A_1B_1 cuts the line c_1d_1, to *h* on the base line of the sheer plan, then *h* is another point in the same trace; hence the line *hg*, which joins them, is the vertical projection of the intersection of the plane of the bevelling edge with the plane of the side of deadwood, and therefore the point *l*, where it cuts the bearding line, is the ending of the projection of the bevelling edge. Through *l* draw *lp* perpendicular to *ab* or *AB*, then the ending of the bevelling edge, when laid off, will be on this line *lp*. Construct the horizontal trace a_1z of a plane perpendicular to the plane of the cant, whose trace coincides with the vertical trace of the latter, as before (Art. 125). Through *l* draw a level line *lk*, cutting *ab* and *AB* at *k* and *m*; project these points upon the middle line of half-breadth at k_1 and m_1. Through k_1 draw k_1z_1 parallel to a_1z, and through m_1 draw m_1o_1 parallel to a_1b_1 or A_1B_1, cutting c_1d_1 at o_1. Produce o_1m_1 to cut k_1z_1 at n_1, project n_1 to *n* on the level line *kl*, and through *n* draw *nr* perpendicular to *ab*. Then with centre *r* and radius equal to n_1o, sweep an arc of a circle cutting *lp* in *p*; *p* is the ending of the bevelling edge against a tapering deadwood.

128. We will now proceed to consider *the mode of laying off a double cant by diagonal lines.*

To Lay off the Moulding Edge of a Double Cant by Diagonal Lines.—In Plate LVII., *ab* is the vertical, and a_1b_1 the horizontal trace of the plane of the moulding edge; *cd*, c_1d_1, c_2d_2, are the projections of the diagonal line in the body, half-breadth, and sheer plans respectively; also c_3d_3 is the rabatted diagonal in the half-breadth plan. Draw ef, e_1f_1, the projections of a bow line, in the body and half-breadth plans; and through the point f, where the bow line cuts the diagonal line in the body plan, draw a level line, and produce it over into the sheer plan to cut the trace ab at g. It should be observed that the body and sheer plans have a common base line, XY. From the point g drop a perpendicular to g_1 on the middle line of the half-breadth plan, through which point draw g_1h parallel to a_1b_1; it is clear that g_1h is the horizontal projection of the trace of the level plane fg with the plane of the moulding edge. Project the point k_1, where the line g_1h cuts the bow line e_1f_1, to k on the level line fg. Now the line g_1h being in the level plane, whose trace is fg, the point k_1 is in that plane; it is therefore a point common to the level plane and the plane of the moulding edge, and therefore the point k is also a point in the latter plane. Again, the line ab being on the sheer plane, by levelling over the point c from the middle line of body to o in the line ab, we have another point o, which is in the cant and diagonal planes. Hence the line ok is in those planes, and therefore the point l, where the line ok cuts the diagonal projection c_2d_2, is a point common to the cant and diagonal planes, and the surface of the ship. Wherefore l is a point in the projection of the moulding edge of the cant. In rabatting the plane of the cant about the trace ab, the point l will move along a line lP, drawn through l perpendicular to ab.

Project the point o upon the middle line of the half-breadth plan at o_1, also project the point l upon the rabatted diagonal at l_1. Join o_1l_1; then with centre o and radius equal to o_1l_1, sweep an arc of a circle, cutting lP at the point P, which will be a point in the moulding edge of the cant when rabatted. If we had not drawn the rabatted diagonal c_3d_3, but had only the projected diagonal c_1d_1, then by dropping the perpendicular from l to the line c_1d_1 at l_2 and joining o_1l_2, the required radius o_1l_1 could be found by constructing a right angled triangle whose base is equal to o_1l_2, and perpendicular om, the hypothenuse of which triangle will be equal to o_1l_1. Other points in the moulding edge can be found by a similar construction, and the curve drawn, it being ended at a point found by the methods given in Arts. 120 and 121.

129. To Lay off the Bevelling Edge of a Double Cant by Diagonal Lines.—The traces of the plane of the bevelling edge are obtained in the manner already stated, when describing the mode of laying off the bevelling edge by level lines (Art. 122).

The projection of the bevelling edge in the sheer plan may be obtained in a similar manner to that of the moulding edge, or it may be found by drawing through the point C (Plate LVIII.), where the level cC cuts the vertical trace AB of the plane of the bevelling edge, a line CL parallel to ol; then the point L, where this line intersects the projection of the diagonal plane c_2d_2, will be a point in the disposition of the cant.

To lay off the bevelling edge, we may proceed as with the moulding edge, and then make the necessary correction as when laying it off by level lines in Art. 122, or we may project its plane upon that of the moulding edge, and then rabat the latter plane about its vertical trace. The former method need not be repeated. To lay it off by the latter, we again measure our distances for rabatting from a plane perpendicular to the plane of the cant, and whose vertical trace coincides with the vertical trace of the moulding edge.

Lines such as e_1E_1 (see Plate LV.), parallel to a_1l_1, the horizontal trace of this perpendicular plane, are the intersections of the perpendicular plane with level planes. In the present case, we require the intersections of the several diagonal planes with the perpendicular plane.

Returning to Plate LVIII., construct a_1z, the horizontal trace of the perpendicular plane, as before. Draw in the body plan a level line mn, cutting the diagonal line dc produced at n, and let the intersection of this level line with the vertical trace of the moulding edge be m_1; project this point to the middle line of the half-breadth plan at m_2, through which draw m_2z_1 parallel to a_1z, then m_2z_1 is the horizontal projection of the intersection of the level plane mn and the perpendicular plane. Draw a line x_2y_2 parallel to the middle line X_1Y_1, and at a distance from it equal to mn; x_2y_2 is the horizontal projection of the intersection of the level plane, whose trace is *mn*, with the diagonal plane whose trace is *cd*, and therefore z_1, where it cuts m_2z_1, is a point common to the diagonal plane, level plane, and perpendicular plane. Now rabat this point z_1 with the diagonal plane about the trace of the latter with the sheer plane, that is, about the axis X_1Y_1. To do this, draw through the point z_1 the line z_2z_3 perpendicular to X_1Y_1, and make z_2z_3 equal to *nc*, then z_3 is the rabatted position of the point z_1. Join o_1z_3, then this line is the rabatment of o_1z_1, the horizontal projection of the intersection of the perpendicular and the diagonal planes, and is therefore the line from which to measure the distances along the intersection of the bevelling edge with the diagonal plane to the corresponding rabatted diagonal line, in order that the bevelling edge may be rabatted in the required position for taking the bevellings. We now want the point on the line o_1z_3 from which to measure; or, in other words, we want to find the intersection of this line with the plane of the bevelling edge.

Project C to the middle line of half-breadth at C_1, and L to the rabatted diagonal line at L_1; join C_1L_1, then C_1L_1 is the trace of the plane of the bevelling edge with the diagonal plane, after being rabatted with the diagonal c_3d_3 upon the horizontal plane of projection. Produce C_1L_1 to cut o_1z_3 at o_2, then o_2, being a point common to the plane of the bevelling edge, the perpendicular plane, and the diagonal plane, is the point required; also o_2L_1 is the distance from the ending o_2 to the surface of the ship measured in the diagonal plane, which distance will be rabatted in the sheer plan in finding a point in the bevelling edge when laid off. But we must first find the point in the sheer plan from which this distance must be measured, that is to say, we must find the point in the sheer corresponding to o_2 when the plane of the bevelling edge is rabatted about the vertical trace of the plane of the moulding edge.

From the point o_2 draw o_2r perpendicular to X_1Y_1, and in the body plan measure from the point *c* along the diagonal cr_1 equal to o_2r; through r_1 draw a level line r_1r_2, and project r upon it at the point r_2, then r_2 is the vertical projection of the point o_2. But when the plane of the bevelling edge is rabatted about *ab*, r_2 will be on *ab* at a point *s* found by drawing r_2s perpendicular to ab. Therefore fix the point of one leg of a pair of compasses at s, and then with a radius equal to o_2L_1 sweep an arc of a circle, cutting a line LP (drawn through L perpendicular to ab) at the point P, then P is a point in the curve of the bevelling edge. Other points having been obtained in a similar manner by means of other diagonal lines, the curve can be drawn, observing that the ending either for a parallel or a tapering deadwood is obtained in the manner already described.

It may further be remarked, that what has already been said with regard to the bevelling of the heel against deadwood, etc., applies likewise to this case, as the nature of the lines by which the curve is laid off cannot affect the mode of treating the cant where its plane intersects another plane, such as that of a deadwood, either parallel or tapering.

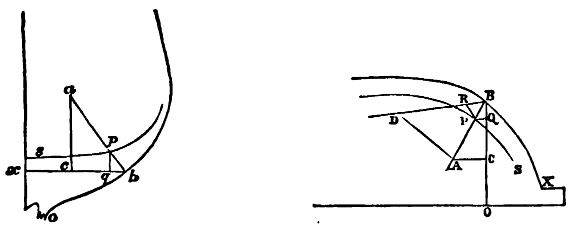
CHAPTER VIII.

130 Putting on and Taking off the Plank. — Sheer draughts of wood, or sheathed ships, are sometimes given into the hands of the draughtsman, the lines of which show the outside of the plank and not of the frames; hence, before copying the drawings upon the floor, the plank has to be removed, and lines on the surface of the framing determined. This process, which is termed "taking off the plank," has always to be performed either by the designer or the mould loft draughtsman, as all the hydrostatical qualities of the ship are determined from the actual volume which is immersed.

At the midship section, the operation of "taking off the plank" is easily performed, as it simply consists of setting in, square to the curve, the thickness of plank at certain points in the section, and then passing a curved line through the points so found. In approaching the extremities of the ship, owing to the curvature of the water lines, it is evident that the thickness of the plank, measured in the plane of a transverse section, is greater than the actual thickness; this being especially the case in a bluff ship. Under these circumstances, it becomes necessary to devise some means of obtaining the curves of square stations at these places. In most cases an approximation, which we will now state, is considered sufficiently accurate. Set a pair of compasses to the actual thickness of the plank, and apply it square to the curve of a level line in the half-breadth plan, so that while one point of the compasses is on the level line, the other is on a square station. Then measure the distance of this point on the square station to the level line, in the direction of the station, and set it in square to the curve of the corresponding square station in the body plan, to cut the corresponding level line; performing the operation with a pair of compasses in the same way as before. If points be found in this manner for each level line intersecting a square station, a curve drawn through the points will be the line of the outside of the frame at that station. The same operation being performed in the case of the other stations, new level lines can be copied from them into the half-breadth plan.

It need hardly be remarked that the process of "putting on the plank" is the converse of the preceding.

131. The Same by an Exact Method.—An exact method of taking off the plank is given at page 114 in *Shipbuilding, Theoretical and Practical,** which, by the kindness of the authors, we are enabled to insert here.



Body Plan. Fig. 8. *Half-breadth Plan.*

Let BX, *bx*, fig. 8, be a level line, and BO, *bo* a square station; these showing the outside of plank. At the point B, *b* draw normals BA, *ba* to the curves BX, *bo*, respectively. These are the projections of a line normal to the surface at *B*, *b*. On OB set off any distance OC, and make *xc* equal to OC. Through *c* and C draw *ca* and CA perpendicular to *bx* and OB, cutting *ba* and BA at *a* and A respectively. Then *a* and A are projections of a point in the normal to the ship's surface at *b*, B. Through A draw AD perpendicular to AB, and make AD equal to *ac*. Join BD, then BD is the normal to the surface rabatted upon the level plane BX. Make BR equal to the thickness of the bottom plank, draw RP perpendicular to AB, then P is the horizontal projection of a point in the outer surface of the framing. Draw PQ perpendicular to BO, cutting it in Q; in *xb* take *xq* equal to

* *Shipbuilding, Theoretical and Practical.* Edited by Professor Rankine.

OQ, and draw qp perpendicular to bx, cutting ab in p; then p is the vertical projections of a point on the outer surface of the frames, P being its vertical projection. This point will not generally be situated either in the plane of the level line, or that of the square station; it will therefore be necessary to find similar points corresponding to several of the level lines at the square stations. Curves PS and ps drawn through the horizontal and vertical projections of these points are the projections of a line in the inner surface of the ship, and the intersection of this line with the plane of each level line will give a point through which the level line, corresponding to the inner surface of the skin, will pass.

132. Middle of Rabbet and Bearding Line by an Exact Method.—It was stated at Arts. 14, 15, and 16, that the modes of finding the middle of rabbet and the bearding line, which we have there given, are not strictly correct, although the approximations are sufficiently good for all practical purposes.

We will now state an exact solution of these problems, which solution, like that just mentioned for taking off the plank, is copied, by permission of the authors, from *Shipbuilding, Theoretical and Practical*, pp. 115, 116.

In Plate LIX., let ab, a_2b_2 be the vertical traces of a level plane, and let a_1b_1 be the projection in the half-breadth plan of its intersection with the surface of the plank. At the point b, where the level line in the sheer plan cuts the fore edge of rabbet, draw a tangent line cd to that curve, cutting the base line of sheer at the point d. Project the point d upon the middle line of the half-breadth plan at d_1, from which draw the perpendicular d_1g, making d_1g equal to f_1g_1 in the body plan. Then g is the horizontal trace of the tangent to the fore edge of rabbet at b. Through b_1, the fore edge of rabbet in the half-breadth plan at the height of the level line a_1b_1, draw a tangent hk to the latter line, cutting the middle line in v_1, which point project upon the level line in the sheer plan at v. Also through the point g draw lm parallel to hk, cutting the middle line at n_1, which point project upon the base line of sheer plan at n. Join nv, then the line nv is the vertical trace of the tangent plane to the surface of the ship at b, b_1. Through b and b_1 draw bp and b_1p_1 perpendiculars to nv and $n_1 l$ respectively, that is, to the vertical and horizontal traces of the tangent plane. Therefore, bp and $b_1 p_1$ are the vertical and horizontal projections of a perpendicular to the tangent plane at the point b, b_1. Take any point p, p_1, in the perpendicular, and consider for the present that the plane of the level line ab is the horizontal plane of projection. Through p_1 draw $p_1 s_1$ perpendicular to $p_1 b_1$, and make $p_1 s_1$ equal to ps in the sheer. Join $b_1 s_1$; this is the rabatment on the horizontal plane of a line perpendicular to the tangent plane at b, b_1. Set off on $b_1 s_1$ the distance $b_1 t$ equal to the thickness of the bottom plank, and through t draw tt_1 parallel to $s_1 p_1$ cutting $b_1 p_1$ at t_1, then t_1 is the horizontal projection of a point in the middle of the rabbet. By projecting the point t_1 upon the line bp, a point t_2 is found in the vertical projection of the middle of rabbet. Similarly the point t_2 may be projected over into the body plan at t_3. Other points in the middle of rabbet having been found in the three plans, the line of the middle of rabbet can be drawn, and all the level lines in the sheer and body plans will end at their intersections with it. These endings can then be projected into the half-breadth plan, and the level lines in that plan ended at the points thus given.

To obtain the bearding line.—Draw in the half-breadth plan short lines parallel to the middle line of that plan, and at a distance from it equal to the half siding of stem at each of the level lines; the points where these lines intersect the corresponding level lines, will be in the horizontal projection of the bearding line, and the vertical projection of that line is found by projecting these intersections upon the corresponding level lines in the sheer plan, and passing a curve through the points so obtained.

PART II.—LAYING OFF IRON SHIPS.

CHAPTER IX.

133. Laying off Mercantile Iron Ships.—The advantages of iron over wood, as a material for the construction of ships, are exemplified not only in the superiority of the ships when built, but also in the comparative simplicity of all the operations connected with the building thereof. In no department of iron shipbuilding is this relative simplicity more apparent than in that which is carried out on the mould loft floor. Many of the difficulties which beset the draughtsman in determining the forms of timbers disposed in peculiar directions, and in providing check data for the due erection and permanent maintenance of these timbers in the required positions and to the required curvatures, are removed when he has to deal with such a malleable and weldable material as iron.

134. Variety of Systems.—In considering the laying off of iron ships, we will first devote our attention to those of the mercantile navy. Our iron shipbuilding industry has four principal centres, viz., the Clyde, Tyne, Thames, and Mersey. The practices on these rivers differ in some respects; for while on the Thames the work of the mould loft floor conforms somewhat to that of wood shipbuilding, on the other rivers, especially the Clyde, the mode of procedure does not appear to be much, if at all affected by the traditions of the earlier trade.

135. General Characteristics.—Owing to the hardness of the material, and the small sizes of the scantlings, compared with those of wood ships, which are required in order to give the necessary strength, it is essential that the work of the draughtsman should be performed with great accuracy, as it is not possible to correct unfairness by the dubbing process so freely resorted to by some of our wood shipbuilders.

As a consequence, we find that the trade has acquired some of the practices which are necessarily followed by engineers and others, with the parts of whose work great nicety of correspondence is required. Hence moulds are comparatively disused, and templates, sketches with figured dimensions, etc., are to a great extent substituted. The ease with which the material can be fashioned during the course of preparation, and the difficulty of making alterations when once it is combined, have thus produced a regularity of arrangement, a uniformity of parts, and hence a simplicity of labour. It will therefore be seen that the work of laying off an iron ship for the mercantile navy is reduced to very small dimensions indeed. As we shall show hereafter, the complex character of the framing of an iron-clad ship of war makes theirs to be a case of a different character, although even with iron-clad ships the geometrical problems are fewer than in a wooden ship of equal rating.

136. The Sheer Draught of an iron ship for the merchant navy shows the outer surface of the framing, and is therefore in a fit condition for transference to the floor. It may here be remarked that this is the designed draught, for, as the plating is thin, the volume of the draught is not much greater than if the plating were removed. In many private shipyards, it is not usual to give the person who lays off the ship a copy of the sheer draught, but a tabulated form is provided for him, giving the length and breadth of the ship, the spacing of the frames, the distances between the level lines, and the lengths of the ordinates of the body plan, at about four or five frame spaces apart. Besides these, he is given a tracing of the stem, keel, stern post, and rudder frame; and, in exceptional cases, any other information which may be necessary for his use. Having this information, he proceeds to construct a body plan, and to make drawings of the stem and stern post upon the floor to full size, in order that moulds may be made to them. In the case of an ordinary bar stem and stern post, he can have these moulds made at once before fairing the body, as they are not affected by the curvature of the surface. Plain batten moulds are made for these forgings, having the thickness of keel and the shape of scarph marked upon them, and in the case of the stern post the necessary sections, including those at the boss, are likewise made, and the forgings are set in hand without delay.

137. Fairing the Body.—The draughtsman fairs the body by the aid of the same lines as are used for wood ships. The positions of these are not restricted by any such considerations as heads and heels of timbers, but are entirely questions of choice and convenience.

138. Plate Edges.—When the body is faired, the intermediate stations are drawn, and the lines of the outer plate edges (termed "sight edges," to distinguish them from the inner) are got in (see Plate LX.). The positions of these at amidships are given by the midship section, and certain sections near the bow and stern are then divided into the same number of strakes as are shown by the section at amidships. When the girth of the ship, at the midship section, is so much in excess of each or either of those at the extremities as to cause the plates to be very narrow if the same number were retained right fore and aft, it becomes necessary to introduce "stealers," that is to say, to cause certain plates to stop somewhere between the extremities and midships, and thus reduce the number of strakes which end on the stem and stern post. The plates which end on the stem are arranged so as to be of equal widths, or, at least, in widths bearing the same ratio to each other as at the midship section. The plates at the stern section will not, generally, be of equal width in a screw ship, as it is considered advisable to arrange them so that the edges of an outer strake shall be equidistant on each side of the centre of shaft. This is done in order that the after end of the strake referred to may be left off until the work in connection with fitting the shaft tube is completed; and as this is generally one of the last jobs done prior to launching, these plates are the last to be riveted in place.

When the points forward, aft, and midships are determined through which the plate sight edges must pass, these edges are drawn in the body plan on the mould loft floor. In drawing them, care is taken to keep the lines as nearly as possible square to the curve of each square station, as by so doing the edges of the plates have the minimum of curvature.

This precaution not only facilitates the work in fitting these plates, but also prevents the waste which would occur if the plates were ordered from the maker of a larger size than when fitted in place, in order to provide for curved edges and oblique butts.

When the sight edges are drawn in the body, they are transferred to the sheer plan by measuring the height above the base line of body at which a sight edge cuts each square station, and setting these distances upon the corresponding square stations in the sheer plan; a curve passed through the points so found will be the projection of the sight edge in the sheer plan. Generally, a batten will not pass through all the points, in which case it is fixed at the points on the bow, stern, and midship sections, and then allowed to spring fairly, at the same time passing as nearly to the other points as is consistent with fairness. The line of the sight edge in the body plan is then rubbed out and copied from the line in the sheer plan, when, if the body is fair, a curve will pass fairly through the new points. All the sight edges are treated in a similar manner, after which the lines of the edges of the inner strakes are drawn parallel to the former, and at distances equal to the widths of the laps, these widths being measured along the square stations. The breadths of these laps are governed by the size and character of the riveting, of which we shall say more in a future chapter.

139. Model.—In the meantime, a half block model of the ship has been made to a scale of one-quarter of an inch to a foot, and the draughtsman now proceeds to draw upon it the square stations and plate edges. To get in the former, the model is fixed upright in a frame, upon the base of which the positions of the square stations are marked. A portable bracket (the plane of whose side is kept square to the base of the frame) is then moved along the base and held at each square station, when, by means of a long, flat, and straight-sided pencil, the line of the station is drawn upon the model. It should be observed that the pencil slides against the face of the bracket when drawing the line on the curved side of the model; also, that to ensure accuracy it is usual to have several brackets, of which the edges presented to the model are cut to different curvatures, so that the bracket may be held close to the model when drawing the lines, and that the brackets may be changed, in moving from midship towards forward and aft, for such others as may be of more suitable curvature for the part being marked.

The square stations being drawn, the lines of the plate edges are next transferred to the model from the floor by bending a batten to certain square stations sufficiently close together, and marking upon the batten the positions of the plate edges. These are then measured, reduced in scale, marked upon strips of paper which are bent round the model, keeping the "pitching spot" in its right place, and the positions of the plate edges are then set off on the respective square stations.

In order to draw the lines of the plate edges on such a curved surface as that of the model of a ship, several expedients are adopted, one of which is to stretch india-rubber rings round the model at different places, and cause them to keep penning battens in the required positions by means of their elastic force, in the same way as the weight of ordinary drawing leads is utilized when drawing curved lines upon a plane surface. Another very common method is to make the battens of soft fir, and then keep them against the surface of the model in the required positions by means of ordinary draughtsmen's pins.

The edges of the plates being drawn, we have next to arrange the butts, as it is highly important that the sizes of the plates required in building the ship should be known as early as possible, in order that the manufacturer may be enabled to supply them without causing delay. But of this we will say more presently. When, as is usually the case, the plating varies in thickness at the two extremities of the ship, the thicknesses are blended one into the other as gradually as possible, in order to prevent sudden discontinuity of thickness and strength. The boundaries of the patches of plating having the same thickness are marked on the model with coloured pencils, and the thicknesses of the plating are also marked in coloured pencils, so as to reduce the possibility of error in ordering the iron.

140. Floors.—We will now again direct our attention to the mould loft floor, where the draughtsman is drawing the lines of the insides of the floors. The size of the floor plate at amidships is given by the midship section. In proceeding forward and aft, while the depth of the floor remains constant, or is reduced but slightly, the length of the floor plate is considerably diminished. This is due to structural considerations, as it is evident that there is much less lateral strain on the frames at the extremities, where the ship is narrow, than at midships, where she attains her maximum width. It is also clear that this reduction in the length of floor will follow, if considerations of fairness in the interior of the ship alone be studied.

Having, then, in the body plan, fixed upon the spread of the floors at the extremities of the ship, these points are joined with the ends of floors at midships, the lines joining them being generally concave towards the base line, the concavity increasing towards midships. When the ship is propelled by steam power, and the frames are deepened to form supports for the engines and boilers in the wake of those fittings, there will consequently be a break in the continuity of the lines just referred to at the extremities of the engine and boiler space.

The lines of the ends of floors should be faired in the sheer plan in the same manner as the sight edges of plates. After this the curves of the insides of floors are drawn in the body plan. At first these will be drawn approximately, care being taken to conform to the character of the curvature of the inside of floor given in the midship section.

In order to fair these curves, bow and buttock lines are drawn in the body plan, the number of these being governed by the size of the ship; generally two or three such lines are found to be sufficient. The traces of these bow and buttock planes with the surface of the inside of floors, are then projected in the sheer plan, and there faired by the ordinary process, after which the correct lines of insides of floors are drawn in the body plan in lieu of those drawn in the first instance. It is not customary to draw the lines of the inside of the portion of the framing above the floors, as these lines are parallel to the respective lines of the outside, the distances between them being given in the midship section.

141. Harpins and Ribbands.—The body being now perfectly fair, both as regards the outside of frames and inside of floors, one or two harpins are generally laid off, these being at the upper parts of the bow and stern. As the particulars furnished for these harpins are similar to those for a wooden ship, it is not necessary to give any further particulars regarding them. They are usually made of angle irons marked at the frame stations, and having holes punched in them for securing the frames at their heads. Sometimes, however, they are of wood. The ribbands used for the straight parts of the ship are of wood, generally stout fir quartering, the positions of the frames being marked off on them by ribband battens, the same as in the case of a wood ship (see Art. 79 and Plate XIV.).

142. Beams.—The lines of the beams at side are also drawn upon the body plan, the intersections of these lines with the square stations being the ends of the beams of the respective frames (see Art. 52).

To get the beam end line in the body plan, a common mode is to level over upon the middle line of the body plan the height at which the beam middle line in the sheer plan cuts each square station. Then a beam mould is constructed and laid upon the floor, square to the middle line of the body, and with its middle point coincident with the middle line of that plan. The mould being thus placed, with its upper or curved side successively to each of the points just found, the intersection of that side with the corresponding square station gives the beam end of that frame. In some cases the beams are cut and shaped at their ends by direct reference to the beam end line on the board sent to the bending slab, which we shall describe presently. Usually, however, the lengths of all the beams are marked upon the beam mould, and separate moulds are made to the shapes of the beam arms.

143. Side Keelsons, etc.—The lines of the side keelsons and other longitudinal ties are drawn and faired in the same way as already described, when referring to the edges of the floor plates (see Art. 140).

144. Scrive Board.—The body is now ready for transferring to the "scrive board," that is, if working by the

Scotch and North of England systems, or for making the moulds if by the Thames system. It may here be remarked that the workmen on the latter river are rapidly adopting the northern systems in this and many other respects.

The *scrive board* is composed of a number of wide boards secured edge to edge by clamps at their backs, the upper surface being made as plane as possible. The surface having been painted black, a copy of the body on the mould loft floor is drawn upon it. As the scrive board is kept near the bending slab, the necessary dimensions have to be taken on battens and transferred to the board. This is done by first drawing the base and middle line of body; also the diagonal lines used in the process of fairing, after which the plate edges, and the beam, harpin, side keelson, floor, etc., lines, are also transferred to the board, and then painted in. When the lines of the sections or frames are accurately drawn, they are scratched or "scrived" in by a sharp-pointed tool.

In order to protect the scrive board from being burnt by the "set iron" or frames when checking their curvature, strips of half round iron are fastened on the surface of the board, these being placed between the plate edges, and in directions about parallel to the latter.

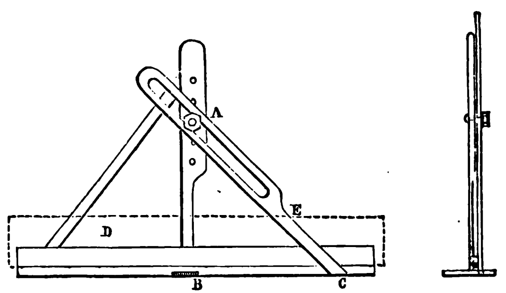
145. Batten Moulds.—On the Thames a batten mould is made, and upon this the square stations, etc., are marked similarly to the moulds of a wooden ship's frames. There being, however, no arrangement of futtocks, the mould is made in one piece for the whole depth of the frame; and when the ship is not very large, one mould will serve for all the frames of each body. The plate edges are represented by battens, as also are the other important lines in the body.

146. Cants.—Cant frames are rarely required in iron ships owing to their usually sharp form, and the facility with which angle irons can be opened or closed to the required bevelling. In cases where considerable bluffness would necessitate angle irons being opened or closed to an undue extent, so as to reduce their strength, or interfere with the riveting, cants are introduced. These are dealt with, as regards their curvature, in a similar manner to that already given (see Art. 60).

147. Bevellings.—The bevellings for the frames of an iron ship are usually given at the lines of the plate edges, harpins, and ribbands. As there is only one set of bevellings for each frame instead of two, as in a wood ship, the artifices, which have already been referred to, for obtaining the mean bevelling of a frame at any point are not now required (see Art. 42). The bevellings of an iron ship are taken from the floor in a very simple manner. The perpendicular distances between consecutive frames at the bevelling places are set off on a stick; the distances along a line of bevellings from midships to either right forward or aft can be measured off on one stick, keeping a constant starting point upon it.

Having these distances set off on the bevelling stick, they are transferred to the bevelling frame, and the bevellings marked upon the boards in the usual manner (see Art. 44).

Scale ⅜ in. = 1 foot.



Front View. Fig. 9. *End View.*

Fig 9. shows an apparatus which is used upon the Clyde for the purpose of marking bevellings direct from the body plan on the floor, without having recourse to any intermediate process. It will be seen that it consists of a bevel, the tongue of which has a sliding joint, the stock of the bevel being also the tongue of a square. The stock of the square is laid upon the floor with the bevelling board D (shown by dotted lines) resting upon it in the manner shown. The centre line of the tongue of the square being fixed at the point B, where a plate edge cuts a frame in the body, and the centre line of the tongue of the bevel at the point C, where a perpendicular from the frame at the point B on the floor cuts the adjacent frame; then the line EC marked upon the board gives, with the edge of the latter, the bevelling of the frame at the point B. It will be observed that the tongues of the square and bevel are cut away at their lower parts, so that their working edges, if produced, will pass through the point A; the distance AB being the room and space. The *rationalé* of the process is apparent to one who has read the remarks on the bevellings of frames given in Art. 44. It will be observed that several holes are made in the tongue of the square to suit different values of the room and space. As the latter generally varies by certain well known and constant quantities, holes are sufficient for this purpose; otherwise a slot would be required, such as is cut in the tongue of the bevel.

The bevellings of the frames are always "standing" or obtuse, the flanges of the frame angle irons of the fore and after bodies being placed in opposite directions in the two bodies to secure that result. This is done in order to render the riveting practicable at the extremities of the ship. It is evident that the bevellings of the inner or reverse frames are the same as those of the outer or frame angle irons at the same stations. Although the bevellings of the frames are "standing," yet the bevellings furnished to the workmen are the supplements of these angles, and are therefore "under," this being done to suit the manner in which the frames are set to their bevellings, viz., by holding the stock of the bevel on the bending slab, and the tongue against the side of the angle-iron.

148. Ordering Material.—When the bevellings and the scrive board or the moulds are ready, very little remains to be done by the draughtsman on the mould loft floor. But while the preceding work has been carried out, much has been done in the drawing office. The butts of bottom plating are drawn upon the model, also the butts of the angle irons of frames, reverse frames, etc. Sometimes the butts of the frames, reverse frames, and the floor plates, are drawn in the body plan instead. The edges and butts of stringers, tie plates, deck plates, etc., are set off on the several deck plans. Separate sketches are made of the transverse and other bulkheads in the ship; the edges and butts of the plates of these bulkheads and the stiffeners, etc., are marked upon them. In short, drawings are made of all the iron work in the ship sufficiently accurate to allow of the sizes of the plate, angle, and other iron being measured therefrom.

Sometimes the lengths of the frames, reverse frames, and floor plates are measured from the sheer draught, by constructing curves in the half-breadth plan, representing the lengths of these angle irons and plates. These curves are easily constructed by measuring with a flexible scale the lengths of the frames, reverse frames, and floor plates at certain intervals, from the model or body plan, and setting off these measurements to scale on the corresponding square stations in the half-breadth plan. If curves are passed through these points, the lengths of any of the other plates and angle irons can be obtained by measuring the corresponding ordinates of the curves.

The lengths of bottom plates are measured on the model, and the plates are ordered from the manufacturer to lengths of from half-an-inch to an inch in excess of those so found; except the plates near the bow and stern, where a trifle more is allowed, and the plates which end on the stem and stern post are ordered about six inches longer than the lengths measured on the model.

The breadths of the bottom plates are always taken from the floor or scrive board, as the lines on the model are not sufficiently accurate for this purpose. About half an inch in excess of the measured width is allowed in ordering these plates. Parallel edged plates and all angle irons are ordered by figured dimension only; but floor plates and others of a triangular or trapezoidal form are ordered by sketch with figured dimensions. These sketches are not necessarily proportionate in form to the plates they represent, but merely serve as a guide in lining out the plates before cutting them.

The dimensions given for floor plates do not allow for cutting them to the curvature of the bilge, as it is usual to save the expense of the larger size plate, which would be required, if such were done, by heating and bending the ends of the plates to the curvature.

The beams are measured either in the body or deck plans;

a small allowance is made in their length also. Indeed, in every case a margin is allowed for error and for fitting the plates, the extent of the margin being regulated by the degree of accuracy with which the draughtsman performs his work. In well conducted shipyards, it is considered quite sufficient to allow a half inch each way in ordering plates for such parts of the ship as have not much curvature, and in other cases the margin is regulated by circumstances and the judgment of the draughtsman.

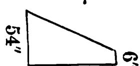
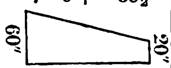
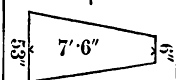
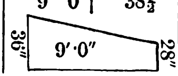
It is highly important that the material for a ship should be ordered in a systematic manner, as the neglect of such a precaution invariably leads to error, and therefore delay and expense. Every shipbuilding firm has its own system of ordering material, although in the same district these systems will naturally conform to a great extent. We give on the following page an extract from the order-book for an iron ship built by a firm whose operations are very extensive. There is nothing unusual about this extract, it being taken indiscriminately. It will be seen that each of the constituents of the ship is represented by initial letters, or abbreviations, and numbers; the letters denoting the purpose of the material, and the figures the particular locality of the same in the ship.

The manufacturer, who supplies the iron, marks each piece with the shipbuilder's letter and number, so that the latter is not only enabled to discover whether or not he is supplied with the whole of his order, but is also aware what part of the ship each piece is intended for, and so reduces the possibility of delay occasioned by material being used for a different purpose to that intended.

By giving the figured dimensions according to the rules already stated, the iron which is served into the yard is, as nearly as possible, of the finished size, otherwise a loss would result from an undue quantity of scrap iron being produced, the value of which is only about 40 per cent. of its cost.

The principles and rules which govern the dispositions of butts, and edges of plates, etc., will be discussed in Chap. XIX.

BULKHEAD PLATES.

Mark.	Length.	Breadth.	Thickness.	No. of Pieces.
	' "	"		
BH $^{10}_{1}$			"	
...	6 0	...	$\frac{7}{16}$	2 of taper one side.
... $^{10}_{2}$	7 8	38½	...	2
... $^{10}_{3}$	7 9	38½	...	3
... $^{10}_{4}$				
...	7 5	...	...	2 of taper one side.
... $^{10}_{5}$	7 5	38½	...	1
... $^{10}_{6}$				
...		..	...	1 of taper both sides.
... $^{10}_{7}$	5 9	29	...	1
BH $^{58}_{1}$	9 0	37	...	2
... $^{58}_{2}$	9 2	38½	...	2
... $^{58}_{3}$	9 4	38½	...	2
... $^{58}_{4}$	9 6	38½	...	2
... $^{58}_{5}$	9 7	38½	...	3
... $^{58}_{6}$	9 0	38	...	2
... $^{58}_{7}$	9 0	38½	...	9
... $^{58}_{8}$			...	2 of taper one side.

FRAMES AND REVERSE FRAMES.

Mark.	Length.	Size.	Length.	Size.
	' "	" " "	' "	" " "
F. & RF 72	43 0	5 × 3 × $\frac{9}{16}$	42 1	3 × 3 × ½
... 73	36 0	...	36 0	...
... 74	43 0	...	42 1	...
... 75	36 0	...	36 0	...
... 76	43 0	...	42 2	...
... 77	36 0	...	36 0	...
... 78	43 0	...	42 2	...
... 79	36 0	...	36 0	...
... 80	43 0	...	42 3	...
... 81	36 2	...	36 0	...
... 82	43 0	...	42 3	...
... 83	36 2	...	36 0	...
... 84	43 0	...	42 4	...
... 85	36 2	...	36 0	...

CHAPTER X.

149. Laying Off Iron Ships of War.—The processes involved in laying off wooden ships for war and mercantile purposes are so nearly alike, that it was not considered necessary to treat of them separately. But with iron ships the case is very different, the additional skill and labour required in laying off an iron-clad ship of war, beyond that of an ordinary iron merchant ship, being very considerable. This, in great part, is due to the fact that ships of war are, to a great extent, built on the longitudinal system, which has been adopted in only a very few cases in the merchant service. Unarmoured iron ships of war usually have continuous transverse frames, with semi-continuous longitudinal frames; hence, in laying off those ships, the problem of the longitudinal is the only addition of importance to the processes already described for a merchant ship.

Private shipbuilding firms have each their particular methods of laying off ships of war, such methods being generally based upon the prevailing systems of laying off iron ships in the several districts, with such modifications as the peculiar nature of the case may call for. Of all her Majesty's dockyards, that at Chatham has had the greatest experience in building iron ships, and a constant succession of various types of war ships has tended to perfect and simplify the systems adopted at that yard. We purpose dwelling more fully on the practice of Chatham yard than of any other, especially as the Royal dockyards throughout the kingdom, where iron ships are built, have copied to a great extent from the Chatham system. But while referring more particularly to the practice of that dockyard, we shall notice the particular features in which the practices of certain other shipbuilding establishments differ therefrom.

150. The Sheer Draught of an iron-clad ship of war, which is supplied to the dockyard authorities, is usually the designed draught, and therefore represents the surface enveloping the outer strakes of bottom plating and the armour plates. But as it is the surface of the frames that is drawn upon the floor, the thicknesses of the outer and inner strakes of bottom plates have to be removed. Hence the moulded breadth of the midship section on the floor is the extreme breadth, minus four times the thickness of one of the strakes of plating on the side of the ship just below the armour. The surface of the ship above the armour shelf, which is drawn upon the floor, is twice the thickness of a strake of the same plates within the surface given on the drawing; and this is the surface which is faired.

It has been customary of late years to set the frames perpendicular to the designed load water line, so that the bulkheads, etc., are vertical when the ship is floating at, or parallel to, her constructed draught. Hence the base line is parallel to the load line, and the water lines are straight in the body plan (see Plates LXI., LXII.).

The body plan is transferred from the drawing to the floor by the aid of the level lines, and certain diagonal lines placed just below the longitudinals, these diagonals being afterwards used for ribbands and harpins. The positions of these longitudinals at midships are given by the midship section, and in order to ensure that the diagonals do not cross the longitudinals, the latter are drawn approximately on the drawing according to the judgment of the draughtsman. It should be observed that as much dependence is not placed in the harpins for checking the form of the ship as when the latter is built of wood, owing to their being in the way of the plating. The longitudinals, together with spread staffs, are more frequently almost the only checks, and when the curvatures of the former are carefully determined, and the moulds properly marked, there is very little need for harpins.

Before copying the body plan upon the floor, it is the custom at Chatham to run off a few of these diagonal lines in sheer and half-breadth plans, drawn upon paper to the same scale as the sheer draught; to these are added several bow and buttock lines at the extremities of the ship. By so doing, the draughtsman determines whether or not there is any extensive deviation from continuity in the surface of the ship as shown upon the drawing; and if there is, he proceeds to correct the same upon paper to this convenient scale before copying the lines upon the floor, and thus saves himself considerable labour should such discontinuity exist.

It has already been stated that the lines drawn upon the mould loft floor represent the outside of the frames; it is sufficient to make the necessary deductions in reading off the ordinates from the drawing, as but little error can occur in such a process.

The body at the comparatively straight portions of the ship is faired by the *contracted* method (see Art. 21); but at the extremities, the same system is adopted as described for wood ships.

151. Plate and Longitudinal Edges.—In the meantime, the plate and longitudinal sight edges are being arranged. The same considerations are involved in setting off the plate edges as were stated in the preceding chapter. The longitudinal sight edges are kept at or near the middle of the outer strakes of plating; hence, in setting off the plate edges, care must be taken to arrange them so as to suit those longitudinals which form watertight flats, etc., at their extremities. At Chatham' yard the plate edges are first arranged on a half block model to a half inch scale, and the longitudinals are also marked upon the model at the same time; after which these lines are transferred to the body plan on the floor and there faired. When so arranged by an experienced person, very little alteration is made in fairing, and such alteration need not be made on the model, as the breadths of plates, etc., are always measured from the body plan.

It is evident that such a practice saves considerable labour on the floor; some builders, however, prefer pursuing the course indicated in the preceding chapter, see Arts 138 and 139, where methods of marking the lines on the model are also given. At Chatham the model is suspended at each end by centres, similar to those of a lathe, and it is marked in that position, instead of when resting on a stand, as before stated.

Some shipbuilders have preferred arranging the longitudinal sight edge so as to be in a diagonal plane differing from an ordinary harpin plane, inasmuch that it intersects the stem and stern post at different heights above the base line, whereas the harpin plane intersects at the same height. Hence the trace of the plane in the body plan is curved instead of straight, as in the case of a harpin. It is sometimes difficult to make a sight edge, drawn in this way, suitable for the plate edges on each side of it; besides which, there is no advantage whatever in keeping the sight edge in a plane.

At the Thames Iron Works, it is the practice to draw the longitudinal sight edges straight in the body plan, by placing them in harpin planes; hence it is necessary to cause the sight edges of the plates to approximate somewhat to this straightness, in order to keep the longitudinals near the middles of the plates. It is evident that, in most cases, the edges of the plates will have considerable curvature, and hence will require a larger plate of iron out of which to cut them, than if they were drawn in the manner stated in the preceding chapter. It may here be stated that the longitudinal edges are drawn straight to suit the particular method of laying them off which is adopted at that yard (see Art. 169).

152. Measuring Plates.—The general character of the disposition of butts of bottom plating, flat keel, vertical keel, and longitudinal plates, also the angle irons of keel, longitudinals, and frames having been arranged upon paper, the whole of these butts are marked upon the model.

In getting an account of the sizes of plates, etc., which must be ordered of the manufacturer, *lengths* only are measured from the model, the *breadths* being taken from the floor. The same margin is allowed as before stated, viz., about half-an-inch in length and breadth at the straight parts of the ship, and about one inch in breadth where there is great curvature. At the lower part of stem and stern post, about six inches, or more, in excess of the measured length is allowed; but where, as at the upper part of stern and the shaft tubes, there is very great curvature, it is customary to "mock up" the moulds to the frames in the wake of the plates, the lengths of which are required, and then to make batten moulds on the outsides of these for the plates. This is always done in the case of armour plates, which must be ordered from the manufacturer long before the framing is erected.

A drawing of an expansion of the inner bottom plating, etc., is then made for the use of the workmen at the ship, also sketches of the general arrangement of keel, longitudinals, shelf plates, etc.

153. Inner Bottom.—The next thing to be done on the floor is to draw the sections of the *inner bottom* in the body plan, and then proceed to fair the same. The surface drawn is that of the insides of the frames; the midship section drawing giving the inner bottom at that place. Reference is then made to the specification to discover to what extent, if any, the longitudinals are to be tapered in breadth throughout the double bottom space. The fore and after limits of the double bottom are given in the profile drawing of the ship. Then the scantlings of the longitudinals are set in square to the curves of the square stations, at the ends of the double bottom, through the points where the longitudinal sight edges cut these sections; and curves passed through these points and the inner edge of vertical keel will be the sections of the inner bottom at the extremities of the latter. It should be observed that in taking the breadths of the longitudinals they are measured to the outside of transverse frames, and not to the inside of strakes of outer plating, which would give their full breadth, this being done in consequence of the lines on the floor being those of the outsides of frames. Should the curves, just referred to, not pass fairly through all the points, it shows that the breadths set in for one or more of the longitudinals, as the case may be, are not suitable; hence these breadths will be modified accordingly. To draw the intermediate sections of the inner bottom, the breadths of the longitudinals, which are set in square to the stations at their intersections with the several longitudinal sight edges, are made to vary proportionally to their distances from midships, unless it is directed that they are to be of constant breadth for a certain distance, and to taper throughout the remainder, in which case the breadths are set in to correspond with such directions. A very usual mode of determining the breadths of the longitudinals at the several stations, is to draw a base line and a series of equidistant and close ordinates, as in the adjoining sketch (fig. 10), where *ab* is the breadth of a longitudinal at one extremity, and *cd* at the other extremity, of the double bottom space. In the case shown, *ef* represents to scale a length of the ship where the longitudinals are of constant depth; *eg* being that depth. Join *ea* and *fd*; then the distance between the lines *ae fd* and *bc*, at any ordinate, is the width of the longitudinal at the corresponding station.

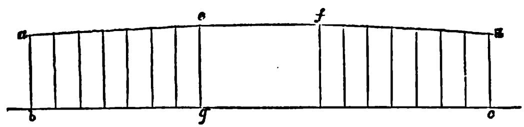


Fig. 10.

The breadths of the longitudinals at the several square stations having been set in square to the curve of the sections at their intersections with the respective sight edges of the longitudinals, the sections of the inner bottom are obtained by passing curved lines as nearly through these points as is consistent with fairness.

When the curves are drawn at, say, every fourth station, the inner bottom is faired by the same means as the outside of the frames, the diagonal lines being chiefly used for this purpose.

When the surface is faired an expansion drawing is made, and the edges and butts are set off upon it, these being regulated by the butts of the outer bottom plating, butts of longitudinals, man-holes, and positions of bulkheads in hold; the last of these are shown in the plan of hold provided for building the ship.

154. Inner Surface of Framing.—The inner surface of the framing below the armour shelf, before and abaft the double bottom, has next to be drawn upon the floor and faired. This process is similar to that just described, being, however, rather more laborious, as the taper of the longitudinals and armour shelf, and the variations in the curvature, are greater near the extremities of the ship than at the comparatively straight double bottom.

When there is a wing passage bulkhead, and the armour shelf in the wake of the double bottom is no wider than is necessary for lodging the backing and armour, the inner surface of the transverse frames, before and abaft the double bottom, is usually continuous with that of the frames within the latter space. But the inner or reverse angle irons are no longer scored into the longitudinal; hence the latter are reduced in depth by the width of the transverse flange of the reverse angle irons. In the case of certain monitors and broadside ships recently constructed, the armour shelf extends to some distance inside the framing behind armour, in order to form a wide cellular space at the upper part of the double bottom in lieu of a wing passage bulkhead; hence there is a sudden decrease in the depth of the armour shelf and of several of the longitudinals just below it, and the continuity of internal surface just referred to has not existed in these cases.

The breadths of the several longitudinals at their extremities having been decided upon, their breadths at the several stations between the double bottom, bow, and stern, have to be determined by a similar method to that given in the preceding article; it being remembered that the longitudinal commences at the limits of the double bottom with a breadth which is at least the breadth of the reverse frame less than that inside the double bottom. The vertical keel is generally reduced in depth towards the extremities by an amount either shown in the drawing or stated in the specification. The sections of the inside of framing at the extremities of the ship being thus drawn, they are faired in the usual manner.

155. Keel Moulds.—The lengths of the flat keel plates are shown by a sketch handed to the workmen. The usual character of the shift of butts of flat and vertical keel plates and angle irons will be given in Chapter XVII. The positions of the frames are given by "room and space" or "keel" battens; and by means of these the holes are set off in the flat keel plates for riveting the frame angle irons. The keel battens also show which are *bracket, solid,* or *water-tight* frames. The shapes of the flat keel plates are given by section moulds. At Chatham it is the practice to provide a section mould to each butt, and one in the centre of the plate, these moulds being made to the inside surface of the outside plates. Of course, at amidships, one mould will serve for a considerable length.

With this information the flat keel plates can be put in hand as soon as the material for them is obtained, and while the remainder of the hull is being laid off and otherwise prepared.

156. Stem and Stern Post Moulds. — The outlines of the stem and stern post are usually shown in the drawings of the ship. These lines, however, must not be conformed to without previously determining whether or not they are suitable to the lines on the mould loft floor. The fore edge of stem and after edge of post are fixed lines; the after edge of stem and fore edge of post may perhaps require modifying, in order that the arrangement of longitudinal framing, breast-hooks, continuation of vertical keel, etc., may be economically and satisfactorily connected thereto. It will also be necessary to ascertain whether the plating behind armour, wood backing, armour plates, and armour shelf or recess plates, can be suitably terminated on the stem. For this purpose sections of these portions of the hull are usually drawn normal to the contour of stem at certain points; and the rabbets, etc., are then fixed, after which the lines on the stem representing the rabbets, etc., are drawn in.

Similarly, sections are made square to the surface of the stern post, and the latter is shaped so as to suit the hull to which it will be connected, and to adapt it for the several requirements of the marine engineer. Considerable judgment and practical skill are called into play in arranging this portion of the work, and it is advisable to set off a preliminary arrangement upon paper, and thus simplify the work on the floor.

Plane batten moulds are made to the stem and stern post, the edges of which moulds are fashioned to the outlines of the respective forgings. Upon these moulds are marked the lines of the rabbets and any other sudden discontinuities in the surface; also sections of the forgings are painted upon the mould, the middle lines of the sections being coincident with the lines on the mould at which the sections are given. It is necessary that a section should be shown wherever the shape of the stem alters its character or size, consequently the sections are rather numerous in the case of the stem of a vessel intended for ramming (see Plate XCVIII.). The sections of stern post show all the necessary particulars for fashioning the boss for screw shaft and the several rabbets, etc., as for the stem (see Plate C.).

157. Framing above Armour Shelf.—The inside surface of the framing of an iron-clad ship above the shelf is parallel to the outside of armour, and the distances between the two vary with the thickness of the armour and backing, the frames behind armour being generally of uniform size. These remarks apply with strict accuracy only to such portions of the side as are armour-plated. With the system of *embrasures*, etc., so common in armour-clad broadside ships, there are many inequalities in the sides of the ship before and abaft the batteries, and sometimes in the batteries themselves, all of which call for attention when laying off on the floor, but present no difficulties. As the character of these is different in almost every ship, it is impossible to lay down any special instructions regarding them, neither indeed are they sufficiently intricate to need such detailed consideration.

158. Moulds to Framing in Double Bottom.—When drawing the sections of the inner bottom, it will be remembered that the breadths of the longitudinals were set in upon lines drawn square to the curves of the stations at their intersections with the sight edges of the longitudinals in the body plan. Hence these perpendicular lines represent the intersections of the transverse planes with the surfaces of the longitudinals, the latter surfaces being always as nearly normal as possible to that of the ship. The transverse framing in the double bottom consists of an inner continuous angle iron extending across the keel to the armour shelf on each side. In large ships this angle iron is in two lengths, which butt at a few feet on alternate sides of the keel. It also consists of outer frame angle irons, which are in short lengths between the longitudinals in bracket frames, and bent up against the sides of the longitudinals, in "staple" shaped pieces, in the case of water-tight frames. Besides these there are bracket plates on each side of every longitudinal in bracket frames, and solid plates between the longitudinals in water-tight frames;

these plates being pierced with holes for lightening them, to form extra strong frames in lieu of the bracket frames under engines, boilers, etc. A set of moulds for this kind of frame is shown by Plate LXIII.

The mould to the continuous angle iron consists of battens cut to the exact curvature and size of the angle iron in a transverse plane, and the positions of the middle line, longitudinals, etc., are marked upon it. The forms of the frame angle irons, whether straight or staple shaped (as in a water-tight frame), are given by the moulds shown on the plate. In addition to the bevellings given at the longitudinals, other bevellings are given at intermediate points between them, as shown. The edges of the bottom plates should also be marked upon the moulds, in order that the rivets in the brackets and floor plates may be set off clear of those through the frames and bottom plates. The same moulds give the lengths of the short angle irons connecting the bracket plates to longitudinals, also the shapes and sizes of the water-tight and pierced plates. The holes in the latter, for access to the bottom and lightening, are set off upon the diagonal battens at Pembroke yard, but at Chatham a written account is given, or a sketch, showing the sizes and positions of these holes.

The bracket plates are drawn upon the floor, in order that moulds may be made to them; the manner of setting them off being shown by fig. 2, Plate LXIV. They are drawn in pairs on both sides of the longitudinals. The forms of these plates at amidships are transferred from the midship section drawing provided for building the ship, to the midship section in the body plan upon the floor; and the bracket plates at the extremities of the double bottom are drawn in proportionately to those at amidships. A batten is then bent so as to pass through the ends of the bracket plates and the backs of the circular arcs, as shown in the figure, and the shapes of the bracket plates of the intermediate frames are constructed by those lines.

Fig. 1, Plate LXIV., shows the mould of a bracket frame and its continuous angle iron, as made at Pembroke yard; but at Chatham it is the practice to mark all the brackets on both sides of a longitudinal upon a board, as shown by fig. 2,

Plate LXIV., and to furnish moulds for the angle irons between the longitudinals similar to those shown by Plate LXIII.

159. The Framing Before and Abaft the Double Bottom is treated similarly to that within, the depths of longitudinals and the sizes of bracket plates being graduated in the manner already described. The moulds for these frames are very similar to those shown on the several plates already referred to.

Sometimes, especially in full-bodied ships, it is necessary to cant the frames at the extremities, in order to avoid excessive bevelling, which would weaken the angle irons and interfere with the riveting. In such cases, the cants are laid off and the bevellings obtained similarly to those of a wood ship. In one or two iron-clad rams recently built, several of the bow frames have been fitted square to the ship's surface, hence the surface of the frame has been twisted to just the same extent as the portion of the ship's surface at which it has been fitted. Such a surface is not generally developable, and cannot therefore be "laid off" in the strict sense of the term. The form of the frame has been determined in such cases by a similar method to that which we shall presently state, when showing how a longitudinal mould is obtained by the "mocking up" process (see Art. 170).

160. Scantling Battens.—In addition to the moulds already referred to, it is customary at Chatham to provide *scantling battens*, giving the widths of the frames at each longitudinal (see fig. 2, Plate LXV.). These battens are made to the thicknesses of the longitudinals, and, as will be seen, they show the two thicknesses of bottom plating, the widths of the longitudinals, and reverse or continuous angle irons. They are very useful as a check upon the widths of the frames, thus preserving a fair inside surface to the ship, both in the wake of the double bottom and elsewhere. Before sending the moulds out to the workmen, they are put together on the floor in sets; these scantling battens are placed between the bracket plates in the spaces left for the longitudinals, and in this way the whole is checked by the lines on the floor.

161. Frames above Armour.—A very simple account is necessary for the frames above armour, consisting of batten moulds fashioned to the required curvatures, and with the necessary marks upon them, such as the lines of beams, harpins, etc., which serve as bevelling spots and for checking their positions when in place.

162. Bevellings.—The bevellings may be taken from the floor in the manner described in the previous chapter (Art. 147). At Chatham yard it is customary to measure off on a stick the square distances between successive frames at the several bevelling spots previously decided upon (see Plate LXIII.), there being three bevellings to each piece of frame angle iron. The distances taken on the stick are set off on the *bevelling frame*, and the bevellings marked in the manner described at Art. 44. The frame angle irons are usually placed in such positions that their bevellings are never less than right angles, and are therefore either square or *standing*, hence they face in opposite directions before and abaft the middle of the ship. For the convenience of the workmen who bend and set these angle irons, the angle given is the supplement, or the deficiency of the bevelling from two right angles, hence the bevellings provided are either square or *under*.

When the continuous angle irons face in an opposite direction to the outer or frame angle irons, the bevellings of the two sets will be the same; but when they face in the same direction, one bevelling is the supplement of the other. It should, however, be stated that at Pembroke it has been usual to give a separate set of bevellings, in consequence of the tapering of the longitudinals; but this appears to be unnecessary, as the alteration of the bevelling in the width of an angle iron cannot be appreciable, or, at any rate, will not exceed the limit of error ordinarily admitted in bending and setting angle irons. Fig. 2, Plate LXIII., shows an ordinary bevelling board for the frames of an iron ship.

Owing to the longitudinals being higher at the extremities than at the middle of the ship, a projection of the sight edge of the longitudinal in the sheer plan of the fore body, shows an apparent acute angle for the bevelling of the angle iron connecting the bracket plate to the longitudinal, should that angle iron be on the upper fore, or lower after sides of the intersection of the longitudinal and frame surfaces; and *vice versa*, if the angle iron is in either of the other two positions. But as the bevellings for these angle irons are given so as to be applied square to the edge of a bracket plate, and not in a plane parallel to the sheer plane, the angle shown in the sheer is not the correct angle of bevelling. Indeed, it frequently happens that the actual bevelling is *standing* when the apparent bevelling is *under*. The bevelling is obtained by measuring the mean distance between consecutive longitudinal intersections in the body plan, and setting that distance off in marking the bevellings, the battens of the bevelling frame being the *room and space* apart. If in the fore body the longitudinal intersection on the fore side is below that on its after side, the bevelling of the angle iron (if in the position already stated) is standing, and if the intersection is above, the bevelling is under; and so on with the other positions.

163. Harpins are more commonly employed in the Royal than in private shipyards. They are situated near the longitudinals, yet sufficiently clear of them not to be in the way when fitting that portion of the framing. The number of harpins will be governed by the size of the ship, and the extent and character of the curvature. Three or four at each extremity of the ship are usually sufficient. As in the case of a wood ship, they are laid off only for such a length, as the curvature may be considerable; in the straighter portions, ribbands are considered sufficient. At Chatham yard it is customary to provide bevellings for the ribbands, to be applied at points marked upon the *ribband battens.* The moulds to the harpins of an iron ship, and the *half-breadth* or *spread staffs,* are similar to those of a wood ship; a straight line and spiling on the harpin are employed to check the curvature and position of the latter when in place.

164. Beams.—The beams of iron ships are usually cut to the lengths given by the lines on the mould loft floor. A level line is drawn in the sheer plan touching the beam middle line at midships; this level line is also drawn in the body plan. A beam curve is then constructed (see Art. 52), with its middle point coincident with the middle line of the body plan, and with the curve of the beam touching the level line.

The vertical distances between the level line in the sheer plan, and the points where the beam middle line cuts each square station, are then measured off, and set down vertically below the intersection of the beam curve with the corresponding square stations in the body plan. A curve passed through the points so found gives the beam end line in the body plan. The lengths of the beams are then set off on a beam mould (fig. 1, Plate LXV.), these lengths being determined by placing the beam mould with its middle line at the middle line of the body plan (the mould being square to the latter), and then setting off on it the distances from the middle line at which the square stations and the beam end line intersect. The actual length of the beam is usually less than this, by twice the width of the angle iron connecting the reverse frame to the skin plating. It is usual to give additional moulds to the shape of the *beam arm*, all the *arms* to a set of beams in each body being usually marked on one board.

165. Longitudinal.—As has already been stated, the surface of a longitudinal is, in most cases, as nearly as possible normal to the surface of the ship; hence, as the latter is undevelopable, so also is the former. It being, therefore, impossible to accurately delineate the outline of the longitudinal plate upon a plane surface, certain artifices have been adopted to obtain an approximation sufficiently near the truth for all practical purposes. It will be observed that the difficulty does not consist in determining the length of a line on the surface of a ship (that being a question easily solved, as in the case of a *sheer harpin*, see Art. 90), but in unwrapping the longitudinal upon the floor, as if it were a sheet of paper, in such a manner as to enable a mould to be made by which a plate of iron can be cut and then bent into the exact shape required.

By the method about to be described, it is possible to approximate to the shape of the surface with considerable nicety, but when there is great twist in the surface of the longitudinal, as at the bow and stern, it is impossible to determine the shape of the plate by any geometrical process. Hence, in such cases, what is termed the "mocking up" method, which will be alluded to hereafter, has to be resorted to.

166. The Longitudinal Sight Edge.—Allusion has already been made to the practice of causing the longitudinal sight edge to be in a diagonal plane, the trace of which with the sheer plane is not usually parallel to the base line. We will now briefly describe the method of obtaining the edge in the body plan when the plane is so situated. In the sheer plan, join the points where the plane intersects the rabbets of stem and stern post. Next level over upon the middle line of body the height at which the line so found intersects the rabbets and each square station. Join the outer edges of the longitudinal at the midship section in the body plan with the endings at the rabbets in the two bodies; and through the points on the middle line of body, just found, draw lines parallel to the two lines so drawn to intersect the square stations corresponding to the respective points. A curve passed through these points in each half of the body plan will be the sight edge of the longitudinal. If the trace of the diagonal plane with the sheer plane is parallel to the base line, then the sight edge in the body plan is straight, being an ordinary harpin (see Art. 151).

167. To Develop the Surface of a Longitudinal.—In Plate LXVI., *ABCD*, etc., is the sight edge of the longitudinal; through the points *A*, *B*, *C*, etc., draw *aAo*, *bBn*, *cCm*, etc., perpendicular to the square stations; these are the projections of the intersections of the planes of the square stations with the surface of the longitudinal. If the breadths AA_3, BB_3, CC_3, etc., of the longitudinal in the plane of these sections be set off, then the line A_3G_3 drawn through the points A_3, B_3, C_3, etc., is the curve of the inside edge of the longitudinal plate. Choose any odd number of square stations, and draw the two lines *XY*, *xy*, each perpendicular to the middle intersection *dl*, and at a convenient distance apart; also at a convenient distance draw the line *Yy* perpendicular to each of these, or parallel to *dl*. Next draw the two parallel straight lines x_2y_2, X_2Y_2, at the same distance apart as *xy*, *XY*; and draw perpendicular to these the same number of straight lines, distant the "room and space" apart, as there are square stations in the length of longitudinal under consideration. Then measure on a batten the distances from the point *Y* to *h*,

i, k, etc., and set them up on the corresponding lines in the *development plan*, measuring from the straight line X_2Y_2, and pass a curve x_1py_1 through the points so found. Pen a batten to this curve, and mark upon it the intersections of the perpendicular lines; then keeping the point p at l_1 let the batten spring straight, and set off the intersections at the points h_2, i_2, k_2, m_2, etc.

Again, measure on a batten the distances from the point y to a, b, c, etc., and set them down on the corresponding lines in the *development plan*, measuring from the straight line x_2y_2, and pass a curve X_1PY_1 through the points so found. Pen a batten to this curve, and mark upon it the intersections of the perpendicular lines; then keeping the point P at d_1, let the batten spring straight, and set off the intersections at the points a_2, b_2, c_2, e_2, etc. Join the opposite points a_2o_2, b_2n_2, c_2m_2, etc. Then measure the distances from the line XY in the body along the lines oa, nb, mc, etc., to the sight edge $ABCD$, etc., and set them off on the lines o_2a_2, n_2b_2, m_2c_2, measuring from the line X_2Y_2. A curve $A_1B_1C_1D_1$, etc., drawn through the points so found, is the moulding edge required. If the breadth of the longitudinal plate in the plane of the square stations, that is, the distances A_1A_4 equal to AA_3, G_1G_4 equal to GG_3, etc., be set off along the respective lines o_2a_2, n_2b_2, etc., a curve, A_4G_4, passed through the points so found is the inside edge of the longitudinal.

168. The Longitudinal by a More Correct Method.— It will be observed that by the preceding method of laying off the longitudinal, the process consists in unwrapping the surface containing the straight lines ao, bn, cm, etc., by keeping the line dl fixed, and then determining the positions which the other straight lines will assume when unwrapped. These are approximately shown by the respective lines a_2o_2, b_2n_2, c_2m_2, etc., in the development plan. The remainder of the construction is self evident. Now, unless the lines ao, bn, cm, etc., are parallel, the line XY will not be straight when the surface is unwrapped, as shown by X_2Y_2; for in the process of unwrapping, each point in the line ao is instantaneously moving in a plane perpendicular to the adjacent straight line, such as bn; similarly each point in bn is moving in a plane perpendicular to cm, and so on. Hence, in order that the line X_2Y_2 may be straight when unwrapped, it is necessary that XY, in the body plan, should be a curve perpendicular to all the straight lines *ao*, *bn*, *cm*, etc., that can be drawn on the surface of the longitudinal. In the case shown by Plate LXVI., the error introduced by XY and X_2Y_2 being drawn straight in the two plans is inconsiderable, as the longitudinal surface is nearly cylindrical. But at the extremities of the ship, especially where the longitudinal is bent down to form a watertight or other flat, a great inaccuracy would result if this method were applied; hence it has been found necessary to resort to the "mocking up" process, which will be referred to in Art. 170.

At Pembroke yard, however, it has occasionally been the practice to resort to the more correct method just alluded to, and by so doing, not only has it been possible to lay off the longitudinal, in cases where the inaccuracy of the preceding method has rendered it necessary to "mock up," but the whole, or nearly the whole, length of the longitudinal has been laid off at one operation, thus ensuring great accuracy in fitting the butts of successive plates, and considerably simplifying the work. By the preceding method, only about sixty feet at midships can be laid off at one operation; it being necessary, beyond these limits, to choose a new line, such as *dl* (Plate LXVI.), by which to draw XY and xy for every separate piece laid off. As the twist increases, these pieces become shorter, and therefore more numerous.

In fig. 11, ABCDE is the sight edge of the longitudinal, and *af*, *bg*, *ch*, *dk*, etc., its intersections with the planes of the square stations. XY and *xy* are curves to which each of the lines *af*, *bg*, *ch*, etc., are normals; or, in other words, if these lines be produced so as to intersect, then XY and *xy* are involutes of the envelop MN of the lines. Having drawn the lines XY and *xy*, proceed as before by drawing Y*y* parallel to *ch*, and then construct a development plan, as in Plate LXVI. If this method is carefully carried out, there appears to be no reason why the longitudinal should not be laid off in one length, even if twisted to the extent shown in fig. 11—a by no means unusual case. The tendency to disuse harpins and depend upon the accuracy of the longitudinals in keeping the ship to her designed form, is no doubt the chief cause of the hesitation which draughtsmen evince in laying off the longitudinal in such extreme cases, especially as great accuracy is added to simplicity in the "mocking up," process. Before stating the latter, we will briefly refer to the practice of the Thames Iron Works.

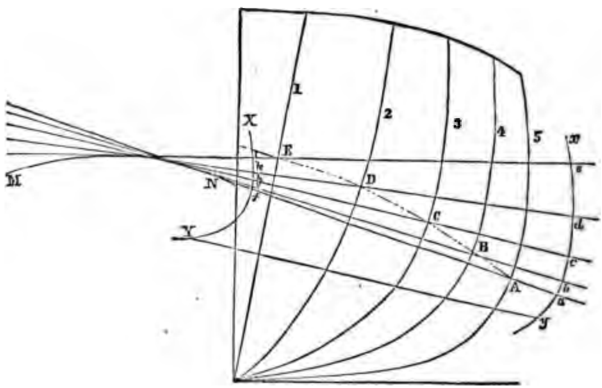


Fig. 11.

169. The Longitudinal by the Thames Method.—It has already been remarked that the sight edge is placed in a harpin plane. In Plate LXVII., PQ is the trace of that plane in the body plan. *ah*, *bk*, *el*, etc., are the projections of the intersections of the longitudinal surface with the planes of the square stations. Now, if these lines coincided with PQ, then the rabatted diagonal would give the outline of the longitudinal surface; but when they are as shown in the figure, a modification of the harpin curve must be made. This modification is based upon the assumption, that the surface of the longitudinal is cylindrical, and hence developable. The assumption is practically true for a short length at amidships, and the result of its adoption at other parts of the ship, except where the twist is extreme, gives a tolerably good approximation. Considering the portion of the longitudinal between stations 1 and 5: through *a* draw *ap* perpendicular to the extreme intersection *ep*, and cutting the others at *k*, *l*, *m*, etc. Then in the half-breadth plan, rabat the portion *abcde* of the trace PQ in the usual manner, as shown at $a_1b_1c_1d_1e_1$. Now, as we have already stated, if the traces *ah*, *bk*, etc., coincided with PQ, then the curve $a_1b_1c_1$, etc., would be the curve of the longitudinal sight edge when laid off; for the cylinder would be of infinite radius, that is, a plane, the trace of which would be PQ. In the present case it is not so, hence, to modify the curve, take e_1p_1 equal to *ep*, and join a_1p_1, cutting the square stations 2, 3, 4, at f_1, g_1, o_1. Then set off f_1b_2 equal to *fb*, g_1c_2 equal to *gc*, o_1d_2 equal to *od*; the points b_2, c_2, d_2, will be found to fall on the inside of the curve $a_1b_1c_1d_1$, etc. Pass a curve through these points, and the line $a_1b_2c_2d_2e_1$, so found is the longitudinal sight edge. It will be seen that the modification decreases the convexity of the curve.

170. The Mocking up System.—Plate LXVIII. shows a portion of the body plan of an iron ship; *BDFP* is the sight edge of a longitudinal; and *BA*, *DC*, *FE*, etc., are the intersections of the longitudinal surface with the square stations, Nos. 13, 15, 17, etc., respectively. *XY* is the trace of a level or diagonal plane drawn conveniently near the sight edge. *A*, *C*, *E*, etc., are points chosen in the lines *BA*, *DC*, *FE*, etc., respectively, being generally at a distance of about 3 feet from the points *B*, *D*, *F*, etc. From the points *A*, *B*, *C*, *D*, *E*, *F*, etc., the lines AA_1, BB_1, CC_1, DD_1, etc., are drawn perpendicular to *XY*, after which the plane *XY*, if level, is projected, and if diagonal, is rabatted upon the half-breadth plane, and with it the points B_1, D_1, F_1, etc. The last-mentioned operation is similar to that described in Arts. 13 and 18, the points B_1, D_1, F_1, etc., being treated as if they were the intersections of *XY* with the square stations. In Plate LXIX., $B_1D_1F_1P_1$ is the line so obtained.

Again referring to Plate LXVIII., a *batten frame*, as shown at No. 19 station, is made to each of the trapezoidal areas AA_1B_1B, CC_1D_1D, etc., observing that the points of the nails joining the pieces are not beaten down, as the same battens can be used in making several *frames* in succession for different longitudinals. These *batten frames* are then erected in the half-breadth plan upon the floor, keeping them to the square stations, and with the points B_1, D_1, F_1, etc., coincident with the corresponding points in the curve $B_1D_1F_1P_1$

laid off upon the floor. The battens are set vertical, and connected by a ribband piece *RS*, the *frames* being further aided in maintaining a vertical position by means of shoe pieces, which are lightly tacked to the floor, while the remainder of the work is being performed.

A very thin board, such as is used for mould making, is then bent down closely upon the *frames*, and the points *B*, *D*, *F*, etc., are marked upon its under side, also the directions of the square stations as given by the lines *AB*, *CD*, *EF*, etc., of the tops of the *frames*. The board is then removed, a batten is bent to the points corresponding to *B*, *D*, *F*, etc., which are marked upon it, and the line of the sight edge drawn in. After this, the breadth of the longitudinal is set off upon the lines corresponding to *AB*, *CD*, *EF*, etc., which are marked upon the thin board; whereupon the line of the inside of the longitudinal is also drawn in. The lines of the butts can also be drawn, taking care to keep them about midway between, and in the direction of the square stations on each side of them. Batten moulds, such as is shown by Plate LXIX., or more in detail by fig. 3, Plate LXV., are made by means of this board.

Scale $\frac{3}{8}$ in. to a foot.

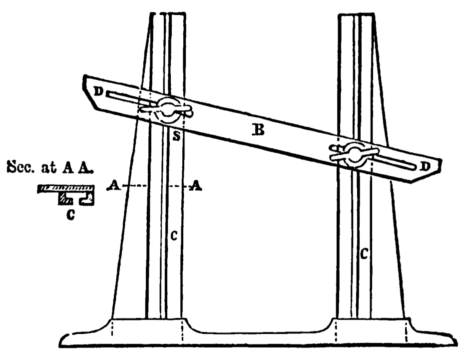


Fig. 12.

A refinement of the preceding method is adopted at Pembroke and Portsmouth. Instead of the temporary *batten frames* shown in Plate LXVIII. and LXIX., a set of permanent *frames* are kept on the floor, which are made so that they can be set to any inclination of the longitudinal trace. Such a *frame* is shown by fig. 12, and needs little description. The batten B is secured by a thumb screw S, which, when not tightened, travels in the grooves C, and allows the batten B to be inclined at any angle by means of the slots D. The mode of obtaining the curvature of the longitudinal with the aid of these is the same as already described; although at Pembroke it has been usual to work with considerable nicety, and in so doing, various modifications have been adopted, neither of which are of sufficient importance to claim our notice.

PART III.—WOOD SHIPBUILDING.

CHAPTER XI.

171. **Laying Blocks.**—Before commencing to build a ship, it is necessary to prepare a suitable foundation upon which she shall rest until ready for launching. This consists not only in securing good solid ground, capable of bearing the weight of the ship without yielding in any degree; but also in laying the blocks, which are immediately below the keel, in such a manner as will permit of their ready removal when occasion requires, and at such a height and declivity as shall afford the best facilities for launching the ship after she is built. With regard to the solidity of the ground foundations, it is customary to take the same precautions as are adopted in the case of permanent structures on similar sites, such as piling, forming beds of concrete, etc. When piles are driven, it is usual and very advisable to rest logs on their upper ends, sufficiently near the surface of the ground to provide bases and securities for the heels of the shores, or props, which keep the vessel upright. In the Royal dockyards, where the ground of the building slip is paved with hewn stone, it is customary to alternate with the latter transverse baulks of timber, termed "land ties," the surface of which coincides with that of the surrounding paving; this being done in order to allow nails, bolts, and other fastenings to be driven into the ground for securing the blocks, shores, and launching ways. These slips are made to a declivity of $\frac{7}{8}$ths of an inch to a foot.

The spacing, declivity, and sizes of the blocks upon which a ship is built, are governed by her dimensions and weight. They are usually laid about 5 feet apart, and in the Royal dockyards are built up of waste pieces of English and African oak, or other hard material, while in some large private shipyards, short ends of yellow pine logs and other soft woods are used, with a cap piece of beech upon which the keel rests. As a general rule, the logs should be about 14 or 16 inches siding, the largest should be placed nearest the ground, and the top piece should be of some free grained material, in order that it may be readily split out at a time when the weight of the ship is resting upon it. The top, or cap piece, when laid for a wooden ship, should be a little thicker than the false keel, in order that when it is split out, there may be sufficient space above the blocks to get the false keel into place. Ships are sometimes built upon wedge-shaped blocks, such as are shown by fig. 13, and the facility with which such blocks can be knocked away, renders splitting out quite unnecessary. It is only in the Royal dockyards, however, that they have totally displaced the older style of plain blocks; while in some private yards it is usual to split out the plain blocks upon which the ship has been built, and replace them by these angle blocks just prior to launching, this being done in order that when the ship is resting wholly upon her cradle and a few blocks, the latter may be readily removed. Blocks of this description are always laid in dry docks, the angular block and that below the wedges being sheathed with iron, while the wedges are made wholly of that material. The blocks are lashed to each other, and to ring bolts in the floor of the dock, with spun yarn. The wedges are very often placed about 2 feet above the floor of the dock, the remainder of the height above the angular block being built up with plain blocks.

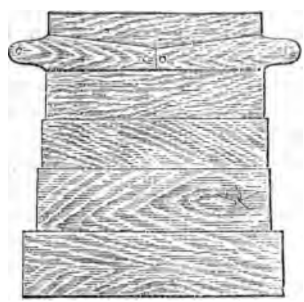


Fig. 13.

The declivity *of the surface* of the blocks upon which *a ship is to be built,* varies according to the conditions already cited, the average slope being about $\frac{5}{8}$ths of an inch to a foot.

Having decided upon the necessary declivity, the position of the bow of the ship must next be measured on the slip; and when this point is determined, the places of the foremost and aftermost blocks can be laid down. We have next to determine the height of the foremost block. In the case of a built slip, as in H.M. dockyards, this height must be very carefully arrived at, as there is no means of excavating the after end of the slip when the time comes for launching, if it should be found that the ship has been built too near the ground. In private yards, where building slips are rarely, if ever, prepared with any degree of nicety, such difficulties are not experienced.

The questions to be taken into consideration are:—

1. To provide sufficient space between the ship and the ground for performing all the building operations at the keel and bilges.

2. To leave sufficient space between the ground and bilges, at one-sixth the breadth of the ship on each side of the keel, for fitting the ground ways, sliding plank, and driving in the wedges which tighten the cradle under the ship, so as to support her after the shores and blocks are knocked away.

3. To make such an allowance for the excess, if any, in the declivity of the launching ways over that of the blocks, as will prevent the fore foot of the ship from touching the ground when she has reached the end of the ways, and her after part is raised by the buoyancy of the water.

In order to obtain the required height of the foremost block with great accuracy, a sketch of the ground or slip upon which the ship is to be built should be made in elevation and section, and two pieces of card-board should be cut, one to the shape of the transverse, and the other to the longitudinal, section of the ship, both drawings and card-board being on the same scale. By placing the cards upon the sketches, and trying them in various positions, all risks of error in deciding the height of the foremost block can be avoided.

The launching ways are usually at a greater declivity than the blocks, and the distance which the fore foot of the ship falls below the line of the blocks when it reaches the lowest part of the slip, can be found by a simple arithmetical calculation; the remaining distance between the fore foot and the ground should not be less than from 9 to 12 inches. For instance, in the case of a ship built on a slip 300 feet long, upon blocks at an inclination of $\frac{5}{8}$ths of an inch to a foot, and launched at $\frac{3}{4}$ths inch to a foot, it is evident that the bow falls $\frac{1}{8}$th inch below the line of the blocks for every foot the ship slides down the ways; hence, in the 300 feet, there is a total relative fall of $37\frac{1}{2}$ inches; and thus the foremost block, if at the head of the slip, must be kept $37\frac{1}{2}$ in. + 12 in. = $49\frac{1}{2}$ in. above a line, which, at an inclination of $\frac{5}{8}$ths of an inch to a foot, just touches the after end of the slip.

From this data the foremost block can readily be built to its correct height; after which, in order to lay the other blocks, prepare a "declivity batten," that is, a batten about 20 feet long the edges of which are straight, and inclined to each other at an angle equal to the required declivity of the blocks. Then put up a block, at 20 feet abaft the foremost one, to such a height as will cause the upper edge of the batten to be level (as indicated by a spirit level), while the lower edge rests upon the two blocks.

The other blocks are laid in a similar manner, or by sighting them with the two thus placed; and when this is done, they can be proved by stretching a line along their upper surfaces, and by trying the declivity batten along the whole range of the blocks.

The blocks being laid, they are secured to the ground by nails, dogs, etc., and to each other by nails, dogs, treenails, or pieces of quartering, which connect together all the logs of each block. "Spur shores" are also placed, reaching from the ground against the fore side of each block to the upper part of the after side of the one in front of it, in order to prevent the blocks from tripping, a casualty which has at times occurred when such precautions have not been taken.

172. The Keel.—The keels of wooden ships are usually made of English elm, a very durable timber when constantly immersed in sea water; besides which, its toughness eminently adapts it for such a situation in the hull of the ship.

It is, however, very liable to decay when exposed to the atmosphere, especially with frequent alternations of dryness and moisture; hence, when wooden ships were kept a long time in frame in order to season their timbers, it was customary to fit temporary keels at first, and after the frame had been allowed to season, the actual keel was fitted and fastened.

The pieces of which the keel is composed are set off by the draughtsman on the mould loft floor (see Art. 31), the scarphs standing in opposite directions on each side of the midship section, as shown by Plate XIII. The keel is of parallel siding, except at the ends of the ship, where it tapers to the siding of the stem and stern post at their junctions with it. In H.M. Navy, it was a common practice to commence the taper at a distance of one foot from the stem or stern post for every quarter of an inch difference between the siding of the lower part of stem or stern post and that of the keel at midships.

The information given to the workman for trimming the keel consists of battens, upon which the lengths of the several pieces and the positions of the frame stations are marked, these being sometimes accompanied by a scarph mould (see Art. 32, and fig. 1, Plate XIV.). It should be remarked, that in both cases the siding and moulding of the keel are also given.

As shown by Plate XIII., the keel scarphs are usually placed horizontally; but vertical scarphs have likewise been fitted, the latter being generally known as the French system. The length of the horizontal scarph is made equal to at least twice the room and space, while that of the vertical or French scarph is made equal to three times the depth of the keel.

The following figure (fig. 14) shows in plan and elevation the mode of forming and bolting a keel scarph. The dotted lines at *a* show what is termed the *tabling* of the scarph, which is intended to serve the twofold purpose of a dowel and a stop for the caulk. The raised portion of the tabling is left on the lip end of the scarph, and the rule for marking out this tabling is to make the stop *b* of the tabling at half *the length* of the scarph, and its width equal to one-third the breadth of the keel; the depth usually given to the tabling is about $1\frac{1}{2}$ inches.

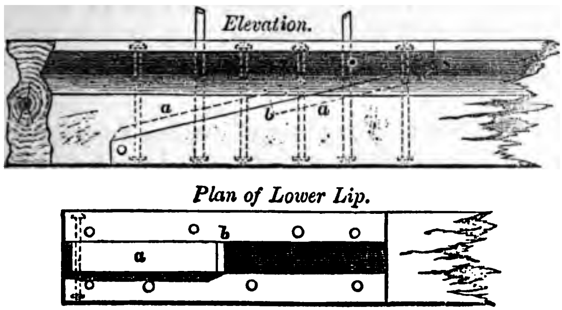


Fig. 14.

The lowest strake of plank on each side of the ship's bottom, *i.e.*, the lowest strake of *thick garboard* (see Art. 26), is housed by a rabbet cut into the keel, the shape of which is given by moulds provided from the mould loft. It is not usual to cut the rabbets in the wake of the scarphs until after the pieces of keel are bolted together.

The keel pieces being laid upon the blocks and fitted together, the whole is sighted, and thus proved to be straight, after which it is kept in this position by driving short treenails in the blocks close against the side of the keel. All the bolts are then driven through the keel scarphs, except the two which are intended to pass through the keelson and floors, which, of course, cannot be driven until the work is further advanced.

The positions of the frame stations are then transferred from the keel battens to the keel, after which the latter is ready to receive the frames, and to be jointed to the stem and stern post.

In order to prevent any water, which may find its way into the joint of the keel scarph, from getting behind the garboards, a stopwater is placed in the joint of the scarph, sometimes at the point S, and sometimes where the scarph is crossed by the *upper* edge of rabbet. This stopwater consists of a plug of soft fir, which is driven tightly into a hole bored right through the joint at the place referred to, and the expansion of which, when immersed, prevents water from insinuating itself any further up through the scarph and behind the bottom planking.

The mode of trimming a piece of keel, or any other straight rectangular sectioned timber, is given at Arts. 237 and 238.

173. The Stem.—The stems of wooden ships for H.M. service are invariably made of oak, but Lloyd's committee, while placing teak and oak at the head of their list, yet sanction other woods subject to a lower classification. The pieces of which the stem is composed are connected by scarphs similar to those of the keel, and they are so disposed as to give good shift to the pieces of apron. Sometimes, however, dowels are substituted for the tabling in these scarphs.

The stem is generally jointed to the fore piece of keel by means of a curved scarph, as shown by Plate XIII., and it is very important that the stem should be converted from timber of the necessary curvature, so as to avoid shortness of grain in the thin lip of the scarph. To aid the conversion of timber, a portion of the curvature of the fore foot is included in the fore piece of keel, by placing the scarph a little higher up the stem. The stem was formerly connected to the keel by means of a vertical scarph, and this mode is still retained by some private shipbuilders.

It will be seen, by reference to Plates XIII. and XXII., that an abutment is often prepared at the end of the fore piece of keel to receive the gripe piece, which, besides fashioning the bow and assisting in keeping the ship from falling off the wind when sailing, is also of great advantage in freeing the ship should she take the ground, as, being only temporarily secured, it is easily carried away, sometimes taking with it the fore piece of false keel also.

The pieces of stem are trimmed to their curvature by the aid of moulds sent from the mould loft floor (see Plate XV.); a separate mould being made to each piece, having marked upon it the position of the several heads and sir-*marks, level* and port sill lines, the two edges of rabbet, and a vertical line by which to set the stem in its correct position.

The stem usually has a tapered siding, increasing uniformly from the fore end of keel to a siding given at the lower part of lower cheek; but in merchant ships the taper sometimes extends to the top of the stem, while in H.M. service three sidings are fixed, viz., at head, lower part of lower cheek, and keel.

The mode of trimming such a timber as the stem is given at Art. 237, and when this is done, the several heads and sirmarks, the fore edge of rabbet, bearding line, and the vertical line for setting it in position, are all transferred upon upon it from the moulds. The rabbet is sometimes roughly cut, except in the wake of the scarphs; but it is advisable not to cut the rabbet to the exact depth, but leave enough wood to allow of its being faired when the outside of the frame timbers are dubbed off.

The stem, apron, and knight heads of small vessels are usually dowelled and bolted together before lifting them into place; when, however, the combined weight of these timbers is too great to allow of their being so lifted, the pieces of stem, after being fitted together on the ground, are built up separately in place. In either case a bolt is driven through each of the lips of the scarph from the lip side, and clenched upon the other. After the apron is fixed in place, the remaining bolts of the scarph are driven through the two sets of timbers, except where it has been arranged that a knee of head or independent piece bolt is to pass through the scarph. Plate LXXXI. shows a specimen of the fastening in stem, apron, knee of head, etc.

The stem is hoisted into place by tackles, and its rake proved by means of the vertical line marked upon it from the mould, and a spiling measured from this line to a frame station on the keel. It is set vertically by continuing a line along the middle of keel sufficiently far forward to be below the most projecting part of the stem; then if a plumb line, held against the middle line of stem at different heights, touches the line produced, it is a proof that the stem is vertical, and free from any bulging or lateral curvature; whereupon it is securely shored to this position.

174. The Apron (see Plate XIII.).—As indicated by the preceding remarks, the apron is really a portion of the stem, although it is distinguished from the stem proper by a separate name. Its chief function is to join the several pieces of the stem together, and in the same way the stem joins together the several pieces of apron. If it were possible to obtain one piece of oak timber large enough to convert the whole of the fore part of the backbone of the ship, then the apron would not be needed; but as this is impossible in large ships, it is found necessary to make it of two sets of timbers, the butts of which give shift to each other. Of these, the foremost set is termed the stem, and the aftermost the apron.

The pieces of apron are united with plain flat scarphs, which are dowelled and bolted, the apron and stem being connected in a similar manner. It is usual to connect the scarphs of the pieces of apron with bolts near the ends of the lips before fastening the apron and stem together, after doing which the other bolts in the scarphs of both stem and apron are driven through the two sets of timbers.

175. The Stern Post.—As there is a considerable difference between the modes of forming the stern post of a screw ship and that of a sailing or paddle wheel ship, we will consider them separately.

The stern post of a sailing or paddle wheel ship is formed of two pieces, named the *main* and *inner posts* respectively. The former is the larger of the two, and the rudder is hung to it, while the latter is chiefly useful in making up the necessary breadth for securing the after ends, or *hoods*, of the outside plank, as well as to receive the tenons of the after deadwood, and so protect the main piece from being wounded. The importance of the inner post, however, as a portion of the verterbræ of the ship, must not be undervalued, since the only reason for fitting it is the difficulty of getting timber sufficiently large to form the post in one piece.

Each of the pieces of stern post extends from the keel to the under side of the deck at which the tiller works; they are usually of oak or teak; and, when possible, the timber is worked so that the butt end shall be next the keel, as being the least sound, it is therefore more in need of the preserving influence of the sea water than the younger and sounder wood at the other end of the log.

The pieces of stern post are jointed by tabling formed as follows:—A score, the width of which is equal to the siding of the post, minus twice the thickness of bottom plank, and about ¾ inch deep, is cut out of each of the faying surfaces, so that the two scores may correspond when the pieces are fitted together. A piece of hard durable wood, such as teak, is prepared so as to fit tightly into these grooves, and thus form a dowel, which serves not only to keep the pieces of post from altering their relative positions to each other, but also as a stop to the caulking. In fig. 15, *a* shows a horizontal section of the pieces before the tabling is put in, and *b* shows the two pieces fitted together and the tabling in place.

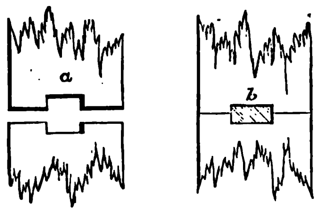


Fig. 15.

The stern post is tenoned to the after piece of keel, two of the tenons being on the heel of the after piece, and one in that of the inner piece of post. The common rule for the size of these tenons, is to make their length equal to one-fourth the depth of the keel, their thickness equal to one-third the breadth of the keel, and their width equal to twice their thickness. Besides these, a portion of the lower end of the post, the same thickness as the tenons, is let down to a depth of ¾ inch into the keel, so as to form a stop for the caulking. A dovetail plate of mixed metal is also fitted on each side of the post and keel, being connected by through bolts in order to more securely unite the keel and post. This dovetail plate is sometimes cast with projections or dowels upon it, the bolts being placed through the dowels.

In order to prevent water getting behind the bottom planking through the joint of stern post and keel, a hole is bored through at the point where the fore edge of rabbet crosses the joint, and a plug or stopwater of soft wood is driven tightly into the hole. for the same reasons as were given at Art. 172.

The stern post is trimmed in a similar manner to a piece of keel (see Art. 238), and when to the required shape, the line of the after edge of rabbet, middle of rabbet, bearding line, positions of heads and sirmarks, level and port sill lines, post timbers, transoms, and other principal stations, are marked upon it, not omitting a vertical line as a guide when erecting it in place.

The form of the rabbet is supplied by section moulds from the mould loft floor, and it is sometimes cut before the stern post is raised in place, care being taken, as with the rabbet of stem, to leave enough wood to allow for fairing when the surface of the frame timbers is dubbed off.

The deviations from the preceding description rendered necessary in a screw ship, consist chiefly in there being two sets of stern posts, named the after and body posts respectively, having the screw aperture between them.

The after post of a screw ship is formed similarly to the rudder post of a sailing ship, except that no rabbet is required in it, owing to the plank ending on the body post. As the latter has to provide sufficient body to encase the screw shaft (see Art. 25), it is formed very differently to the after post, being necessarily composed of many pieces of timber.

Plate XVI. shows some of the modes of combination which have been adopted; but, as is evident, these depend almost entirely upon the size and shape of the timber in store. In vessels with very "clean runs," a considerable amount of skill is required in so combining the numerous pieces forming the body post and deadwood, that they may give good scarph to each other, and provide such facilities for bolting the whole together as will allow the shaft hole to be bored without weakening the structure, and at the same time permit efficient caulking. This will be the better understood when it is stated that the body post of a certain screw corvette is composed of no less than twenty-nine pieces of oak timber.

These pieces of post are all united by tabling, similarly to the two pieces composing the post of a sailing ship; but, in *this case*, the tabling has to branch off on each side, so as to *encircle* the hole for the screw shaft.

A stopwater is fitted, as has already been stated with reference to the stern post of a sailing ship.

The body and rudder posts of screw ships are connected at their lower parts by the aid of brass connecting plates. Sometimes the keel is extended to the after end of the rudder post, and both the latter and the body post are tenoned to it in the manner already stated. In this case, which was more common some years ago than at present, the connecting plates are auxiliaries to the other connections (see fig. 1, Plate LI.). Of late years, however, in order to obtain as great a space as possible for the screw propellor to revolve in, the connecting plates have been the only connection between the two stern posts at their lower extremities. See fig. 2, Plate LI., and for details of the work see Plate LXX., which shows the connecting plate of a recent wooden screw corvette. As will be seen, by the former method two plates are required, whereas by the latter the plate is a single casting; in both cases, the bolts pass through from side to side.

176. The Deadwood.—This name is given to those pieces of timber which form the lean or acute portions of the bow and stern of the ship between the extremities and the cutting down line, or line of the inside of timbers. This line generally bounds the upper side of the deadwood, the latter thus giving just the necessary amount of heeling for the cant timbers; but, in very fine ships, the cutting down line is sometimes on the keelson, stemson, and sternson, in order to save the great weight of timber at the extremities caused by making the deadwood deep enough, of itself, to receive the abutments of the cants.

The necessity of the deadwood at the extremities of fine ships, is shown by figs. 16 and 17; the former of which shows the shape of the timber which would be required if the frames crossed over the keels, while fig. 17 shows the advantage, in point of conversion, by fitting the deadwood in such a case. Indeed, it would be impossible to get a sufficient quantity of timber of the shape shown by fig. 16, to enable the system to be adopted, even if there were not other arguments, such as weakness, expense, etc., against it. Plate XIII. is the arrangement of the deadwood in the fore and after bodies of a line of battle ship; a much greater number of pieces than there shown would be required in a vessel of finer form.

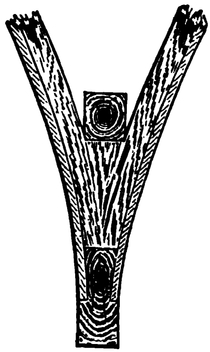


Fig. 16.

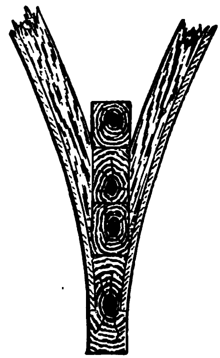


Fig. 17.

The pieces of which the deadwood is composed, are arranged in such a manner that their butts may give good shift to each other, and to those of the keel. When a floor crosses the deadwood, the lip of the deadwood scarph is so situated as to receive a bolt through the former, and in all cases the butts and scarphs are so placed as to be in the most favourable position to receive through fastenings. In both screw and sailing ships, the pieces of deadwood are tenoned into the pieces of stern post that they abut against, and the former are also dowelled and bolted together, the dowels being spaced about the room and space apart.

The mould to deadwood, as sent from the mould loft floor, is made of battens, upon which the joints of the several pieces composing the deadwood are marked, together with the upper edge of rabbet or bearding line, the cutting down line of the timbers, and the positions of the heels of the cants and square frames (see Plates XV. and XVI.).

Half section moulds of the deadwood at several square stations are also given, these being tacked to the mould so as to form a part of it in such a position that the middle line of the half section mould coincides with the line, upon the mould, at which the section is given. The section moulds generally give the form of the rabbet and the taper, if any, of the deadwood.

The deadwood is usually trimmed to the taper of the keel, stem, or post; but sometimes it is made of parallel siding, the latter being the greatest siding of that portion of the keel that the deadwood rests upon. In either case the marks upon the mould, together with the sections, give the necessary data for trimming the several pieces. These latter are first fitted together on the ground, the positions of dowels marked on their sides, they are then put together in place, and the whole temporarily secured either by treenails or clamps at the side.

The through bolts shown by Plate LXXXI. are not driven until the keel, stemson, and sternson are in place, when the whole is bolted together.

177. The Frames.—For our purpose in describing the construction and combination of the frames of a wooden ship, it will be necessary to classify them as follows:—

1. The frames of the square body.
2. The frames of the cant body.
3. The frames of the stern.

178. Frames of Square Body.—A wooden ship is composed of a series of transverse ribs or frames covered with a longitudinal series of planks, which bind the frames together, and keep out the water. These frames are generally spaced at equidistant intervals, the length of which is known as the "room and space," and is fixed by the designer.

In consequence of the great curvature of the transverse sections, especially at amidships, it is necessary to compose a frame of many pieces; and in order that these may be as rigidly united as possible, they are disposed in two sets, the butts of which give shift to each other, and the whole of the pieces are so combined that they may yield mutual support in the most efficient manner attainable.

Plate XII. shows the midship section of the ship whose sheer draught is given on Plate I. Fig. 2, on Plate XII., shows an elevation, and fig. 3 a developed plan of the same, this being the system adopted in the Royal dockyards, and occasionally by private shipbuilders. By reference to the figure, it will be seen that three timbers are situated between each pair of butts that are in a horizontal line; and that in order to secure this result, it is necessary to group the timbers composing the frames in two different systems, which alternate with each other; the combination by one of the systems being called a *frame*, and by the other system a *filling frame*. The butts of the pieces composing both *frames* and *filling frames* are situated at the intersections of diagonal planes on the timber surface of the ship, the lines of the butts of *frame* timbers being termed *heads*, and those of the *filling frames*, *filling heads* or *sirmarks*. In the succeeding pages we will term them *sirmarks*. These *heads* and *sirmarks* alternate, as shown in the Plate.

Still referring to fig. 3, Plate XII., it will be seen that one of the timbers of each frame crosses the keel, and extends to equal distances on each side, stopping at the line of floor heads; these are termed frame floors, while the adjacent timbers of the same frame, which butt against each other on the keel, are termed frame 1st futtocks. The timbers of the filling frames which cross the keel, have long and short arms extending to the 1st sirmark and floor sirmark respectively; these are termed filling floors. It is unnecessary for us to point out in further detail the names and heights to which the timbers of the frames and filling frames extend, as they are clearly indicated in the figure on Plate XII., and have already been referred to at Art. 39. It must, however, be remarked, in passing, that the mode of combination we have just been alluding to, is by no means the only one adopted. Indeed, except in the Royal dockyards, it is almost unknown, and private shipbuilders usually content themselves with having only one timber between two consecutive butts in the same diagonal line. There is no difficulty in doing this, as it simply consists in having all the frames combined in the same manner, which is usually that which, in the preceding method, has been distinguished as the *frame* system; although sometimes frames combined on the *filling frame* system are preferred, in consequence of the difficulty in procuring timber of the requisite shape for the floors. For many years the ships of the Royal Navy were built entirely of frames combined on the *frame* system; but the difficulty of obtaining timber of the necessary length, caused the lines of the butts to be so close to each other, that it was deemed necessary to keep butts, in the same line, further apart by introducing *filling frames* in the manner already referred to. It is evident that by so doing, shorter timber can be used without any diminution from the strength of the other systems; and when long timbers of the required curvature can be obtained, then the adoption of the system results in a very strong combination indeed.

A disposition of the frames throughout the ship is drawn upon a board, and, with other particulars to be stated presently, is supplied to the workman for his guidance in trimming and erecting.

The floors and frame 1st futtocks are always close jointed, as shown in figs. 2 and 3, Plate XII.; but generally the remainder of the timbers composing a frame have a space or opening between them, the joints of the frames, shown by dotted lines in the plan, being kept as nearly as possible in the middle of the opening. By so doing a free current of air is allowed to pass on both sides of the timber, and so prevent premature decay. In consequence of the room and space being greater than twice the siding of the floors, there is always an opening between adjacent frames, which increases at the upper part of the ship by reason of the reduction in the siding of the timbers. By thus separating the timbers on each side of the joint, the openings between adjacent frames are reduced, and the strength of the ship's side is equalised. Although openings are thus made between the tiers of timbers, yet these spaces are considerably filled up by means of the *fillings*, which will be referred to more minutely hereafter (Art. 193).

The frames and filling frames of the small wooden sloops recently built in H.M. dockyards have been made close jointed throughout the whole girth, and these sets of timbers have been dowelled and bolted together while on the ground, after which they have been lifted bodily into place across the keel. However, for the present we will consider the case of frames combined in the manner shown by Plate XII.

By this system the timbers are first put together on the ground, and when the butts are fitted, the position of dowels marked, dowel holes bored, and dowels fitted, the several portions of the frame are hoisted into place, there secured by shores, harpins, ribbands, and cross spalls, and then set to their correct position, both as regards their curvature and inclination to the keel. It should be remarked that, generally, the frames stand square to the keel, but certain of H.M. ships recently built have their frames square to the load water line.

The system of framing that we have just described must be followed out in large vessels, the frames of which would be too heavy to lift into place entire, whereas the method previously alluded to is peculiarly suitable to small vessels, wherein frames are necessarily lighter, as, by so lifting them bodily, greater economy is effected both in the cost and time of construction.

At Art. 41 will be found particulars regarding the moulds, and other information required by the workman in trimming the frame timbers, while the mode of trimming them is described at Art. 237.

We will suppose, then, that the keel is laid in place on the blocks, the position of frame joints marked off and lettered or numbered. By reference to the disposition board (Art. 39), the workman will see which are frames and which filling frames, also the particular side of the joint at which the frame floors are situated. It should be remarked that the usual practice was to place the floors on the fore side of the joint in the fore body and on the aft side in the after body; but at the present time they are generally kept on the same side of the joint right fore and aft, the particular side being a matter of indifference.

Scoring the Floors.—The scores* are then cut on the upper side of the keel to receive the floors and filling floors, these being let down from about 1½ inches to 2 inches (according to the size of the ship), of which a half is taken out of the keel and the other half out of the seating

* It is necessary to state that the practice of scoring floors upon the keel is not universal; sometimes the whole of the timbers crossing the keel are simply dowelled to it, and at others the whole of the scores are cut out of the floors, and none out of the keel. Indeed, in this, as in many other details given in these pages, different methods are adopted at different yards.

of the timbers. Sometimes the floors are scored or faced into the side as well as the top of the keel. Scores are not cut into the top of the keel to receive the 1st futtock frames, and consequently about 1½ inches or 2 inches have to be cut out of the seating of these timbers in order to keep a uniform throating. The floor mould shows the depth of these scores, and the scantling of the timber is increased by the amount to be scored down in order that the requisite throating may remain.

Butt Dowels.—The frame timbers are connected at their heads and heels by dowels, which serve to prevent lateral working, and keep the heads and heels in their relative positions to each other. It is therefore highly important that the butts should be well fayed and the dowels tightly fitted. The timbers composing a frame having been trimmed, they are fitted together on the ground in a horizontal position, and their curvature checked by the moulds to the frame. When they are open jointed, the timbers are kept in their correct relative position by placing blocks of the required thickness between the two tiers composing the frame, but in some cases it is found preferable to fit together each tier of the frame separately. When the timbers are fitted together, so that their butts are close while the sides of the timbers are to the correct curvature, the positions of the dowel holes in the butts, or heads and heels, are set off.

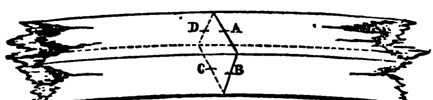


Fig. 18.

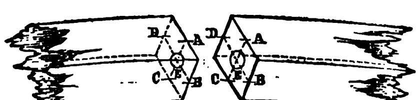


Fig. 19.

This is done in the following manner :—Referring to fig. 18, marks A, B, C, D, are made at the middle of the sides of the timbers at the butt, so that each mark will be upon both timbers; the timbers are then separated, and the marks on opposite sides, A and C, B and D, are joined by lines, AC, BD, fig. 19, on the butt surface of each timber; the intersections E give a point in the centre line of the dowel. The holes for the latter are then bored in the two butts, square to the surfaces of the butts, and to depths, each of which is equal to half the length of the dowel, or about $1\frac{1}{2}$ inches.

Ribbands and Cross Spalls.—The timbers of the square body, when in place, are temporarily supported by *ribbands*, and the two sides of each frame are connected by *cross spalls*, the whole being supported by shores, and the temporary connections are obtained by means of Blake's screws. The ribbands are sometimes placed just below the lines of the sirmarks, or heads of filling frame futtocks, although some builders place them about 6 inches below the lines of the heads of the frame futtocks; it appears, however, to be quite immaterial which mode is adopted. The ribband is made of 5 in. or 6 in. fir quartering; and, being used at the comparatively straight portion of the ship, does not require to be trimmed to curvature and bevelling; but the side which fits against the timbers having been faired by a plane, it is secured to the frames by Blake's screws, the correct shape of the ship being maintained by means of careful checking with the breadth staffs provided from the mould loft floor (see Plate XIV.).

The cross spalls are temporary beams serving to keep the two sides of the ship in the correct relative positions before the actual beams can be put into place and secured. There are several tiers of cross spalls, the number varying with the depth of the ship. As a general rule, there are as many tiers of cross spalls as there are fighting decks in the ship, so that very small vessels require only one tier. Before connecting the cross spall to the frame, a middle line is marked upon the former, and the breadth of the ship to the outside of the timber is carefully set off upon it, so that, besides their temporary structural uses, they are valuable aids in plumbing the frames and keeping the side of the ship fair. They are usually placed in such positions as to afford good support for staging, and not interfere with the fitting of the beams. The cross spalls are generally supported by pillars and spur shores, this being especially the case in very broad ships.

Plumbing and Horning.—Before the frames can be bolted together or planked, it is necessary that their position, stand, curvature, etc., should be carefully checked in the following manner, observing that, before temporarily securing the ribbands with Blake's screws, similar means to those we are about to describe are adopted in setting the frames in position.

First, To determine whether or not the frame is vertically square to the keel: drop a plumb from the middle of the cross spall upon the floor, then measure the distance of the side of the cross spall from the joint of the frame, and set off that distance from the joint of the floor on the same side of it; the plumb should fall as much abaft this point as is given by the product of the declivity of the blocks per foot by the number of feet in the height of the cross spall above the floor. Of course, this is on the supposition that the frames are to be square to the keel; if they are required to be square to the load water line, or at any other angle with regard to the keel, the necessary allowance must be made.

Second, To determine whether or not the frame is horizontally square to the keel: a point is selected on the middle line of keel at some distance from the frame to be *horned*, as it is termed, and points are marked at corresponding heights on each side of the frame, say at a head or sirmark; the distance from these latter points to the point on the middle line of keel will be equal when the frame is (horizontally) square to the keel. It is not necessary to *horn* every frame in this way, nor to check their vertical inclinations, as, by the aid of ribband battens (Plate XIV.), which supply from the mould loft floor the distances between the joints of the frame at each ribband, when one frame is set correctly to its position, a great many others can be set by it. It is, however, advisable to institute checks at intervals upon the stations given by the ribband battens. The breadths of the ships at the different heads and heels are also checked by means of breadth and height of breadth staffs measured off the mould loft floor, so that by plumbing and horning, station staffs and breadth staffs, the frames of the ship can be so shored and secured as to ensure her external surface being of the designed form.

Joint Dowels.—When open jointed, it is impossible to dowel together the adjacent timbers composing the two tiers of a frame, except at the floors, without having very long dowels, of which a portion will be in the opening between the timbers. This was formerly done, but is now discontinued; dowels are, however, still placed in the joints of the floors, three or four on each side being the usual number (see Plate LXXV.). The frames of some of the small ships for H.M. Navy, which have recently been built, are close jointed, and the adjacent timbers of each frame are generally dowelled together in the manner shown by fig. 1, Plate LXXI., there being a dowel just above and below each butt, in addition to the butt dowel itself; hence by this system there are four dowels in each timber.

Frame and Chain Bolting.—It will be seen that the adjacent timbers of these frames are likewise connected by short bolts: these being termed *frame bolts.* The futtocks of both open and close jointed frames are connected by these bolts; but, whereas in the latter each frame is independent of the others, as far as the frame bolting is concerned, it was customary to bolt the open jointed frames together in the manner shown by fig. 2, Plate LXXI., this system being known as *chain bolting*, for reasons which are at once suggested by the sketch. Frame and chain bolts are generally of square iron, the reason for using that shape of section being, probably, the extra holding power of the bolt; it being remembered that these bolts are not clenched. The chain bolting is not performed until after the fillings (see Art. 193) are fitted, as it would be necessary to score the latter over the bolts, and thus seriously impair their efficiency, if the bolts were driven first. With reference to the frame bolts in close jointed frames, it may be remarked that sometimes they are driven through the dowels, and at other times between them; in the former case, advantage is taken of the holes which are bored through one timber in order to get the positions of the centres of the dowels in the adjacent timber, and so these holes are in this way filled up.

Chocked Butts.—Before leaving the subject of the frames of the square body, it is necessary to state that the frames were formerly connected at their butts by chocks, as shown by fig. 20, which were treenailed together, and further secured by the bolt fastenings of the bottom plank. The facilities for the conversion of oak timber was the chief advantage offered by this method, but the great tendency to decay at the joining surfaces caused the system to be given up in favour of the plain butt and dowel. In framing by the *chock* system, the timbers were all put into place and secured by spalls, ribbands, harpins, and shores, after which the chocks were fitted and secured. Ships are still framed in this manner by some private builders, and it has its structural advantages; it has, however, been discontinued in the Royal dockyards for many years.

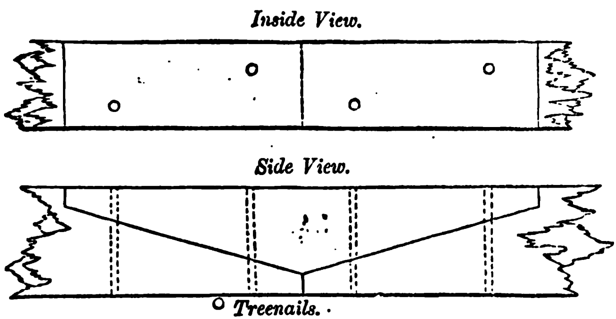


Fig. 20.

CHAPTER XII.

179. Cant Frames.—Reference was made in Art. 54 to the cant framing, an elevation of which in the fore body is given by Plate XVII. It will be remembered that all the cant futtocks are disposed in the "frame" system of combination, *i.e.*, the heads and heels are in the lines of heads and not sirmarks; hence there is only one timber between two consecutive butts in the same line.

The comparative weakness occasioned by dispensing with the filling frames is, however, compensated by the greater lengths of the futtocks, the timber for which can easily be obtained, owing to the reduction in the curvature of the transverse sections of the ship at the extremities. Hence, although the butts are closer together in a horizontal direction, yet by fitting futtocks extending over, at least, twice the number of harpins comprised by those at amidships, the number of butts is considerably reduced.* Indeed, in some small vessels, as, for instance, the case illustrated by Plate XVII., the whole of one side of a cant frame can be made of a single timber.

180. Cant Floors.—The increase in distance between the cutting down and bearding lines, due to the fairing of the ship towards the extremities, usually becomes so great that it is impossible to obtain timber of the required size and form to cross the keel, owing to the depth of the throatings (see figs. 16 and 17).

This generally occurs just about where it becomes necessary to cant the timbers, so that the first cant frame heels against the deadwood, the latter commencing at the extremity of the square body. This is true of moderately fine vessels. It has frequently occurred, however, especially in earlier

* A timber extending from the deadwood to the 2nd head is termed a "double futtock."

ships, where the fulness of the body has been carried far forward, that the throating of the floors has not begun to increase until some considerable distance nearer the extremities than it has been found possible to extend the square body. In such cases the cant frames have crossed over the keel instead of heeling against the deadwood. The only difference between such frames and ordinary cants has been with regard to the floors, termed *cant floors,* the manner of trimming which is given in Art. 240. Again, there have been cases in which the fineness of the vessel's extremities has extended considerably beyond the cant body, so that either square frames have heeled against the deadwood, or the conversion of floors has been aided by placing *rising wood* under them.

181. Openings.—Openings are not usually allowed between the cant frames at their abutments on the deadwood, so that there is generally a solid mass of timber at that place. This closeness of joint is maintained to a gradually increasing height as they proceed towards the extremities, so that right forward it is not at all unusual to see the timbers closely fitted together all the way up.

If the *hawse timbers* are not close jointed, the spaces between them are filled in a short distance above and below the hawse pipes, in order to receive such of the bolts for fastening the latter as it may not be convenient to drive wholly through a timber; besides which, it is necessary that these pipes should have a solid bearing, well caulked, and lined with lead.

182. Harpins.—The first thing to be done in commencing to build the cant bodies, is to mark the stations of the joints of the heels of the cants on the keel and deadwood. This is done by means of the marks on the deadwood moulds. Next, the harpins have to be prepared and fixed in place; these and the cants may be trimmed simultaneously, and the whole then erected, beginning with the former.

The harpins are continuations of the ribbands already in place. But while the latter are trimmed without either mould or bevelling, and are simply checked with breadth staffs and marked with ribband battens, greater precautions are required with the harpins. The harpin mould is described at Art. 85, and illustrated by Plate XXXVI.

The harpin is usually made of oak or elm plank, trimmed and bevelled as required; the pieces of which it is composed are connected by wood-keyed hook scarphs, which are fastened with treenails, and further supported by a piece of inch or inch and a quarter oak or elm board firmly nailed to the under side. Having been trimmed by the mould and bevellings in the same manner as an ordinary futtock (see Art. 177), the lines of the joints of the cants are transferred from the mould and marked upon the harpin; also, the straight line and spiling for checking its curvature. The harpin, if for the fore body, is then fixed in its proper position at the stem, and with its after end to the foremost frames of the square body, at the line of the heads and heels for the harpin in question. The intermediate portion is then adjusted to a correct diagonal plane, and to the proper curvature by the following process (see Plate LXXII.): Stretch a line *AB* upon the harpin to coincide with that already drawn upon it, and then by means of the spilings set the harpin to the required curvature. Then to fix it in a plane, place two straight edged battens, *CD* and *EF*, upon the upper side of the harpin at each extremity, and look them *out of winding*, or in one plane. Next, hold another straight edged batten *GH* at different places on the upper side of the harpin between those two, and shore the harpin so that the three battens may be out of winding at every intermediate point. When so corrected, the harpin should be securely shored. Sometimes a further correction is made by means of breadth staffs measured at a given height from the line of lower part of keel on the mould loft floor, and at others the height of the harpin above a base line, levelled out from the keel, is given in order that the extremities of the ship may be built exactly to the designed form.

183. Trimming and Erecting the Cants.—The several harpins having been fixed in position, the cant frames can be erected, before doing which, however, they must be trimmed. The mould of an ordinary cant is shown by Plate XXX. The timbers of the cant frames are erected separately, and are carefully set in position, so that the marks upon them shall coincide with the corresponding marks on the harpins which are already in place.

184. Security of Heels, etc.—The cants are secured to the keel and deadwood with bolts, which pass through and secure the heels of the cants on the opposite side of the ship. These bolts are placed alternately high and low, so as to avoid the weakness caused by a line of bolt holes. Formerly it was the practice to score the heels of all the cants into the deadwood, the line of the under side of the score being termed the *stepping line*. At present, however, the cants are heeled against the keel and deadwood without any such stepping, but the thin "sliver" edges of the foremost cants are cut away, and a piece of batten is fitted in a score cut beneath, being fastened with short plugs and lightly caulked. The aftermost cants of a screw ship that heel against the body post, are still scored into the latter, a sufficient abutment being given to allow of a light caulk.

185. The Stem Piece.—We have already had occasion to describe the nature and functions of the *stem piece* (see Art. 99). The information usually furnished to the workman for trimming this timber, consists of a mould to the side of the timber which fays against the stem, and section moulds at certain level lines, the position and direction of which are marked upon the mould of the timber. Bevellings at harpins and sirmarks are sometimes given, in which case the positions of these harpins and sirmarks are marked upon the mould.

The section moulds are, however, preferable, and should be given at a sufficient number of level lines to allow the correct form of the outer surface of the timber (which usually has considerable twist) being obtained. The fore edge of the timber, which coincides with the bearding line, is the moulding edge; and the after edge of the side which fays against the stem, coincides with the cutting down line. Sketches of a stem piece mould with the section moulds, are given on Plate XLII., and a method of trimming the timber will be found at Art. 239.

186. The Knight Head.—When the size of the ship is not so great as to necessitate a stem piece being fitted, the particulars supplied for trimming a knight head are the same as those given in the previous article; but when a stem piece is placed between the knight head and the stem, the fore side of the knight head fays closely against the after side of the stem piece. This timber is usually moulded on its after edge, and the mould supplied gives the exact shape of that side, including the boxen at the head for housing the external and internal plank in the wake of the bowsprit hole. As in the case of the stem piece, it is sometimes considered advisable to trim the timber by the aid of section moulds at the several level lines; but this practice is not so common as with the former timber. When trimmed by bevellings, these are given at the heads and sirmarks, and the positions of the latter are therefore given on the mould. In addition to the bevellings, the sidings at the different bevelling spots must be given, owing to the taper of the timber, both as regards its siding and moulding. It is on this account that the section moulds are very useful as a guide to the workmen in trimming the fore edge of the timber, so that it shall fay closely against the stem piece (see Plates XL. and XLI.)

187. Security of Stem Piece and Knight Head.—The stem pieces and knight heads on both sides of the stem are usually fastened altogether with dowels and bolts passing through from side to side. When the lines of the ship are too fine to allow bolts to go through the two knight heads and the stem, the stem pieces only are bolted to the stem by through bolts, after which the knight heads are bolted to the stem pieces. In each case the timbers are dowelled together. Whenever practicable, the stem pieces and knight heads are both secured to the stem before the latter is raised into place, but in every case the stem pieces are so secured.

188. Fore Cants of Bluff Ships.—Formerly, in bluff bowed ships, it was customary to dispose the knight head, stem piece, and hawse timbers in a fore and aft plane, stepping their heels against the foremost canted frame that heeled against the deadwood (see Plate XXIV.). Such an arrangement was unavoidable in the very full bows of some old ships, as there was not sufficient space on the deadwood to allow all the timbers to heel thereon that were required to fill up the space between the foremost frame of the square body and the stem, allowing an ordinary size for openings.

189. Cant Frames of After Body.—The cant frames of the after body, between the fashion timber and the aftermost square frame, are similar to those of the fore body. Abaft the fashion timber, however, we have an assemblage of timbers of a very complex character, which varies according to the particular mode of stern which is adopted. As was stated at Art. 57, various styles of stern have been in vogue during the present century, and are still to be found at the present day. The causes of these varieties have not been so much a regard for beauty, as the considerations involved in working guns and obtaining a strong combination of materials. The nature of the latter, when of wood, narrows the limits within which the timbers of the stern, particularly in screw steam-ships, can be combined.

Notwithstanding these limits, there can be no doubt but that a desire to please the eye has influenced to some extent the form of the stern, and therefore the disposition of the timbers. Recently, however, in ships built for the Royal Navy, ideas of beauty have been subservient in the highest degree to those of utility, and hence we find that the combination of timbers adopted in the sterns of British warships of the present day is far simpler than has ever been the case before. Nevertheless, even in these the nature of the material has had its limitating influences, as will be seen hereafter.

190. The Square or Transom Stern.—The oldest form of stern that we have any occasion to consider is that known as the *Square* or *Transom Stern;* then followed the *Circular Stern,* and the *Elliptical Stern,* which, in a modified form and shorn of all, or nearly all, its embellishments, remains at the present day.

Although the *square stern* is now almost a thing of the past, yet, as it is still retained in some vessels (chiefly of North American build) of the mercantile marine, we will devote a small space to its consideration.

The square stern abaft the fashion timber is composed of two sets of timbers, viz.:—

1. Horizontal timbers, extending from fashion timber to

fashion timber, and scoring into the stern post. These are termed *transoms*.

2. Vertical timbers, extending from the upper transom between the stern posts to the rail. These are termed *stern timbers*.

It must, however, be observed that the farthest of these *stern timbers* from the middle line, and which partakes of the rake of the stern and that of the topside, is termed the *side counter timber*. It heels upon the upper transom, and fays against the fashion timber.

The transoms situated at certain positions are distinguished by particular names. The upper one, which forms the base of the stern, that is, the transom upon which the stern timbers step and to which they are tenoned, is termed the *wing transom*. Boxen wood is left on the upper edge of this timber in order to house the plank of the bottom, and receive the fastenings of their *hooding ends*. The line at which the planks end is called the *margin;* and a rail, called the *Tuck Rail*, is fitted over the boxen left above the margin, and gives a finished appearance at the ends of the planking.

The next principal transom is called the *deck transom*. It is situated at the height of the lower deck, and its upper surface conforms to the round up of the beam, being made sufficiently wide to receive the fastenings of the lower deck plank, which stop at a rabbet or score in it. Between the wing and deck transoms certain others are fitted, the number being regulated by the distance between. These are called *filling transoms*.

Below the deck transom a series of other transoms are fitted, being sufficient in number to extend from the deck transom to a short distance above the heel of the fashion timber, the space between the lowest and the bearding line being fitted in by short canted timbers, which are tenoned to the under side of the lowest transom.

The transoms below the deck transom are distinguished by numbers, according to the order of their position below it. All except the deck and wing transoms have their upper and lower surfaces in a plane, which is either horizontal or square to the after side of stern post. The deck and wing transoms, however, have their upper and lower sides trimmed to a surface which partakes of the round of the beam and the sheer of the topsides and deck respectively (see *Ekeing*, Arts. 210 and 241).

191. The Circular Stern.—In the circular stern the transoms are entirely omitted, and cants termed *stern timbers*, which heel upon the fashion timber, extend round the stern from side to side.

The name *circular* was given in consequence of the outline of the stern above the knuckle being made of a circular instead of a nearly rectilinear character, as by the preceding system.

192. The Elliptical Stern.—The *elliptical stern* was so fully described at Chap. VI., that it is scarcely necessary to say more concerning it. The description there given, and the Plates XXV., XXVI., and XXVII., refer more particularly to the arrangement which was in vogue at Devonport, although the general outline of the construction was common to all the yards. At Portsmouth yard it was customary to place a transom across the stern abaft the rudder post, extending from fashion timber to fashion timber; also to tenon the heels of the stern timbers into its upper side. The timbers forming the side of the aperture in this case were tenoned into the transom and fashion timbers similarly to carlings, and were styled *aperture carlings*.

Again, at Chatham and Pembroke yards, it was the practice to frame the portion of the stern abaft the rudder post, similarly to that shown on Plates XXV., XXVI., and XXVII.; but the fashion timber was heeled further forward, and a transom carried across against the body post. The heels of stern timbers were tenoned into this transom, and by moulding the timbers to an additional thickness equal to that of the sum of the outer and inner plank, the timbers were made to fork over the transom, the two forks taking the place of the planking at that place.

It need hardly be remarked that a great many different combinations of timbers may be adopted, still preserving the general features of the system.

However, the subject of the *elliptical stern* is now of very slight interest when viewed with reference to passing events. As none of the wooden ships built in the Royal dockyards at the present day are larger than corvette size, there is very little scope for the adaptation of this style, even if it were considered desirable. Plate LII. shows the general method of framing the stern of a wooden war ship as now built. It will be seen, that when twin screws are fitted, or when it is not considered necessary to provide a *well* for raising the propellor, the stern framing consists of cant frames stepping on two fore and aft post timbers, which are tabled and bolted to both body and rudder posts, and are carried up from one of the after cants to the rail. These timbers are either scored around the posts and fitted with close joints, or else a middle line timber is fitted between them, fig. 1, Plate LII. The post timbers are thus equivalent to a continuation of the deadwood, and the aftermost cant frames heel against them, being either tenoned or dowelled.

When it is necessary to have a screw well, the only modification made is in the form of the post timbers, as shown by fig. 2, Plate LII.

Special arrangements are fitted to the stern frames of screw wooden ships in H.M. Navy, in order to reduce the vibration of this part to a minimum, and altogether strengthen this necessarily weak portion of the framing. Such means are shown in elevation by Plate LXXIII. As will be seen, it consists of iron deck plating at *C*, *C*, transverse iron bulkheads at *A* and *B*, and a fore and aft iron connection at *D*. The upper parts of the rudder and body posts are covered with iron plates through bolted to the posts, the bulkheads being connected to them as shown. In this way, by means of the assemblages of iron plates, etc., situated in planes mutually at right angles, the overhanging part of the stern is supported, and considerable resistance offered to vibration in all directions.

193. Fillings.—We have now to notice a small but very important element in the framing of a wood ship—an element which was only introduced at the latter portion of the period during which wood was exclusively used in the construction of large ships. In the earlier days of naval architecture, before the introduction of the marine engine, ships were not generally very long compared with their breadth, and consequently the difference between the buoyancy and the weights concentrated at particular points, could not constitute an important bending moment tending to alter the form of the vessel. But with the marine engine, and even before its introduction, ships were being built of proportionately greater length than heretofore, and at the same time the whole of their dimensions were increased, and the weights of their armament and other portions of their equipment were augmented in due ratio. Their extremities were likewise made finer, so that the whole of these modifications tended to increase the differences between the weights at the extremities and the displacement or buoyancy at these points, especially when compared with the conditions at amidships. As a result it was found that the extremities tended to droop with reference to the midship part, and the ship was said to *break*, this particular form of breakage being termed *hogging*. The contrary form of breakage, when the midship portion sinks with reference to the extremities, is termed *sagging*—a result which follows when the ship grounds at the extremities, or when she is unduly loaded at amidships.

In this small work it is impossible to give more than a passing glance at these strains, and the remedies adopted to counteract them. It will be seen that the *hogging* strains are those to which a ship is chiefly subjected, and it was to reduce the effect of these, as far as possible, that *fillings* were introduced by the late Sir Robert Seppings.

Hogging, being a drooping of the extremities with regard to the midship portion, is therefore accompanied by an extension of the upper part of the ship, and a compression of the lower.

Now, it is evident that the structure at the stage to which we have now arrived, is totally unfitted to resist any such strains as these. Hence, in the further progress of the ship towards completion, provision has to be made not only for keeping out water, but in doing so, at the same time, to combine with the portion of the structure already erected, such an arrangement of material as will co-operate with the framing in giving the required strength in the particular directions that it is most needed.

The upper and lower portions of the ship evidently demand primary consideration with reference to these *hogging* strains, particularly the lower. For if we can make that part of the hull sufficiently solid to resist compression, it is evident there will be a reduction in the tendency to extend at the upper portion. In combining wood, it is generally easier to resist compression than extension; the converse is usually the case in combinations of iron. Hence, as we shall presently see, this latter material is generally used in wood ships at the present day to resist those tensile strains which were formerly opposed by combinations of wood.

By reference to the midship sections shown by Plates XII. and LXXIV., it will be seen how wood fillings are placed between the frames to a certain height, generally to the lower side of the lower or orlop deck clamps, their moulded width diminishing as they extend out from the keel, being nearly the full moulding of the floors at the latter place. The fillings are made of the same material as the floors and futtocks, and with the grain of the wood in the same direction. They are closely fitted, and are caulked both inside and out, the oakum being driven to the depth of about three inches in each case.

The fillings are fitted previous to the keelson being secured, their butts are rabbeted, and are arranged so that the pieces may extend to some distance on each side of the middle line. When these fillings are strongly caulked, the lower part of the ship offers considerable resistance to compression, besides which the framework of the ship is made sufficiently tight to keep out water, should the plank of bottom be carried away. This is an important consideration, and one which has proved effectual in cases where ships have grounded with sufficient force to displace some of the exterior plank, and even to drive large stones into the bottom, yet by reason of these fillings, and the efficient caulking, sufficient water has not been admitted to produce any serious danger.

194. Dubbing Out.—At this stage, the inside of the ship is trimmed and faired to the correct scantlings by a process termed *dubbing out,* which consists in making the otherwise comparatively uneven and rough surfaces of the timbers fair, both longitudinally and transversely. This is done by the aid of fair and flexible battens, which being laid or bent on the inside surface in different directions, reveal to the practised eye of the workman any unevenness, which he then removes with the adze. He is further aided by *scantling sticks*, giving the exact mouldings which the timbers should have at the several heads and sirmarks. Care should be taken not to reduce the frames to less scantlings than those given. When the inside is dubbed out, the ship is in a fit condition to receive the *iron riders, shelves, etc.*

195. Riders and Trusses.—The necessarily imperfect connection of the numerous timbers composing the frame of a ship, even when tied together and assisted by the fillings, external and internal plank, beams and deck plank, has caused the introduction of further systems of framing in order to give special aid in resisting strains of a *hogging* and *sagging* character, particularly the former. As any such alteration in a ship's form must be accompanied by a local yielding among the joints of the timbers, and changes in the relative position of the planking and frames, these additional connections were introduced with a view of preventing any such working among the parts of the hull.

196. Vertical Riders.—The first attempt which was made in this direction consisted of a system of *vertical wood riders.* This was an assemblage of timbers placed transversely over the interior planking and opposite to the frame timbers. They were arranged in shifts, the parts of which were termed *floor, 1st, 2nd, etc., futtock riders.* Those next the middle line, on opposite sides of the ship, were connected by chocks, and the other futtocks were bolted together either where they overlapped side by side, or by chocks at their butts. They were all through bolted, either from the inside or outside; in the former case the bolts were clenched upon the plank of bottom, and in the latter upon the riders themselves.

It is evident that this assemblage of timbers only served to prevent transverse alteration of form. This, however, was of considerable importance in the case of heavily armed ships, the ratio of whose length to breadth was only as 3 to 1, this system was soon displaced by one which was better suited to the longer ships then commenced to be built.

197. Trussed Frame.—The second system was known as the *trussed frame.* It consisted of three assemblages of timbers termed *riders*, *fore and aft pieces*, and *trusses* respectively. The former were fitted diagonally at an angle of about 45 degrees, against the inside of the frame timbers, and extended from the thick strakes under the orlop deck to the binding strakes over the floor heads (see Art. 218), the butts scoring into the edges of the planks. The upper ends of the *riders* were inclined forward in the fore body, and aft in the after body. The *fore and aft pieces* were fitted in short lengths between the riders, immediately over the heads and heels of the frame timbers; and the *trusses* were fitted in an opposite direction to the riders, and at the same angle, viz., about 45 degrees. The trusses abutted against and scored into the riders, the whole forming a kind of lattice work girder similar to the construction of an ordinary gate, but far less efficient, as the combination was not in the plane of the bending force. This and the disadvantage of having such a great weight of timber put into the ship, together with the loss of internal capacity consequent thereon, caused the system to be superseded by another, which, in a variety of forms, is that in vogue at the present day.

198. Iron Plate Rider is the name by which this sytem is known. In the Royal dockyards it is carried out differently to that required by Lloyd's committee.

By the former system the *iron plate riders* are fitted on the inside of the frame timbers, being usually scored half their thickness into the frame, and the other half into the internal plank. When, however, the wood binding strakes, etc., are replaced by those of iron, as is now the practice, the whole of the rider is scored into the frame. As shown by Plate XII., the riders stand in a diagonal direction, being inclined at an angle of about 45 degrees, the upper ends of those in the fore body being inclined aft, and *vice versâ*, two or three of the midship riders overlapping each other (see Plate LXXI.).

It will be seen that any tendency to hogging is accompanied by a tendency to elongate these riders, and thus their tensile strength is brought into request.

In a large ship the riders are placed about 6 to 8 feet *apart* (measuring square to the riders), and less in small vessels,* care being taken to keep them from crossing ports, to do which it is sometimes necessary to "joggle" or bend them. They extend from the floors to about the height of the upper deck spirketting, and are from about 3 to 6 inches broad, and $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches thick, being fastened with a bolt passing through every timber they cross.

In some cases, as in armour-clad wooden ships, the two sets of riders have overlapped each other for a great distance, even to the whole length of the ship, and by this means provision has been made for resisting not only the hogging strains, to which most wooden vessels are found to yield, but also to the sagging strains which, in a vessel heavily armoured at amidships, must be considerable.

Besides these plate riders, a complementary set of diagonal wood internal frames, termed *trusses*, are fitted between the thick strakes or clamps under the orlop deck beams and the binding strake over the floor heads. These truss frames are the same thickness as the binding strakes, and are placed at an angle of 45 degrees in an opposite direction to the plate riders. See Plate XII.

At the time these plate riders were first introduced, another set on the inside surface of the interior plank was associated with them. These were the same size as the outer riders, and were scored into the plank, but were placed in an opposite direction to those on the timbers.

199. Plate Riders by Lloyd's Rules.—By Lloyd's rules, riders, termed *diagonal iron plates*, are fitted on the *outside* of the frames of fir built ships of more than 600 tons, and all ships whose length exceeds five times their breadth. They stand in the same direction as those in the Royal Navy, and extend from the height of a short distance below the midship 1st futtock heads to the upper side of the upper tier of beams. They are spaced from 6 to 8 feet apart (measuring square to the rider), and vary in size from $3\frac{1}{2}$ inches by $\frac{7}{16}$ of an inch for a ship of 100 tons, to $6\frac{1}{2}$ inches by $\frac{7}{8}$ of an inch for ships of 2000 tons and upwards. The riders are bolted to every alternate timber that they cross, and four pairs cross each other at amidships. In conjunction with

* Plate LXXI. shows the riders of a ship of about 1000 to 1500 *tons; in this case they are* spaced 3 feet apart.

these, a set of internal riders are required in all ships of 400 tons and upwards, the frames of which are of fir. These are termed *iron knee riders,* being usually a continuation of the beam knees. Their inclination to the keel increases in proceeding forward and aft, their direction being the same as that of the external riders. They are fitted under each hold or lower deck beam extending to the floors, so as to enable two bolts to be driven through the latter. The beam knees of the other decks are also continued nearly to the deck below, and inclined similarly to the hold *knee riders.*

200. The Systems Compared.—In comparing the Admiralty and Lloyd's systems of plate riders, there can be little doubt but that the advantage in point of strength is with the latter; but the former is the more easily fitted of the two. In the Admiralty system the riders are kept against the frames by the bolts, and any tendency to elongation induces the rider to leave the ship's side, and hence brings a considerable strain on the bolt heads.

By Lloyd's system the riders support the frames, instead of the frames supporting the riders by means of the bolts. Hence a strain upon the rider tends to press it more closely against the timbers, thus setting up a frictional resistance independent of the aid given by the scores in the timbers, both of which relieve the bolts most considerably.

It is evident, however, that it is far easier to fit the riders on the inside of the ship, which, when just framed and ready to receive them, is clearer, and gives greater scope for such work than can be obtained on the outside of the vessel, crossed, as it is, with harpins, ribbands, stages, etc., and supported by innumerable shores.

May 23. Chap.

CHAPTER XIII.

201. The Shelf.—The ends of the deck beams rest upon a line of timbers secured on the inside surface of the frames. This combination of timbers is termed the *shelf;* it is made of teak, mahogany, greenheart, or some other straight-grained tough timber. The several pieces composing the shelf are connected with vertical flat scarphs, the length of each of which is equal to twice the room and space; the

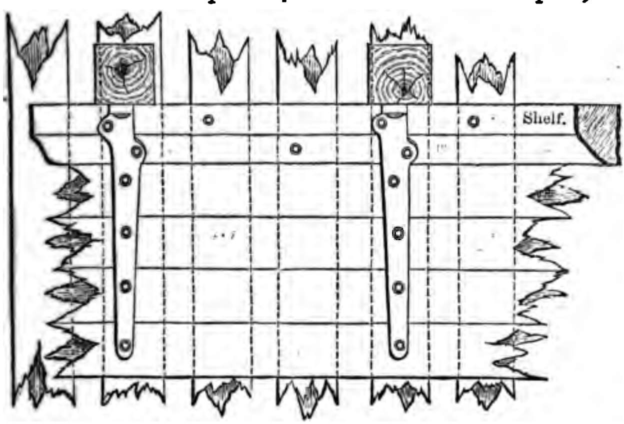


Fig. 21.

scarphs being situated between the ports, when over a fighting deck, and so disposed, with reference to a beam, that a bolt securing the knee shall pass through the end of the exposed lip. The shelf is fastened with bolts, one of which passes through each timber, except in the close jointed frames at the extremity of the ship, where they are spaced about 3 feet apart. In the wake of a beam, however, two bolts are driven through the shelf, which bolts serve also to secure the beam knee (see Plate LXXIV. and fig. 21).

The last-mentioned bolts pass through "lugs" on the knee, one of which is on the vertical, and the other on the champhered face of the shelf. In H.M. service the whole of the fastenings of the shelf, including the knee bolts, are clenched on the outside of the exterior plank.

As soon as the shelf is in place, the exterior plank in its wake is trimmed and fitted, and then, when fastened, the whole constitutes a very rigid ribband, which preserves the form of the ship, while the remainder of the plank is being put on. It should be stated that, as the beam knees are not fitted until some considerable time after the shelf is put in place, Blake's screws are used to temporarily secure the shelf at places where knee bolts will subsequently be driven. The section of the shelf is shown by Plates XII. and LXXIV., the upper surface usually sloping slightly towards the interior of the ship to prevent water from lodging.

The shelf in war ships varies in size from about 16 in. by 16 in. to 11 in. by 11 in., according to the class of the vessel. In every case the front is champhered, at half its depth, from its full moulding to the thickness of the clamp below.

Lloyd's rules require for ships whose length is five times their breadth, and between eight and nine times their depth, that the sectional areas of shelves and waterways shall not be less than that of the beams, the latter being determined by a table giving the scantling according to the breadth of the ship at amidships. They also require that the breadths of the faying surfaces of such shelves shall not be less than the siding given for the beam. When the fastenings are of iron they need not go through the exterior plank, but may be clenched either on the inside of shelf, or outside of timbers; when of copper or yellow metal, they must be clenched on the outer plank.

The *clamps* formerly did the work of the shelf in war ships, the beams being connected in a different manner to that which has been most recently adopted. Indeed, the clamps were a most important item in the building of the ship. Their butts were at one time connected by hook scarphs, and afterwards by dowelled scarphs, similarly to the shelf at the present day. Besides this, special rules were laid down for the number of strakes of clamp under each tier of beams, together with the modes of fastening them to the timbers. In fact they constituted a most important assemblage of longitudinal ties, the functions of which are now performed by the shelf, aided below the gun decks by the less important strakes beneath it, which still retain the name of clamps, originally given to the more important assemblage.

Considerable difference of opinion has existed with reference to the utility of scarphing the various lengths of timber composing the shelf; some advocating the necessity of so doing on the ground that the greater the number of plain butts in the length of the ship, the less the resistance offered to such changes of form as sagging and hogging; and, therefore, by preserving, as far as possible, a continuity of strength in the shelf, the ship would be materially aided in resisting breakage. This was more especially urged in the case of war ships, the sides of which being perforated by ports, the only longitudinal ties of any importance, secured to the inside surface of the frames in the wake of the decks, are the shelves and waterways. On the other hand, it was maintained that the scarphing of a single course of longitudinal timbers could afford but little additional support; and that, too, not proportionate to the expense involved in labour and material for scarphing. Experience has, however, proved that there is a great advantage in scarphing over plain butting the shelf; and ships which have been treated by the latter method have shown signs of weakness at that point, which have required compensatory strengthenings of at least equal cost.

The introduction of iron beams and deck plating into recent wooden ships, especially in the Royal Navy, has reduced the importance of the assemblages of internal plank as longitudinal ties. At the present day we hear very little of *shelves, clamps, thickstrakes, spirketting*, etc.; but, instead of these comparatively ill-connected planks and timbers, we have the simple and light, yet rigid combinations of *iron beams, stringers, side keelsons* or *binding strakes*, etc. See Plate LXXV., which shows the midship section of a modern wood ship of war.

202. Getting in the Lines on Ship's Side.—When the inside of the ship is dubbed out fair, and the iron diagonal riders are fastened, the lines are got in on the ship's side for the beams and port sills. Points for these lines could have been marked on the several futtocks when trimming them by means of the moulds made to the lines on the floor; but they would not be sufficiently accurate for working to, as in jointing the timbers and erecting the frame, it is impossible to ensure that such points would be in the correct lines when the frames are secured.

The first operation when getting in the line of a tier of beams, is that of marking on the ship's side a straight line, at or near the height of the beam at middle line at amidships. The straight line is first drawn upon the sheer draught, and its height is measured from the keel; three base boards are then put across from side to side, one being near each extremity of the ship, and one at the middle. These boards are set perfectly horizontal by means of a spirit level, and they are so placed that the upper edges of the two extreme boards are at the height of the straight line, and out of winding with the lower edge of the middle board, this being done by looking across the edges, or "sighting," as it is termed. Shearing battens are then fixed along the inside of the ship, being temporarily secured by small cleats, termed "hutch hooks," and the batten is so placed that its upper edge coincides with the upper edges of the two extreme base boards, and the lower edge of the middle board. The intermediate portions of the upper edges of the battens are looked level with the three edges of the base boards, and the straight line is thus sighted on the inside surface of the frames. The line is then rased in on the timbers, after which it is painted so as to be distinguishable. In this way a straight line is put in on both sides of the ship, at the same height above the keel.

Next, the perpendicular distance between the straight line and the beam at middle line in the sheer draught is measured at every square station. A small cord is then stretched across the ship at each square station, being kept to the straight lines already drawn on each side of the ship. In this position a spirit level is sometimes applied to the cord, to prove the agreement of the straight lines on the ship's side, The distances measured from the drawing are then set up from the cord, square to the base line, at the respective square stations, and the points so found are marked on the inside surface of the timbers on both sides of the ship. A line drawn through all such points, by the aid of shearing battens, gives the sheer of the deck, or the projection of the beam at middle upon the sides of the timbers.

The beam at side line, *i.e.*, the line of the upper side of the beam ends, is then found by measuring from the beam mould the round down of the beam in the breadth of the ship at each square station, and this distance is set down square to a spirit level held athwartship at the line of the beam at middle; the spots so found are marked on the timbers. A line drawn through all such points, by the aid of shearing battens, is the line of the beam at side. It is evident that by setting beneath this line the moulding of the beam, minus the *snaping* of its end,* we obtain points in the line of the upper edge of shelf, which line can then be drawn by the aid of shearing battens.

In trimming the shelf, moulds are made to the curvature of the side, and the amount of sheer is determined by spilings taken from a straight line drawn on the inside of the timbers, and adjacent to the line of shelf for the length of the piece to be trimmed. These spilings are set off from a corresponding straight line drawn upon the log when trimming it.

The shape of the section of shelf at amidships is given from the mould loft, and the shelf is kept the same siding and moulding throughout its length, the shape being governed

* It will be observed that the amount of snape will be greatest at amidships, and will disappear at the extremities of the deck, provided the upper side of the shelf is level; this being due to the fact that a tangent to the curve of the round of beam is level at the middle line, and increases in its inclination in proceeding towards the side. The snape at each beam can be found by setting off on the beam mould the breadth of the ship to the inside of the shelf, and then measuring down the depth of the beam from the upper edge of mould at that place: a line drawn through this point, at the same inclination as that of the upper side of shelf, is the line of the under side of beam, and the distance from the upper side of the beam mould to this line, taken at the breadth of ship measured to inside of timbers, gives the depth of the beam end, which, being set down below the *beam at side* line, gives the *shelf line*.

by keeping the inside face parallel to the back of the shelf, while the champher is ended at the inside surface of the clamps. The upper side usually slopes slightly inwards, and the under side is more frequently parallel to the under side of the beam than square to the surface of the timbers. At the extremities of the ship the shelf is tapered away to the thickness of the clamps, the latter being worked up in lieu of the former.

203. Beams.—The beams serve the twofold purpose of connecting the two sides of the ship, and forming the bases of platforms for fighting the guns and carrying out the internal economy of the ship. Besides this, the beams, in combination with the deck plank, form a continuation of the frames and planking, it being evident that when the ship is rolling and working heavily in a seaway, the deck and beams are, at intervals, subjected to the same strains as the frames and plank of side. In the Royal Navy iron has superseded wood as a material for beams of wood ships (see Plate LXXV.); but, in the merchant navy, wood beams are still fitted, although Lloyd's rules provide for iron beams, if the builders choose to use them.

The framing of a deck, when the beams are of wood, consists of *beams*, *half beams*, and *carlings*, these being of teak, mahogany, African oak, or other tough material. The *beams* are those which extend from side to side; the *half beams* are short beams of reduced scantling, which extend from the side to fore and aft pieces of deck framing, termed *carlings*, the latter being fitted between the beams. The arrangement of deck framing is given in the design of the ship, and is adapted to the required positions of hatchways, scuttles, ports, etc. The beam is of parallel siding and moulding; the upper surface is made to the curvature of a circular arc, the versed sine of which is termed the round up (see Art. 51).

This curvature prevents the water from lodging on the deck, and adds to the bearing power of the beam when its ends are fixed. Owing to the difficulty in getting long pieces of timber, it is usually necessary to make the beams of large ships of several pieces which are scarphed together. Several kinds of scarphs have been adopted, but it is not necessary for us to consider the details of but one, viz., that known as

Edye's scarph, which is the form that was universally adopted in the Royal dockyards prior to the total disuse of wood beams—see fig. 22, which shows the manner of making this scarph. The scarph, which is vertical, varies in length with the scantling of the beam, an average length being about 7 feet 6 in. or 8 feet. In setting off the scarph, the points A and D are joined, and the length AD is trisected at B and C. A distance equal to two-thirds the breadth of the keys (shown at E) is set above AD at B and below it at C,

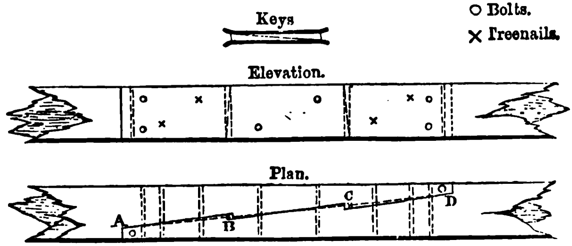


Fig. 22.

the remaining one-third of the breadth being set off on the opposite sides. The shape of the scarph is then drawn by joining the points, as shown in the figure. By this means the three bearing faces are parallel to each other, and thus when the keys are driven in and the scarph tightened, these surfaces still remain in contact. It should be stated that a strip of copper is placed on each side of the keys. The scarph is fastened with six bolts and four treenails, which are indicated by the sketch; there being also a tie bolt in each lip, as in the case of a keel scarph; these lip bolts are likewise shown.

There have been four or five different kinds of beam scarphs adopted or recommended at different times; the majority of these being dowelled and bolted, no keys being used. The dowels had to be very accurately fitted in order to secure a satisfactory scarph, and even then no opportunity was afforded for remedying the looseness and play among the parts which are almost certain to follow a long continued vibration, such as the deck beams of a ship are subjected to. Besides this, the dowelled scarphs were inferior in consequence of the surfaces in contact being plain, and the butts of each lip not being scored into the other piece of the beam, as in the case shown at A and D in fig. 22, consequently, any force tending to deflect the beam had to be entirely borne by the dowels and bolts, whereas in Edye's scarph, with close fitted butts and tight keys, the beam deflects almost as one piece, even without the fastenings. This method has the further advantage that if by shrinkage of the wood, or any other cause, the scarph should loosen, it can be readily tightened by punching in the keys, and this without interfering with any adjacent work in the ship. It may be remarked that Edye's scarph was used by house carpenters for some time previous to its introduction into ships.

The beam rests upon the shelf at each side of the ship, and its efficiency as a tie is obtained by the following means:—

1. By dowelling it to the shelf, one or two dowels being put in each end of the beam, according to its size.

2. By bolts driven up and down through the shelf, beam, and waterway, and by iron knees.

3. By scoring the waterway down over the beam, the former being of course bolted to the ship's side.

The dowels in the beam and shelf are now usually of African oak, although iron is frequently employed, on account of the great strength and durability of that material as compared with wood.

The bolts passing through shelf, beam, and waterway, are shown by Plate LXXIV.

204. Beam Knee.—The chief function of the knees at the beam ends (see Plates XII. and LXXIV., and fig. 21) is to preserve a constant angle between the beam and ship's side, it being evident that the working of a ship in a seaway tends to alter that angle. Various kinds of beam knees have been, and are still in use in wooden ships. Plate LXXIV. and fig. 21, show the form which was adopted in the Royal Navy before the recent introduction of iron beams (Plate LXXV.). The earliest form of beam knee was a wooden angle chock, generally a curved branch of a tree, or a piece of timber at the junction of a trunk and branch. This was unsightly, heavy, and occupied a great deal of space, besides which the timber was difficult to obtain. Next followed a plain chock under the beam, with an iron plate arm on each side, connecting the two together, the chock being bolted to the side. This was succeeded by *hanging* and *lodging knees*. Hanging knees are such as shown by Plate LXXIV. and fig. 21, being vertical, and connect the beam with one timber of the frame only; whereas lodging knees are horizontal, one being fitted on each side of the beam, above the shelf, and bolted through several frame timbers, besides being through bolted to the beam.

Hanging knees are of several kinds. Plate LXXIV. and fig. 21, show the kind known as *lug knees*, the lugs being forged to the knee in order to receive the bolts which secure it to the shelf, instead of weakening the throat of the knee by holes. The *horn knee* had no lugs, but simply a clasp on each side of its upper arm, bent in the form of a horn; bolts were driven through the beam and clenched on these horns, besides the vertical bolts clenched on the upper side of beam. Lang's hanging knee had neither lugs nor horns, but was simply a bent bar of iron, the upper arm of which was bolted to the beam, and the lower fitted close against and bolted to the frame timbers, the knee extending from the beam to the under side of the clamps of the next deck.

Lodging knees have not been fitted of late years to H.M. ships, but they are still required in merchant ships which are classed at Lloyd's, being fitted on the sides of those beams which are adjacent to the masts. In all other cases hanging knees are fitted. A modification of Lang's knee is, however, required in hold beams of ships which have fir frames; the lower arms being extended down over the floors so as to receive fastenings through them, the knees acting likewise as riders (see Art. 199). The fastenings of hanging knees do not pass through the deck plank, but those through the side are upon rings on the exterior plank.

205. To take the Length of a Beam.—The length of a wooden beam is measured at the ship. This can be done either by measuring the breadth of the ship straight across, at the level of the upper edge of beam, then applying this length to the beam mould, and measuring the length of the curved edge of the mould in the straight distance; or it can be done by putting the beam mould in place, and marking off the length upon it. By the latter method the bevelling of the beam end can be marked upon the mould at the same time. When the length is taken by the former method, the bevelling of the end can be obtained by holding the stock of a bevel along the line and fitting the tongue against the inside surface of the timbers. This bevelling must be marked on the beam mould at the spot already set off for the end of the beam in question, by holding the stock of the bevel against the level line which is always drawn on the mould, and marking by against the tongue; then shifting the bevel and holding the stock on the curved edge of the mould, and setting the tongue to the line just marked on it, we have the bevelling which must be applied to the beam by holding the stock along its upper face, whether the beam is to its correct round or not.

In order to take account of the snape of the beam end, also the bevelling and length at one process, whether the beam is to its correct round or not, the following is an ordinary method:—A batten is placed across the ship at the position of the beam to be fitted, and the upper edge is kept well with a cord, stretched tightly across the ship, and secured to the beam end line at each extremity. A piece of mould is then made to the shape of each of the beam ends, the under side of each mould being upon the shelf, and the end fitted against the timber with the upper part of that end coincident with the beam end line. These moulds are then nailed to the ends of the batten, while the latter is in the position already named, and the moulds in their proper positions. The batten with the end moulds are then laid upon the beam to be cut, taking care to keep the middle of the batten as much below the upper edge of the beam as there is round up in the breadth of the beam mould at that place. The ends are then marked by the mould, and in order to ensure that the beam fits closely against the timbers, it is customary to allow an extra length, say of $\frac{1}{4}$ or $\frac{3}{8}$ of an inch, in proportion to the length of the beam, the exact amount being regulated by a slip of wood kept by the workman, who thereby ensures that all the timbers are pressed against to the same extent. The fore and aft bevellings of the beam end are taken with a bevel held against the athwartship line and the insides of the timbers. It is of the utmost importance that the beam should fit closely against the timbers of the frame, as "a close joint" is popularly said to be "half the fastening," and nowhere is this more true than in the case of beams.

The beams being of rectangular section are easily trimmed, the manner of cutting them to their lengths has just been stated. They are moulded on the upper edge, and the lower then trimmed parallel to it. In setting off the positions of the beam at the slip, battens are put up representing the centres of masts, and the beams are set off from these; their relative positions being given by the designed deck plans.

206. To get the Beam in Place.—No difficulty is experienced in getting the beams in place, unless it is when there is a considerable "fall home" to the ship's side. In such a case it is evident that the beams cannot be lowered into place over the dowels. The usual mode of procedure in such a case is to first fit the shelf in place and temporarily secure it; next, measure the lengths of the beams, and cut and trim the latter as already described. Then remove the temporary fastenings from the shelf, and lower it sufficiently to allow the beams being crossed and raised to their required height, in which position they are to be securely shored. The shelf is then lifted up under the beams, dowelled thereto, and bolted to the side.

207. Carlings.—The carlings are scored down between the beams by two different methods, known as *single* and *double stops* respectively. The *single stop* is shown at A, and the *double stop* at B, fig. 23. By this means, the carling is prevented from shifting or sinking any lower than its fitted position. The double stop is generally used for deeper carlings than the single stop method is applied to. It will be observed that the score and butt of carling are cut so that the latter may "gain," or become tighter, as it is driven down into place.

208. Iron Beams.—The introduction of iron beams, stringers, waterways, etc., into wooden ships has caused a radical change in the modes of combination, and in the relative structural importance of the several parts of the ship. It will be seen by Plate LXXV. that, on the upper deck, the wood waterway is now superseded by the gutter

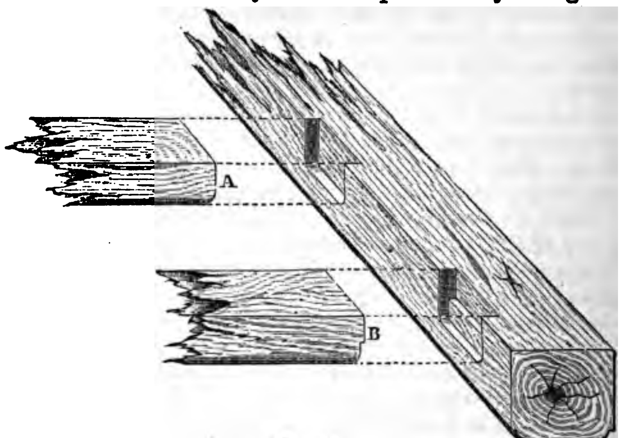


Fig. 23

watercourse, which, with the iron stringer on the top of the beam, forms a far more efficient longitudinal tie than the wood shelf and waterway it has supplanted. The beam is connected to the ship's side by an angle-iron on each side of the bent beam arm; the angle-irons are riveted to the beam and bolted to the ship's side, the bolts being clenched on the outside plank.

In some of the earliest examples of iron beams in wooden ships the shelf was retained, in which cases the beam end was not made into the form of a knee, but was butted against the frame timbers, and connected to them by a lodging knee on each side. It is evident that this method is not so satisfactory as that now adopted, which is shown by Plate LXXV. With reference to the latter arrangement, it may be observed that sometimes a portion of the beam arm, for a depth equal to the width of the upper strake of inside plank, is extended to the frame, and connected to the upper edge of the second strake of plank by an angle-iron on each side of it, which is riveted to the beam and secured by screws to the edge of the plank. The remainder of the knee in this case stops at the inside plank, as does the whole of the knee in other cases, except the flange, which is carried in against the timbers; the connection to the ship's side is obtained by two angle-irons riveted to the beam arm, and through bolted to the side. By the ordinary method the whole of the inside strakes of plank are continuous, instead of any being cut by the knees.

The deck framing of a wood ship with iron beams is so exactly similar to that of an iron ship, that further reference thereto is postponed to Chap. XX.

209. The Waterway, as its name would suggest, is a portion of the hull so situated that, in addition to its other functions, it forms a channel for carrying water to the scuppers on each side of the ship. The pieces of which it is composed should be so connected together, and to the adjacent parts of the structure, as to develop its full efficiency as a longitudinal tie, and in connecting the beams to the ship's side.

The waterway is usually made of teak or oak, and the main piece, or waterway proper, is known as the *thick waterway*, to distinguish it from the adjacent piece of deck plank which, by partaking of the form of the watercourse, is known as the *thin waterway* (see Plate LXXIV. and fig. 31). In the following remarks, the term waterway must be understood to refer to the thick waterway.

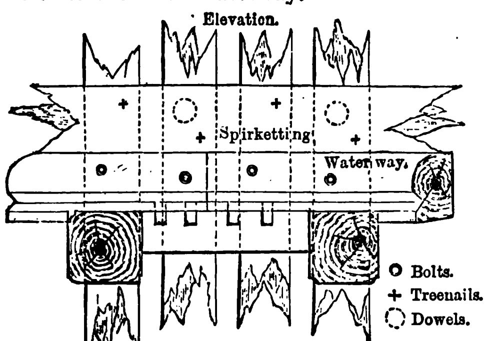


Fig. 24.

Unlike the shelf, the adjacent pieces of waterway are not usually scarphed together, but are butted one against the other, both ends resting on and being dowelled and bolted to a carling let down between the beams (see fig. 24). This practice of plain butting has not, however, been uniformly adopted. The butts of the waterway are brought under the ports of fighting decks, in order to give shift to the butts of *spirketting* (or thick strake of inside plank under the ports) which are placed between the ports. Indeed, the butts of shelf, spirketting, clamps, and waterway should all be carefully disposed with reference to each other.

The waterway is either dowelled to the beams or scored into them in a dovetailed manner, as shown by fig. 25 and Plate LXXIV. The dovetailed score is the mode usually preferred, although sometimes the beam has been both dovetailed and dowelled to the waterway. As will be seen, the score is dovetailed in two directions. The *letting down* or *binding strake*, shown in fig. 25, is a continuous plank, which, in passing the beams, is scored to them in such a manner that half the score is taken out of each. It will be seen by Plate LXXIV. that the binding strake is bolted to the ship's side, the bolts passing through the waterway between the beams. These binding strakes have not been fitted of late years.

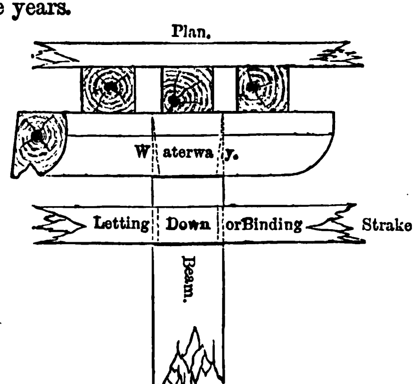


Fig. 25.

In wooden ships with iron beams, the wooden waterways are not generally fitted, but an iron stringer is riveted to the beams in the same manner as in an iron ship. The stringer is connected to the frames by an angle-iron, and in some cases a wooden waterway is fitted over this, while the more usual practice is to construct an angle-iron watercourse similar to that of an iron ship (see Plate LXXV.); the latter method is usually adopted on upper decks.

210. Breasthooks, Ekeings, Deck Hooks, Deck Transoms, Crutches, and Standards are the names given to those portions of a ship which connect the two sides together at the bow and stern. It is evident that they are of considerable importance, as the most careful distribution of timbers, plank, and fastenings, whereby the strength of each side of the ship is raised to a maximum, becomes of little avail unless the two sides are so connected as to keep up the continuity of strength.

Formerly the whole of these connections were of wood, but the difficulty of obtaining timber of the requisite shape, and having the grain in the direction of the curvature, also the great amount of space occupied thereby, have led to their being replaced to a great extent by iron.

Deck Hooks (see Plate LXXVI.) are those ties which, being laid under the deck plank so as to take the place of the beams at the fore extremity of the ship, are necessarily trimmed to the round of the beams. For mode of trimming, see Art. 242. The deck hooks forward are through bolted to the stem and apron, also to the frame timbers; the bolts through the former are clenched upon the independent piece prior to the knee of head being erected and fastened. The deck hook is frequently fitted as shown by fig. 2, Plate LXXXVI. The after deck hooks are termed *deck transoms.*

Ekeing is the name given to the timber which, resting upon the shelf, *ekes out* or fills up the spaces between the apron and the foremost beam, and between the stern post and aftermost beam, the deck hook and deck transom, just referred to, connecting the two sides. See Plate LXXVI., which shows a very usual manner of fitting the waterway, ekeing, and deck hook, before the common use of iron for deck framing.

The ekeing is trimmed to the round of the beam and the sheer of the deck; the mode of performing that work is given at Art. 241.

Breasthooks were the knee-shaped timbers connecting the two sides of the ship at the extremities, in other places than at decks. They were placed square to the curvature of the inside of the stemson or sternson, and were bolted to these and to the frames, the bolts in the former being clenched on the independent piece, and those through the timbers on the outer plank. No particular skill was required in trimming them, as it was not absolutely necessary that they should be placed in any exact position. Their places are now supplied by crutches and breasthooks of iron.

Crutches are symmetrical iron knees, which are bent over the inside of stemson and sternson, and extend over a number of the frame timbers so as to be bolted to them. They are placed as nearly as possible square to the curvature of the inside of the ship. The iron breasthooks now commonly fitted in wooden ships of the Royal Navy consist of a plate of iron placed square to the curvature of the stem, and connected to it by an angle-iron riveted to the plate and bolted to the ship's side. Both deck hooks and breasthooks are frequently associated with iron crutches, as in Plate LXXVI.

Standards are knees for connecting the stern posts to the deck beams of screw ships, in order to aid in resisting the vibration caused by the working of the propeller. They consist simply of iron knees bolted to the stern post and to several beams and a carling under which the standard extends. Standards were fitted in sailing ships connecting the fore side of inner post with the after end of the keelson.

To give more effectual assistance of this kind, mixed metal knees, termed "buttock knees," were fitted beneath the counters of screw wooden ships, connecting the framing of stern with the after stern post. *A*, fig. 1, Plate LI., shows one of these knees. The internal framing of iron, shown by Plate LXXIII., has rendered these knees unnecessary.

211. Deck Framing.—After the beams are laid, and prior to laying the deck, it becomes necessary to make preparations for the fittings and other arrangements to suit the requirements of the several decks. These fittings consist of *hatchways*, *scuttles*, *mast partners*, *bitts*, *bollards*, *capstans*, *deck pipes*, *pillars*, *gun pivots*, etc.

The sides of hatchways are formed with carlings, which are scored into the beams in the manner already described (Art. 207), and above these with *coamings* and *headledges*, the former being placed in a fore and aft, and the latter in a transverse direction. They are referred to by the general name of *coamings*, and extend to a sufficient height above the deck plank to prevent water getting through the hatchway under ordinary conditions. The coamings are connected together in a double dovetailed manner, as shown by Plate LXXVII.; they rest upon the beams and carlings with their inside surfaces flush with those of the former, leaving a space upon them before and abaft the headledges sufficiently wide to take the fastenings through the butts of the deck plank. The coamings are dowelled and bolted to the beams, the number of dowels and bolts being regulated by the length and breadth of the hatchways; one of the bolts is placed at each corner of the hatchway, and connects the pieces at the dovetailed joints.

In the wooden ships now being built for the Royal Navy, the coamings, whether of wood or iron, are connected to the iron beams similarly to those of an iron ship.

Scuttles are framed similarly to hatchways; the difference in the two being that the latter are passages for free communication between the different decks, whereas the former are openings by which to obtain access to certain compartments when necessary, and are therefore generally kept closed. So that while hatchways, when not in use, are fitted with large open gratings, scuttles in some cases are covered with *cap* and in others with *flush* covers. In the former they have raised coamings, and are termed *cap scuttles*, and in the latter the framework is nearly flush with the deck, and they are termed *flush scuttles*.

Mast Partners.—The mast holes of a ship with wood beams are framed with a series of carlings termed *fore and aft partners*, *cross partners*, and *angle chocks*, the whole forming a hole, the diameter of which exceeds that of the section of the mast by twice the thickness of the mast wedges, these latter varying from about 3 inches to 6 inches, according to the size of the ship. Plate LXXVIII. shows the framing of the mast hole of a recent wooden ship having iron beams. As will be seen, the partners in this case are simply chocks filling up the space between the beams, carlings, and the mast hole. The whole is connected to the beams by means of the iron plate indicated by the figure. The latter shows also the manner of securing the bitts around the mast, the upper deck being that given in the sketch.

The framing for *capstans, bollards, riding bitts,* etc., consists simply of carlings fitted so as to form a solid resting place or bearing for the fitting in question, and through which the bolt fastenings are driven. When these carlings are required to resist an upward instead of the ordinary downward thrust, they are fitted from below, and lap over the under side of the beams, in which case they are termed *lap carlings.*

In some of the recent wooden ships of the Royal Navy, wood carlings have been fitted between the beams; angle-irons being fitted in the corners, riveted to the beams, and coach screwed to the carlings. To ensure a more rigid connection, an iron plate has been worked upon it, and riveted to the adjacent beams.

CHAPTER XIV.

212. We will suppose that the framing of the ship is completed; it now remains for us to clothe the ship's side, both externally and internally, also the deck beams with assemblages of plank, in such a way as to obtain the necessary longitudinal strength, and at the same time to make the ship watertight. The shelf and waterway, with the ekeings and deck hooks already alluded to, constitute a portion of these assemblages. It is, however, the planks proper that we have now to consider, and we will first notice

The Exterior Plank.—The *exterior plank* of our large wooden war ships was divided into a number of distinct assemblages, each having a special designation, and demanding separate consideration in a descriptive treatise.

Of late, however, many of these terms have become almost entirely forgotten from disuse, consequent upon the small size of the vessels of the Royal Navy which are being built of wood.

The changes in the ships of the mercantile navy have not been so great, and so we find that the names of the assemblages of plank, peculiar to them, remain the same as formerly.

The exterior planking of a ship of the line consisted of the *sheer strakes*, *channel* and *middle wales*, *black strake*, *main wale*, *diminishing plank*, *plank of bottom*, and *garboard strakes*, this list being given in the order of the respective assemblages, beginning at the topside (see Plate LXXIV.).

The sheer strakes were situated between the *planksheer* or *covering plank*, and the ports of the main deck. Below the latter, as far as the ports of the middle deck, the external planks were termed channel wales, as they received the fastenings of the chain plates and preventer bolts to the channels.

The middle wales were situated between the ports of the middle and lower decks, while the strake of plank, immediately below the lower deck ports was termed the black strake, owing to the fact of its upper edge, forming the boundary line of the portion of the ship below the fighting decks, being painted black. From the main wales the plank gradually diminished in thickness to that of the plank of bottom, the strakes in which the taper was worked being known as diminishing plank. The *plank of bottom* extended from the diminishing plank to the garboard strakes, the lower edge of the latter rabbeting into the keel. The planks between the ports were termed *short stuff*, being specially designated according to their situation; as for instance, *short stuff between main deck ports*, and so on.

As the most recent wooden war vessels have but two decks, and fight their guns on the upper one only, it is evident that a great many of the assemblages we have been referring to have no longer any place in the ship. At the present day we hear only of *topside planking, wales, bottom plank*, and *garboards*, with sometimes the addition of *diminishing plank* in the Royal Navy, and *black strakes* in the merchant service.

213. Disposition of Butts and Edges.—Before proceeding to plank the ship, it is necessary that a disposition of edges and butts should be prepared; these being set off either upon an expansion drawing or a model.

The wales are the first to be set off, as they have the same sheer as the adjacent decks; the space between the main wale and the keel having to be filled up in such a way as to give the least possible twist or curvature in the edges of the plank, and in every way to simplify the conversion of material and the work of fitting and securing the plank in place.

In a full-bodied ship it will be found impossible to continue the same number of planks right fore and aft, owing to the difference between the girth amidships and those at the extremities; and in every case there is a considerable reduction in the breadths of the planks before they terminate at the stem or stern. When it is necessary to reduce the number of planks for the above reason, the last plank of the strake which does not extend right forward or aft, as the case may be, is termed a "stealer."

The lengths of the planks composing the wales in a war ship were governed by the distance between the ports, as these planks were so placed as to give as good a shift of butts, with reference to each other and to the ports, as was possible. The lengths of the planks on the bottom were, and are now, regulated so as to suit the available stores of timber. They are always butted on the timbers of the frame, and in the Royal Navy three strakes are placed between consecutive butts on the same frame; the lengths of the planks are as great as is procurable, care being taken to avoid such a succession of butts as is suggested by the name "ladder step."

Lloyd's rules do not allow the butts to be nearer than 5 feet from each other, unless there is a strake wrought between them, and then a distance of 4 feet is allowed; and no butts are permitted on the same timber, unless there are three strakes between them. In ships of extreme proportions, the figures 6 and 5 are substituted for 5 and 4 respectively.

The wales and diminishing plank of the larger size of wooden ships of war, when of oak, were worked in what is termed *top and butt* and *anchor stock* fashions, this being done to aid conversion, as the shapes of the plank, especially by the former system, were more easily and economically obtained than if of parallel width. Plate LXXIX. shows a two port shift of main wale, worked top and butt fashion. The fore and aft length from A to B is one-fourth of BC, and the breadth of the butt is $\frac{3}{8}$ths the distance between the parallel edges. By the anchor stock style the widest part of the plank is at its middle, and the ratio of the width of the butt to that of the double strake of plank is the same as before. It is evident that this latter system is not so favourable to conversion as the former, and hence it was not so frequently adopted.

As we have already said, the disposition of the butts of the wales was governed by the spacing of the ports, so that the length of a plank was a multiple of the distance between the centres of consecutive ports. This is usually expressed by the phrases, two port or three port shift of wale. Plate LXXIX. shows a two port shift, which was the most common arrangement, as it was very difficult to get planks of the required dimensions for the three port shift. By reference to Plate LXXIX., it will be seen that there is at least two strakes between a butt and a port; by the three port shift another strake intervenes, thus giving a more satisfactory arrangement when it was obtainable. The butts of the black strake are placed between the ports, as shown, and the strake is parallel edged, as also are the remainder of the plank below the diminishing strakes.

214. Materials.—English oak was the principal material employed in planking the exterior of war ships from the topside to a short distance below the water line. Of late years, teak, Honduras mahogany, African oak, and greenheart, especially the first, have been largely employed.

Lloyd's rules permit a great variety of materials to be used in these as in other parts of the ships registered by them; the character and period assigned to the ship being dependent upon the nature of the wood, teak holding the highest position.

The bottom plank of ships of the Royal Navy, as far down as a few strakes above the garboards, is usually of Dantzic fir, or of some other wood of the fir species; the fore and after shifts, or "hoods," being generally of oak, in order to strengthen the bow and stern. Sometimes Canada rock elm is used for bottom plank, especially when extra strength is required, in consequence of its great toughness and durability when kept in sea water. The foremost and aftermost butts of bottom and side planking are known as *hooding ends;* they are terminated at rabbets in the stem and stern post, but under the stern they terminate at the knuckle in elliptical sterns, and at the margin on the wing transom in square sterns. In the ships of war recently built (see Plate LI., fig. 2), the hooding ends above the stern post are housed in the boxen left on the post timbers.

215. Fitting in Place.—As already stated, the wales are the planks first fitted to the ship's side; for, being opposite to the beam ends, they can receive the fastenings of the shelf and waterway, and so aid with these in keeping the ship to her form while the remainder of the plank is being fitted.

When it is not intended to fit a temporary keel—or, in other words, when the ship is built right off without allowing the timbers to remain and season in place, the garboards are fitted immediately after the wales, as by this means the binding strakes over the floor heads on the inside of the ship can be secured, and thus rigidly unite the frame timbers at their lower ends; besides which, the planking can proceed from above and below simultaneously, and so facilitate the work.

Before working the plank, the lines of their edges are rased in on the timbers by means of shearing battens, bent in the position indicated by the model or expansion drawing. This is especially the case with regard to the wales, as their edges should correspond with the sheer of the deck; and the appearance of the ship is considerably influenced by the character of their curvature. Care must be taken in rasing in these lines that the front, or sight edge, of the plank is the line drawn; as at the bow and buttock, where there is considerable twist in the surface, a very unsightly edge, and not the true sheer, would be obtained if this precaution were not observed. It is a very common practice to block off the batten to the thickness of the plank, and then square the edge on to the face of the timbers.

As will be understood by the preceding remarks, the edges of the plank are trimmed square to the surface of the timbers, this being expressed in technical language by stating that the "edges stand between two squares;" a little deduction is made from this angle to allow for the caulking seam, of which about $\frac{1}{16}$ of an inch is given to every inch the plank is thick, when the plank does not exceed 6 inches in thickness. The usual mode of determining the seam, adopted by the workman, is to set the two arms of his two-feet rule $\frac{5}{8}$ of an inch apart at their extremities, this gives rather less than $\frac{1}{16}$ of an inch seam for every inch in the thickness of the plank, the diminution being about $\frac{1}{8}$ of an inch in 12 inches.

The mode of taking account of a plank and of afterwards trimming it, is described at Arts. 246-248. For the extremities of the ship it is necessary to soften the planks by boiling or steaming in order to bend them to the great curvature at these parts. To further protect the plank from fracture when being bent, it is customary to place on its outer surface a thin plank of Canada elm, or other tough wood, termed a "backer;" this being very flexible, yields to the set of the shores, and by pressing tightly against the outside of the plank, it prevents the latter from splitting.

216. Fastenings.—The plank, having been trimmed, is lifted into place, and when tightened into its position by means of chains, shores, wedges, etc., it is secured temporarily by screw eye bolts (Blake's screws), the holes for these being bored at places where permanent fastenings will ultimately be driven, in order that the frames and planks may not be unnecessarily weakened. Before setting off the fastenings, it is necessary to bore off from the inside of the ship all the through fastenings for shelves, waterways, beam knees, etc., and to indicate by chalk marks on the plank where the iron riders and other iron work are situated, so that the fastenings may be set off clear of them. When the positions of the above-named fastenings are discovered, then the remainder of the securities of the bottom plank can be set off, these being regulated by the particular nature of the fastenings decided upon.

The principal modes of fastening are known as *single*, *single and double*, and *double fastening* respectively; and the materials employed are iron, copper, mixed metal, and wood. Iron, copper, and mixed metal are used in the forms of bolts and nails; nails of mixed metal being termed dumps, while wood fastenings are known as treenails.

Plate LXXX. shows the three kinds of fastenings named above, also the special form of single fastening termed *dump fastening*.

By Lloyd's rules single fastening is put into planks 8 inches wide and under, double and single fastening into planks above 8 inches and not above 11 inches, while double fastening is put into planks above 11 inches in width. There does not appear to be any stringent rule regulating the nature of the fastenings in ships of the Royal Navy; in which single fastening is by far the most common system employed. Indeed, it has been only in very large and heavily armed ships that either double or double and single fastening has been adopted.

Great variety exists in the relative proportions of the kinds of materials employed in plank fastenings. In the merchant navy, iron bolts and treenails are the most commonly used, although in the higher class of ships at Lloyd's, all the bolts, from the lower part of keel to the height of one-fifth the midship depth of hold below the upper side of the tonnage deck, and parallel thereto fore and aft, are of copper or yellow metal; while in the highest class, copper or yellow metal bolts and dumps are substituted for treenails, from the floor heads to the same height. Above this, all the fastenings may be of iron, if galvanized. The copper or mixed metal bolts and dumps vary in size from $\frac{5}{8}$ inch to 1 inch, and all through bolts are clenched upon rings on the inside or outside plank, while the dumps vary in length from 7 inches long in $2\frac{1}{2}$-inch plank, to 12 inches long in 5-inch plank, and so on, increasing 1 inch in length for every $\frac{1}{2}$ inch increase in the thickness of the plank.

However, these are simply conditions of classification, and the builder or owner is at liberty to decide what proportion of his fastening shall be treenail; being restricted only as regards the butts, each of which must be fastened by two bolts, one of which is through and clenched, a year being deducted from the ship's period when the latter condition is not fulfilled. It should be observed that one of these bolts is placed through the butt timber, and the other in the timber adjacent to it. The rules further require that two-thirds of the bolts and treenails shall be driven through, the former being clenched on rings, and the latter caulked, and so wedged, upon the outer and inner plank.

In the Royal Navy, the proportion of bolts to treenails in the fastening of plank, while varying according to the size and armament of the ship, is generally greater than in the merchant service, although a fastening composed of all bolts is rarely, if ever, adopted. The ratio of four treenails to one bolt is that most usually observed, although a greater number of bolts are sometimes employed. In some corvettes now being built, the ratio is two treenails to one bolt, the fastening being single. In dump fastening, shown on Plate LXXX., four dumps are driven to one bolt. It is hardly necessary to state that these proportions are irrespective of the butt fastening, which invariably consist of two ing of the side. Special care is required in driving treenails in order to avoid "crippling" them, as in such a case it is impossible to drive them any further, and they must be either driven or bored out, and their places supplied by others, which are generally less efficient than if driven through in the first instance. Treenails should be of well seasoned, sound oak timber, and cut with the grain; for if the fibre is cut across it is impossible to obtain an efficient fastening.

217. The Garboard Strakes.—Before concluding our remarks on the external plank, it is necessary that we should briefly notice the garboard strakes, inasmuch as they possess certain features which distinguish them from the remainder of the bottom plank. Formerly, the bottom plank was of uniform thickness throughout; but, in order to aid the keel and keelson in offering the necessary resistance to sagging strains and render the bottom less penetrable, the late Mr. Lang introduced what were termed "safety keels," and are now known as "thick garboards" (see Plates X., XII., LXXIV., and LXXV.). Sometimes the planks are rabbeted together at their edges, at others the edges are plain. In the former case, the rabbet forms a stop for the caulk, and it is usually situated at about the thickness of the bottom plank from the outside surface of the garboard.

The garboards are of English elm; they terminate at the angle of floor, being at that place of the same thickness as the bottom plank. As the extra thickness of the garboards, beyond that of the bottom plank, is obtained by raising the bearding line of the square body to within about $1\frac{1}{2}$ inches of the top of the keel, it consequently follows that where the cants commence to heel against the deadwood and keel at the correct bearding line, the extra thickness will suddenly stop. This has been met in two ways: in some cases by snaping away the heels of the cants to the height of the bearding in the square body, continuing the snaping until the angle of floor entirely disappears, as shown by square station No. 6, on Plate X.; while in other cases the garboards have been scored over the cant body frames. The mode of fastening the garboards is shown by fig. 2, Plate X.; the horizontal bolts are driven in the wake of the openings between the frames so as to avoid the other fastenings—they are spaced about 8 to 10 feet apart. The other bolts are driven in every timber as in single fastening.

It is not at all a usual thing to find thick garboards fitted to merchant ships, although they are sometimes worked in long vessels. Lloyd's rules require that, when fitted, they shall be bolted horizontally through the keel and each other.

218. Interior Plank.—With regard to the interior planking of war ships, even greater modifications have been made of late years than in the planking of the exterior; this being due to the extensive employment of iron in the internal strengthening of those ships. Formerly, the several assemblages of inside plank of a ship of the line were known as *clamps, quickwork, abutment pieces, spirketting, thick strakes, side keelsons,* and *limber strakes;* all the plank below the orlop deck clamps being collectively termed *footwaling.* In addition to the above were the *shelves, waterways,* and *trusses,* which have already been noticed, and do not strictly come under the heading of plank. At one time *clamps* were fitted in lieu of the several lines of shelf, but at present the term *clamp* is applied only to the thick strakes immediately below the shelf when there are no ports in the way.

Quickwork was the name given to the inside plank between the ports; while abutment pieces and trusses were the portions of truss framing, sometimes fitted between the ports in lieu of quickwork. The abutment pieces were vertical and formed the sides of the ports; while the trusses were fitted diagonally between them, the whole being bounded on the underside by the spirketting, which is the name still given to the strakes immediately above the waterway. The spirketting was frequently dowelled to the timbers, as shown by fig. 24.

The thick strakes were plank fitted over the heads and heels of the frame timbers, and the truss framing of the hold was fitted between them. Before the introduction of iron longitudinal ties,* in lieu of wood binding strakes, and after the truss framing was superseded by iron riders, it was customary to fit diagonal ceiling or footwaling in the manner shown by Plate XII.

The side keelsons were thick longitudinal timbers fitted at short distances on each side of the keel, in the wake of the

* These are termed "iron binding strakes."

masts; and in long steam ships they were continued fore and aft for a considerable length of the ship.

The limber strakes (see Plate X., fig. 1), while constituting a longitudinal tie over the floors, served also to form water-courses on each side of the keel, leading to the pumps; the spaces above the fillings, in the openings between the frames, constituting corresponding transverse courses. These water-courses were covered by *limber boards*, as shown by Plate X., to keep the stores or cargo from damage by contact with the bilge water. The limber strakes were secured by bolts which, when possible, passed through and were clenched upon the garboard strakes.

219. Iron Longitudinal Ties.—In war ships at the present time, the lowest assemblages are superseded by iron binding strakes, as shown by Plate LXXV. As will be seen, these consist of an iron plate through bolted to the timbers and bottom plank; being stiffened and strengthened by a T iron riveted to its inner side. The butts of the plates and angle-irons are carefully shifted clear of each other, and butt strapped.

220. Fastenings.—The inside plank is chiefly fastened with the same bolts and treenails that secure the plank of the outside. Lloyd's rules require that at least two-thirds of the bolts and treenails, securing the outer plank, shall be driven through the interior plank, clamps, etc.

The inside planks are trimmed similarly to those of the outside. If possible, the interior and exterior plank should be fitted simultaneously, in order that the fastenings may be squared off readily.

221. Deck Plank.—The *deck plank* bears the same relation to the beams of a wood ship that the plank of side does to the frames. This was especially the case in the long frigates of a few years since, prior to the introduction of iron beams, stringers, deck plates, etc., into wood ships. In those vessels it was a very usual practice to fit strakes of oak plank, about one inch thicker than the remainder of the deck, the extra thickness being scored down over the beams in some instances, and, in others, allowed to project above the adjacent deck, dowels in the beams being substituted for the scoring. These *binding strakes*, as they were termed, were two or three in number on each side of the ship, situated along the sides of the coamings, being the nearest continuous strakes to the middle line. Their butts were placed as far away as possible from large hatchways, mast holes, etc.

222. Diagonal Decks.—About a quarter of a century ago, the decks of ships were frequently laid diagonally, the edges of the planks making an angle of about 45 degrees with the middle line; their midship butts rested upon fore and aft carlings, and against binding strakes as already alluded to. The side ends were butted against the thin waterway, and were fastened to the *side letting down* or *binding strakes* shown by fig. 25. Considerable transverse strength was obtained by fitting deck plank in this manner; besides which shorter plank could be used than by the ordinary longitudinal arrangement.

223. Shift of Butts.—The shift of butts of deck plank adopted in the Government service, and required by Lloyd's rules, is the same as that given to bottom plank, and which has already been referred to.

The planks are always butted on beams, except when deck plating is fitted upon the latter, in which case this rule is generally deviated from, as the flanges of the beams are very much weakened when the fastenings of both deck plank and deck plates are placed through them.

224. Materials.—The lower gun decks of line of battle ships were of Dantzic oak 4½ inches thick, the main deck (and middle, if any), of fir 3½ inches thick, except twelve strakes from the side, which were of oak. The upper deck, orlop deck, poop, and forecastle, were of 3-inch Dantzic fir.

In all these decks, exceptions were made in the case of binding strakes as already mentioned. The lower decks of frigates were of 3-inch fir, and the upper decks of 4-inch fir, except 9 strakes from the side, which were of oak, and the binding strakes as already referred to.

The upper decks of war ships are now usually of teak, in consequence of its great strength, durability, freedom from shakes and from shrinkage, as well as its superiority over oak, viewed with regard to the injurious action of the juices of the latter wood upon iron work. It is also so far preferred by Lloyd's committee over other kind's of wood for deck purposes, that they allow a reduction of one-sixth the thickness for decks of teak. We may here remark that, by the rules of the above society, the thickness of upper deck plank varies from 2½ inches for ships of 50 tons and under, to 4 inches for ships of 700 tons and upwards, when other than teak plank is employed. They also require the plank to be renewed when about one-fifth its original thickness is worn away.

225. Thin Waterway.—The strake of deck plank nearest to the waterway is termed the *thin waterway*. It follows the curvature of the side similar to the waterway, and is somewhat thicker than the deck plank, in order that it may conform to the shape of the waterway at the joining rabbet. The butts of the deck plank, where they snape against the thin waterway, are scored into it in such a mannen as to give an efficient caulk, the latter not being obtainable when the deck plank snapes off to a "sliver edge." The minimum abutment allowed for caulking is about 2 inches (see fig. 27). The thin waterway is usually made of oak or teak.

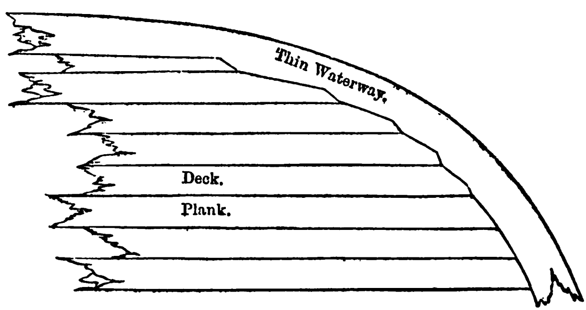


Fig. 27.

226. Fairing the Beams.—Before laying the deck plank, it is necessary to rectify the beams by shoring them to their proper round up, and with their sides in planes. This being done, the beams are firmly secured in their position by a ribband of fir quartering, which is secured by screw eye bolts to the under side of the beam at the middle line, this ribband being continued the whole length of the ship, the several lengths lapping against each other. The ribband is supported by shores the upper ends of which are nailed to the ribband, and their lower ends secured by a rope grommet.

After this the upper sides of the beams are trimmed fair, a batten being used in proving them; whereupon the deck plank can be laid.

227. Laying the Deck.—Great care should be taken in laying the deck plank, as when irregularly or carelessly laid, it presents a very unsightly appearance. The edges should be fair from end to end, but not necessarily straight, as sometimes it is considered advisable to taper the strakes towards the bow in a curvilinear manner, in order to neutralize the optical illusion of curved deck edges, which is produced by parallel straight seams approaching a side of considerable curvature. However, whether straight or curved, it is highly necessary that the edges should be fair.

This is very much more difficult to obtain with crooked and stiff oak plank than when fir plank are used. The usual practice is to select a sufficient number of fair and suitable plank to complete three or four strakes of deck throughout the whole of its length; and these are first laid in their proper position and secured, thus forming a strong resistance against the efforts of the more crooked plank to recover their shape, which are afterwards laid. Great precautions are, however, necessary to prevent unfair seams in the subsequent operations of laying the deck.

It should be stated that the deck plank is laid in accordance with a sketch on a board showing the disposition of the edges and butts.

It is the practice in some private establishments, when yellow pine decks are laid, to get at least four strakes in position at once, and then to make these fair, and fasten them collectively. By so doing very fair and even seams are obtained.

228. Fastenings of Deck Plank.—The deck plank is connected to wood beams by nails, and, in the merchant service, sometimes by treenails; the latter practice having been far more common formerly than at the present time.

The nails in the upper decks of war ships are of mixed metal, and are termed dumps; in the other decks they are of iron. Wooden plugs, cut across the grain, are driven closely and neatly over the heads of the fastenings after the latter are punched well beneath the surface. Two nails or dumps are placed through each plank, securing it to each beam. When treenails were employed, one of them was put through each plank into each half beam. In all cases the butts were fastened by nails. The same amount of caulking seam is allowed for decks as for the plank of side of the same thickness.

The manner of fitting and fastening deck plank on iron beams, stringers, and deck plates, being the same as in iron ships, further reference to this subject will be found at Art. 321.

CHAPTER XV.

229. Pillars serve the twofold purpose of keeping the beams to their correct curvature, and so prevent water from lodging on the deck, and to assist the beams in supporting their loads by transmitting the thrusts of the latter throughout the structure. The second is by far the most important function.

Where possible, pillars are placed under the centres of the beams, in order to obtain their maximum efficiency; also immediately over or under each other, so as to transmit the thrusts in a direct line.

When the circumstances of the case will not allow of either or both of these conditions, then the pillar is placed where convenient, and its supporting aid is given to two or more beams by means of a lap carling.

Pillars are also placed under the long fore and aft carlings by the sides of large hatchways, and in this position it is sometimes necessary to make them portable or swinging, in order to leave a clear space when a large bulk is being passed from the deck through the hatchway. The same thing is necessary in the wake of capstans, in order to provide a clear space for the revolution of the capstan bars.

Formerly the pillars were of wood, being made of some ornamental form in a lathe when required for the lower deck and upwards; below this they had simply their corners champhered off. They were fitted so as to chase or tenon into the under side of the beam, and tenoned into the deck flats and keelson.

These were superseded by solid wrought-iron pillars, which are stronger and more durable than the others, besides giving greater facilities for security to the deck. When portable, the pillar revolves about a pin in its head and its heel is bevelled so as to allow of its being tightened, by driving it over a wedge-shaped iron shoe, screwed to the deck below, until the pillar receives its due share of the weight of the deck. It is evident that these portable pillars do not offer any resistance to the lifting tendency which a deck sometimes has, especially when heavy guns are fired over it.

Iron tubular pillars are now very commonly used, especially in the Government service, as their combined lightness and efficiency give them considerable advantage over solid iron pillars. Further particulars regarding pillaring will be found at Art. 315.

230. Bulkheads is the name given to all the wall-like portions of the interior of the ship, which serve to divide it into compartments. Until of late years these have all been of wood, the thickness varying, according to the purposes for which they were intended, from 3 or 4 inches in the hold to $1\frac{1}{2}$ inches for the cabins and rooms between deck. The wood bulkheads (with the exception of those for the cabins, which are panelled) consist simply of a cant above and below, and vertical plank grooved and tongued together at their edges and nailed to the cants, being also tie-bolted where necessary. The ends and edges are "chinsed" or lightly caulked, as also are the cants, but these precautions cannot be depended upon for making absolutely watertight divisions of the spaces in the hold.

Of late years iron watertight bulkheads have been fitted in wood ships, especially those in H.M.'s service. These bulkheads are important, considered structurally, as well as on account of their use in dividing the ship into watertight spaces. They are constructed similarly to those of an iron ship (see Art. 312), the difference being, of course, in the mode of connecting them to the sides of the vessel. This latter is very simple, consisting simply of an angle-iron on each side of the bulkhead, which is riveted to the latter and bolted to the ship's side. Sometimes the connection has been obtained by means of an angle-iron on only one side of the bulkhead. The bolts are of copper, one in each plank, clenched on the outside plank; and very frequently *coach screws* are placed between the bolts. The rivets in the angle-iron and plates are spaced about four or five diameters apart, so as to secure watertightness; the angle-irons are iron caulked, and oakum is driven between them and the inside plank.

Partial bulkheads, similar to those of an iron ship, are sometimes fitted between the decks, the connection with the ship's side being the same as just described.

The iron bulkheads in hold, for magazines, etc., are constructed similarly to those of an iron ship.

Iron is as yet rarely, if at all, employed for the bulkheads of wooden ships for the merchant service.

231. Channels.—The masts are assisted in resisting the strains brought upon them by the rolling of the ship, and the pressure of the wind upon the sails, by means of an assemblage of ropes upon each side, termed *shrouds*, which are set up to *dumb blocks* or *dead eyes*, the latter being secured to the ship's side with bolts through *chain* and *preventer plates*. The *dead eyes* are kept sufficiently far off from the side to enable the shrouds to clear the hammock berthing by means of horizontal outriggers, termed *channels*. In narrow ships the channels serve also to give sufficient spread to the shrouds to enable them to efficiently resist the transverse strains upon the masts. When the ship has considerable beam, the breadth of the channel is kept within reasonable limits by giving a "tumble home" to the topsides (see Plate LXXIV.).

The upper bar, reaching from the edge of the channel to the ship's side, is termed a chain plate, from the fact that chains were originally fitted for this purpose. Hence the channels were known as the *chains*, a name sometimes given to them at the present day.

The lower bar, which is fitted to give support to the bolt in the lower end of the upper bar, is known as a preventer plate.

The channels were formerly placed at the height of the upper deck beams, and this position is still retained in cases where there is considerable tumble home to the top sides, or the latter are low. Of late years they have been to a great extent dispensed with, especially in ships not having full sail power; and in such cases the chain plates have been secured to the side of the ship so as to bring the dead eyes at the inside of the bulwarks, at the height of the waterway, or else on the outside of the ship at the same height, the bulwarks in the latter case being substituted by guard stanchions and rails.

In the small wooden ships of the Royal Navy, however, they are now usually placed just below the berthing, as shown by Plate LXXV., consequently, there is no necessity for the great amount of tumble home in the sides of these ships.

The fore end of the channel is situated at about abreast the mast, so as to allow the foremost dead eye to be a little abaft the mast. The length of the channel is so adjusted as to provide space for a dead eye to every shroud; and, in addition to these, for dead eyes to the topmast, and top gallant and royal mast backstays; although in some cases separate small channels or *stools* are placed abaft the channels for this purpose.

The channel is built of oak, or other hard wood, the pieces being dowelled together and secured to the ship's side with iron through bolts, placed about 3 feet apart. After the chain plates are fitted in the scores cut for them in the front of the channel, the edge is finished off by a piece of moulding, generally of Canada elm, termed the *channel rail*, which is secured to the channel by iron straps, fastened by forelocked bolts, so that the *rail* may be readily removed when necessary.

The channels are supported by what are termed T plates, in consequence of their being made somewhat in the form of that letter. These T plates are sometimes fitted in two different ways to the same channel; one kind being made so as to prevent the channel from lifting, and the other in order to support it. In the former case, the horizontal arm of the T is above, and the vertical arm passes through the channel also through a hole in an iron plate below it, the end of that arm being secured to the ship's side. The horizontal arm and the iron plate below the channel are connected by through bolts. In the latter case, the horizontal arm of the T is fitted below the channel and the plate of iron above. A lug, in connection with the horizontal arm, passes through the channel and the iron plate above it, the whole being bolted together, and further secured by a forelock through the lug. It may be observed that this lug is forged to both kinds of plates, being utilised by fitting a shackle bolt in it for occasional service in connection with the rigging.

Latterly, however, the chain, preventer, and T plates have been frequently made in one forging, as shown by Plate LXXV.

Chain plates, etc., are, in almost every case, made portable. In order to obtain this quality, several expedients have been adopted, but in all these there is a common feature, viz.:—that the lower bolts are driven outwards from the inside of the ship, the preventer plate being kept from slipping over the points of the bolt by means of a forelock. In some cases this forelock is driven through a groove cut in the plate, in others it is protected by forming the preventer plate in the manner shown by Plate LXXV., so that a portion of the plate covers the point of the bolt. The common practice at the present day is to drive both the upper and lower bolts from the inside of the ship, and secure them by nuts on the outside.

The method of making the chain and preventer plates portable, as shown in Plate LXXIV., has the merit of being rather ingenious, and has been long in use in the Royal Navy. The lower or preventer bolt is driven through from the inside and secured by a forelock. The upper bolt is driven from the outside, and has an oval head with flat sides, the flat sides being placed in a fore and aft direction. This head bears upon a thin plate or washer, with an oval slot cut in it large enough to allow it to be placed over the head of the bolt, and then turned down in such a position that it will not drop off; it is then fastened to the plate by a small tap rivet. The bolt is driven so as to bear slightly on this plate.

To remove the chain plate:—first, take out the rivet, turn the washer round until it drops over the head of the bolt, then knock out the forelock to preventer bolt and relieve the preventer plate, when, owing to the looseness occasioned by removing the washer, the preventer plate can be lifted over the point of the preventer bolt, and then revolved until the slot in it can also pass, like the washer, over the head of the upper bolt. By taking off the channel rail, the chain plate can be at once removed.

Dumb blocks made of malleable cast-iron, coated with zinc, have lately superseded wood dead eyes, especially in the Royal Navy.

The chain and preventer plate is placed in the direction of the shroud it secures, wherever possible, that evidently being the position in which it acts most efficiently.

232. Knee of Head, etc.—This fitting, once a common, and indeed almost an essential, feature of a ship, is rapidly disappearing. Now that ships are built very long, and steam power is superseding sail power in their propulsion, the knee of head being greatly in the way when warping about in confined spaces, such as rivers and docks, and being no longer needed in consequence of the reduction in the amount of sail, straight stems are more commonly met with than otherwise. The preceding remarks apply chiefly to iron ships; but in wood ships, whenever a contour is given to the outline of the bow, it is done by making the stem to the required curvature rather than by fitting an additional knee of head. By this method, the plank being ended at the stem, the cheeks and head rail, formerly placed to give lateral support to the knee, are now dispensed with. A very large forcastle deck can be obtained in this way, which, besides being useful in working the head sail and lifting the anchor, also gives commodious berthing place beneath it for the crew, thus leaving a greater portion of the interior space available for cargo. Of course the seat of ease accommodation must be found elsewhere.

Under the term *head of a ship*, was included all those parts forward which were situated outside the contour of the body, and it was designed to improve the appearance of the structure, to give good security to the bowsprit, and to afford accommodation for the crew.

It consisted of the knee of the head, which may be looked upon as a continuation of the stem; of the *cheeks*, which acted as knees to the knee of the head, connecting it to the body; of the *rails*, which acted as shores to the knee at its extremity; of the *head timbers*, which by resting on the cheeks shored up the rail; of the *cross pieces*, which kept the rails in their proper places, and acted as beams to them; of the *fore and aft carlings*, which tied the cross pieces together, and formed supports for the *seats of ease* which were fitted up in the head; of the *bolsters* and *hawse pipes* between the cheeks, to take the rub of the cable; and, finally, of the *figure*, which surmounted the fore extremity of the knee, often adding much to the beauty of the head or fore part of the vessel.

The knee of head (Plate LXXXI.) was composed of four principal pieces: 1. The *stem* or *independent piece*, after being trimmed and fitted to the other pieces, was fitted, dowelled, and bolted, independently, to the stem; some of these bolts being placed through the deck and breasthooks, so that the knee of head proper could be removed without interfering with the fastenings in these hooks. 2. The *lace piece*. 3. The *bob stay piece*, which formed the front of the knee, and tenoned into the independent piece at its lower end; it took its name from the holes bored in it to take the *bob stays*. 4. The *gammoning piece*, which was fitted on the upper part of the knee in order to secure the *gammoning* of the bowsprit; this piece was dovetailed into the independent piece, and also had a tenon in the heel. The remaining parts of the knee were mere chocks to the other pieces, and their disposition was determined so as to best suit the timber in store.

All the pieces of the knee were dowelled together, the dowels were placed about 18 inches apart, and the several pieces were treenailed together before the knee was hoisted up. The knee was finally secured to the stem with bolts which passed through the knee, stem, apron, and stemson, these being arranged to form good ties to the butts, and were clenched on the inside. The upper bolts were usually of iron in large vessels.

The Cheeks (*A*, Plate LXXXI.) extended to the aft side of the hawse holes, and three or four feet, or as much farther as possible, on the knee. To trim the cheek, see Art. 245. They were fastened to the side with one bolt in each timber, clenched on the inside, and to the knee by bolts which went through the cheek on the opposite side. The bolts were driven from alternate sides, and clenched on the other cheek.

The Rails (Plates XLIV. and XLV., and Art. 103).—The *main rails* extended generally from the catheads to the lace piece, and formed shores to the extremity of the knee. They were secured, by the aid of corner chocks, with two bolts at each end. An iron knee embraced the two rails at the fore end, and was secured with three bolts through the rail, and two short bolts in the lace piece.

The *berthing rail*, which was the uppermost rail in the ship, was let into the lace piece, and had an iron knee at the fore end embracing the rails on each side. It also abutted against the cathead, and an iron knee connected it with the cathead and ship's side.

Rabbets were cut out of the upper edge of the main rail and the lower edge of the berthing rail, into which the berthing between them was fitted.

Head Timbers.—Immediately on the cheeks, and butting against and under the main rail, timbers were fitted which acted as supports to the rail. These timbers were bolted through and through, with one bolt in every two opposite timbers, and to the cross piece with one bolt which was clenched. There were always three timbers, the foremost having the most rake, and the after one the same as the stem. Abaft each timber, to which it fayed, was a *cross piece*, the upper side of which was level with the upper part of rail, and curved upwards in the middle, forming a beam to the rails. It was let into the rail with a double stop, and was fastened to it with two bolts driven from the upper side. Fore and aft pieces again connected the cross pieces together, and formed the framing for the seats of ease, etc., which were placed in the head.

The middle and small rails had their lower ends forward resting on the hair bracket (or continuation of the curve of the cheek), and their after ends simply butted against the side. They were let into the head timbers and were fastened to them, and at their extremities with bolt nails only.

The preceding is a brief description of the head of a first-rate; the same principle was carried out in smaller ships, there being of course a fewer number of cheeks and rails in the latter. Plate LXXXI. shows the knee of head of a modern corvette.

233. The Rudder.—It need hardly be stated that the use of the rudder is to govern the direction of the ship's motion through the water, the operation of so doing being termed "steering." Fig. 1, Plate LXXXII., shows the style of rudder which was adopted in war ships of the Royal Navy, until within the last twelve years, and which is still used in wooden merchant ships. Fig. 2 on the same plate shows the most recent form, and the mode of constructing the rudder of wooden and composite war ships.

In each of these it will be seen that a line through the centres of the pintles, is also the centre line of the rudder head. In Fig. 1 is seen the manner in which this result is obtained when the rudder head is of wood. When it is of mixed metal, as shown by fig. 2, similar means are employed, the end being, however, more satisfactorily attained, owing to the greater facility with which the required form and strength can be obtained by casting metal, than by cutting and trimming timber. Formerly, the fore side of the rudder was straight, and hence the centre line of pintles, about which the rudder revolved, was at a distance about equal to the radius of the pintle on the fore side of the rudder head. It is evident that a large hole was necessary in order to allow the rudder to turn through the required angle, and the difficulty of making this watertight (leather being usually employed), led to this mode being given up in favour of that shown in fig. 2, Plate LXXXII.

The portion marked *A*, known as the *coneing*, serves to graduate from the size of the rudder head, to that of the boss *B*. This *coned* portion fits into a corresponding cavity wrought in the rudder post.

The rudder, fig. 1, is formed of the following pieces:—The main piece *C*, which is of oak; the fore piece *D*, which is generally of elm, and is fitted to receive the *gulleting E*, *E*, and so prevent the main piece from being wounded more than can be avoided. The pieces *F*, *F*, etc., are of fir, or some other light wood; being fitted simply to make the rudder to the required shape. The sole piece *G* is generally of elm, and but slightly connected, in order that the rudder may be readily relieved, by this piece coming off, in the event of the rudder taking the ground. The pieces *F*, *C*, and *D* are dowelled and bolted together. It should be remarked that the arrangement of these pieces is not at all arbitrary, but is left to the discretion of the builder, or governed by the materials at hand, and the shape of the rudder.

The hinges (Plate LXXXIII.), about which the rudder revolves, consist of pintles connected by metal straps to the rudder, being through bolted from side to side; and braces or gudgeons similarly fastened to the rudder post.

Sometimes the pintles are cast with the metal straps, but in the Royal Navy the pintles are portable, and, when worn, can be removed and replaced by unbolting and taking off the strap (see Plate LXXXIII.). In order to ship and unship the rudder, scores are cut below the pintles, and spaces allowed between the latter and the rudder; these spaces are termed the *gulleting of rudder*. The length of the score is a little more than one inch greater than the depth of the brace.

To prevent the rudder from being unshipped when struck by a sea, a piece of wood termed a *wood-lock* is placed in the gulleting of the upper pintle, and fastened by nails, so that it can be removed at pleasure. The portion *B, B*, fig. 2, Plate LXXXIII., cut away to allow the rudder to revolve, is called the *bearding;* it is generally sufficient to admit of a revolution of ·45° each way, as the angle of maximum efficiency is just within these limits.* *H, H*, etc. (Plate LXXXII.), are iron hoops driven over the rudder head, when at a high temperature, and then shrunk by pouring cold water over them; this being done to prevent the head from splitting. The spaces between the hoops are filled up flush with short pieces of batten.

An iron forging, termed a "spider," with a square hole or a socket in the top to receive the *norman head*, is let down over the top of the rudder, being secured to the latter by means of four arms bolted to the head, and further connected with at least two of the iron hoops just referred to passing over them. A hole is cut through the rudder head, between the two upper hoops, and an iron socket is fitted in it to receive the tiller for steering the ship. The hole is cut in a fore and aft direction, and tapered in order that the tiller may be keyed, whether the latter is at the fore or after side of the rudder. The norman head, which fits in the socket

* The usual working limits of the rudder is considerably less.

on the upper end of the rudder, is used for steering the ship on the deck above that at which the tiller is employed.

At K is shown a shackle plate to receive *rudder pendants*, which secure the rudder to the vessel in the event of the former becoming accidentally unshipped; besides which, the rudder has sometimes been steered by the aid of the pendants when the regular steering gear has been carried away or otherwise injured.

The rudder, shown by fig. 2, Plate LXXXII., is that now used in H.M. service. The brass casting A is fitted and bolted to the rudder, and the upper pintle is connected to it, so that the chief strains are borne by metal, rather than by a main piece of wood as in the older method. The simplicity and strength of this rudder, as compared with the other, are obvious; besides which, owing to the portion of the rudder which enters the ship being much nearer the water than formerly, this form of head offers far superior advantages for making watertight, by means of packing in a stuffing box and gland, than the older wooden rudder head.

The method of setting off the *bearding* claims some notice before dismissing this subject. It will be seen by fig. 2, Plate LXXXIII., that although the line through the centres of the pintles C is the axis of rotation, the sides *aa*, *bb*, of the bearded portion of the rudder do not radiate from this line of centres, but from the fore sides of the pintles. This is done in order that the braces on the rudder post may be placed further aft, and so reduce the amount of wood which must be cut out of the latter for the boss B to work in; this being especially desirable at the lower end of the post, which, being of less siding than elsewhere, would be cut off to a sliver edge on each side, if it were bearded from the centre of the pintle.

CHAPTER XVI.

234. **Trimming Timbers.**—We purpose discussing in this chapter the methods adopted in "trimming" or fashioning a log of timber to some of the principal forms required in building a ship. In practice, the term "trimming" includes the process of "lining" the log, as well as the more mechanical operation of removing the superfluous wood with axe, adze, etc. It is in the former sense only that we can consider the subject, as it is this portion of the work which involves thought and ingenuity; skill in the use of tools being acquired by practice only.

Nearly all the timbers constituting a ship are such that cross sections of them are quadrilaterals, generally parallelograms. Also, the majority of the timbers have their opposite sides parallel, at least two of these being generally plane surfaces.

As a result of the above conditions, the processes of trimming the several timbers of a ship are comparatively simple, and consist of the four following principal operations, viz.:—

1. Obtaining a fair surface, generally plane, on one side of the log.
2. Moulding the piece by applying the mould, and then marking by or setting off the curvature.
3. Trimming the two sides adjacent to the first by the aid of bevellings.
4. Setting off the fourth side, if any, parallel to the first, or at any required variable distance therefrom.

It may be remarked that the piece of timber supplied to the shipwright is roughly cut to the required shape by the sawyer, so that the former can generally tell at a glance upon which side of the log the mould is to be applied.

235. **A Plane Surface,** technically termed "straight and

out of winding," is obtained by striking a line along the side of the piece of timber at the required position of the plane surface. A straight-edged batten is nailed against the end of the timber, with its straight edge coinciding with the line just struck. The workman then removes the wood above the line until the edge of a straight batten, held everywhere along the trimmed surface of the timber, is in the same plane as the edge of the batten nailed to the end of the timber. The battens, when in the position just stated, are said to be "out of winding."

236. A Twisted Surface, technically termed a "winding surface," may be straight along one or both edges, or may be curved; in either case the curvature (if any) of an edge is set off (see Plate LXXXIV.). The bevelling spots are also marked, and a straight-edged batten *ab* is nailed across an adjacent side at the middle bevelling spot (see fig. 1 on the plate). A long-armed bevel, termed a "French bevel," is set to the several bevellings of the twisted surface, and the wood is then removed on the side which is being trimmed as far as the edge lined off, until the long arm of the bevel, when held successively at the respective spots, is out of winding with the straight-edged batten, while at the same time the stock fays against the trimmed surface, the bevel being held square to the edge; see fig. 2, where $a_1b_1c_1$ and $a_1b_1d_1$ are the bevellings at c and d respectively. The line a_1b_1 represents the batten ab and the arm of the bevel at the several bevelling spots, the two being out of winding.

237. To Trim a Piece of Timber with Straight Siding and Curved Moulding.—Secure the piece upon blocks, at a convenient height for trimming, in a vertical position, with the convex side nearest the ground.

1. Hold a straight-edged batten, vertically, against each end, as near as possible to the side upon which the mould is to be laid, so that lines joining the outer edges of the two battens, both above and below, may be everywhere within the log. Adjust the battens so that their edges are out of winding. Then, still looking these edges out of winding, determine points along the upper side of the timber which are in a line with the edges of the battens; and strike a

line* along the upper side joining these points. This line will be one edge of a plane surface. Set off the siding of the timber from this line square to the edges of the battens, and strike a line joining the siding spots; champher the edges away to these lines, and remove the surplus wood with axe or adze.

2. Turn the timber over, having previously rased the positions of the battens over the ends; repeat the operation of looking in points and lining the side, also of setting off the siding. Trim the two sides down from these lines to the champhered edges. We have thus two plane sides to the timber, and, if the sidings are uniform, the sides are also parallel. In its present state the timber is said to be *sided.*

3. For *moulding* the curved shape of the timber: supposing it to be a portion of a ship's frame, a mould is provided from the mould loft, having the several heads or sirmarks (or bevelling spots) marked upon it (see Art. 41).

This is laid upon the moulding or joint side of the timber, being kept sufficiently *on* upon the surface to allow wood for obtaining the necessary bevellings; also due regard is had for the required length of the timber. In some cases, when concave curvature is given for convex timbers, as cant moulds, for instance, the mould is held *off* the timber, and the curvature is then copied by spiling (see Art. 68). When the curvature is rased in and the positions of the bevelling spots transferred, the mould is removed, the mouldings of the timbers are set off (see Art. 47), a thin batten is bent so as to pass fairly through the spots, and the line so found is rased in.

Then copy the bevellings from the bevelling board, care being taken to reverse them if the bevellings are to be standing (see Art. 44), unless the timbers are cants, in which case they are to be used as supplied (see Art. 66).

Set a bevel to each of these bevellings in succession, and apply the bevel on the moulded edge, square to the curve and to the edge of the timber at the respective bevelling spots. Hold the bevel so that its tongue just touches the

* This must necessarily be done in short lengths, owing to the curvature of the side.

timber; measure with a pair of compasses the distance between the tongue and the moulded edge, and set this distance in upon the timbers on the opposite side, measuring from the tongue. Bend the thin batten so as to pass through all the points so obtained on the side opposite to the moulded side, and rase in the line. Trim down the curved side of the timber straight from line to line, and the outer surface of the timber will be to its required shape. The inside surface is trimmed parallel to the outer, and through the line obtained by setting off the moulded scantlings. Frame timbers, beams, stem, apron, deadwood, stern posts of screw ships, fore piece of keel, etc., are trimmed in this way.*

238. A Timber having Straight Siding and Moulding is trimmed by a simple and obvious modification of the preceding method; it being evident that the only difference consists in striking straight lines upon the plane surface, instead of marking by a curved mould. The keel, stern post, etc., of paddle and sailing ships are examples of this kind.

239. To Trim a Knight Head *when it fays against the stem, or to trim a stem piece when the latter is fitted* (see Arts. 97, 98, and 99; also Plates XL., XLI., and XLII.).— The information usually furnished to the workman consists of a mould to that side of the timber which fays against the stem, and section moulds at certain level lines, the positions of which are marked upon the mould to the side of the timber. As already stated in the above-mentioned Articles, bevellings at harpins and sirmarks are sometimes provided, in which case the positions of these diagonals are marked upon the moulds. The sectional moulds, however, are quite enough, and indeed preferable to the bevellings.

The fore edge, which coincides with the bearding line, is the moulding edge of the timber, and the after edge of the side faying against the stem coincides with the cutting down line. Fig. 2, Plate XLII., shows a stem piece mould.

To trim the timber.—First trim the side, which fays against

* It is necessary to state that all these timbers, except the frames and the pieces of body post, have square bevellings; also, the beams, stem, keel, etc., are sided from a middle line struck upon the timber.

the stem, straight and out of winding* (see Art. 235), after which place the mould upon the piece, and mark by the two edges together with the positions and directions of the level lines.

Should bevellings be the data provided, then the several heads and sirmarks, at which bevellings are given, should be marked upon the mould. The shape of the outside of the timber is then obtained by trimming through the angles of bevelling, at the level lines or other bevelling spots, on the moulding or fore edge of the timber. If the sections are used, then the bevellings are the angles *ACB* (Plate XLII.), and are to be applied in the directions given by the level lines on the mould. But if the bevellings are given at the heads and sirmarks, then they have to be applied at the corresponding points on the mould, the bevel being held square to the curvature of the edge of the timber.

The inside of the timber, represented by the lines *AD*, etc., is then trimmed, by applying at the respective level lines, etc., the bevellings of the outside reversed. The sidings of the timber, both at the inside and outside, are then set off at the several bevelling points, these being either measured from the sections or provided from the mould loft with the bevellings. This side is straight and out of winding, so that sidings need not be given at more than two bevelling spots. At some yards it is the practice to furnish to the workman the siding of the head and heel, at the outside of the timber, and the taper or angle made by the sides *AC* and *DB*, these being expressed by so many inches in so many feet, or as the case may be. It will be observed that *A* and *D* coincide at the heel of the timber; also that boxen wood must be left at the head of the timber, if shown upon the mould.

When a stem piece is employed, the fore edge of the knight head fays close against the former. The after edge of the knight head is made the moulding edge in this case.

Fig. 2, Plate XL., shows an ordinary mould to a knight

* Generally, the stem is of tapered siding as high as the lower cheek, and parallel above that point, in which case it is necessary, after trimming the timber under consideration, to fit it against the stem by means of a mould made to the angle at the height of the cheek.

head when a stem piece is fitted between it and the stem. As stated at Art. 98, the mould gives the exact shape of the after side of the timber, including the boxen at the head for housing the external and internal planking.

As in the previous case, sometimes section moulds at level lines, and at other times bevellings at heads and sirmarks, are provided for trimming this timber, the former being the preferable method.

The knight head in the case under consideration is trimmed similarly to that already described.

240. To Trim a Cant Floor (see Art. 180).—Two moulds are supplied from the mould loft for the purpose of trimming a cant floor, viz.: (1), The *flight mould*, which is taken from the half-breadth plan, and gives the angle between the two arms in a horizontal direction; and (2), A mould as for an ordinary cant, showing its moulded shape, the two arms of this latter being connected to the middle piece by hinges; see fig. 2, Plate LXXXV., where the mould is shown upon the timber.

The timber must first be sided, to do which

1. Lay the mould No. 2 upon the moulding side of the timber in the position suitable for moulding it, and mark the middle line and seating *s*, also the angles *a*, *a*, fig. 2. Trim the surface between the angles *a*, *a*, straight and out of winding, taking care to do so in such a manner that there shall be sufficient wood left to obtain the required angle or cant of the arms of the floor. Also trim the seating of the timber to the angle of bevelling provided from the mould loft, taking care to leave sufficient wood for the required throating of the floor.

2. Fix the mould No. 1 against the seating, with its edge coincident with the surface between *a*, *a*, as in fig. 1.

Hold a straight-edged batten, *m m*, fig. 1, at the middle line of the floor, and with its edge upon the surface *a a*. Hold a second straight-edged batten *b b* parallel to *m m* near the end of the arm of the floor, having one edge resting upon mould No. 1, and trim a spot through at that extremity of the arm until the edge of the batten *b b*, while parallel to *m m*, and resting upon the mould No. 2 and the side of the floor arm, is also out of winding with the edge of the batten *m m*. Proceed similarly at the other arm of the floor, as at *c c*. Strike lines on both sides of both arms, joining the angles *a a* with the edges trimmed at *b* and *c*. Remove the surplus wood above the lines, and then trim the opposite side of the floor parallel to the first, and to the required siding.

3. Apply the mould No. 2, keeping its middle line coincident with the middle line previously drawn upon the timber, and mark the positions of the several heads and sirmarks upon it. The timber is bevelled, and the mouldings set off in the manner described at Art. 237.

241. To Trim an Ekeing (see Art. 210 and Plate LXXVI.).—It has already been stated that the *ekeing* fills up the space between the foremost beam and the apron, and rests upon the fore end of the shelf. Consequently, as it forms a portion of the deck framing, it conforms to the sheer and round of the deck in question.

1. The first operation is to trim the upper side, the edge *a*, fig. 1, Plate LXXXVI., having to coincide with the beam at side line rased on the inside of the timbers. This curvature is obtained by stretching a line between the positions of the fore and after butts of the ekeing, and then by the aid of a straight-edged batten held near the beam at side line, a straight line is projected or "looked in" upon the side of the timbers. The spaces between the straight line and the beam at side line on the timbers at different points are then measured and set up or down, as the case may be, from the straight line struck upon the piece for the ekeing, and the edge of the latter is champhered down to this line.

2. Cut the after end to an athwartship line, and nail a beam mould *m* against it, as shown by fig. 1, Plate LXXXVI., the upper edge of the mould being coincident with the champhered edge of the ekeing, and the middle line correctly situated. Draw a series of parallel fore and aft lines, *e*, *f*, *g*, *h*, etc., upon the timber being trimmed, and dub down a spot at each line as far as the champhered edge, until the edge of a straight batten, held at each spot, resting upon both the side of the ekeing and the beam mould, and parallel to the middle line *c*, is also out of winding with the edge of a straight batten held at the middle line, and resting in a

similar position. This process is followed out at a sufficient number of spots to ensure a fair surface, when the surplus wood is removed above the champhered line, and a line obtained by bending a batten through the newly found edges on the opposite side of the timber. It is evident that this surface conforms to the required round up of beam and the sheer of the deck.

3. The back of the ekeing must now be trimmed to the necessary curvature and bevelling, to enable it to fay against the inside of the frame timbers. Make a mould to the curvature of the beam end line, and mark upon it and the ship's side the positions chosen for bevelling and square spots, the latter for *counter-moulding.* Take the bevellings at these places by holding the stock of the bevel against the inside of the timber, and the arm out of winding, with a level line stretched across the ship at the after end of the ekeing. Trim the back of the timber to the mould, and apply the bevellings with the arm of the bevel out of winding with the line *bl,* fig. 1, which coincides with the line stretched across the ship. Set off the bevelling spots from the upper to the lower sides; turn the timber over and *counter-mould** it, keeping the mould to the square spots, and checking the bevelling previously trimmed through.

4. The lower surface is trimmed to the stand of the shelf on which it rests by means of bevellings taken between the back seating against the timbers and the upper side of shelf at the bevelling spots, the space between the shelf and beam at side line being the siding of the timber.

The inside of the ekeing is trimmed parallel to the side against the timbers, and to the required moulded breadth.

242. To Trim a Deck Hook (see Plate LXXXVI., fig. 3). —It will be remembered that "deck hook" is the name given to the timber which connects the two sides of the ship together under a deck. It is generally fitted against the ekeings, and fair with the upper surface of the latter, so as

* In trimming such pieces of timber a *counter-mould,* or mould to lower side, should be used as a check upon the bevellings; besides which any inequalities on the surface of the timbers would not be obtained by bevellings only, as a penning batten bent to pass through the bevelling spots would give a fair curve.

to co-operate with it in forming a bed for the fore ends of the deck plank.

As the fore and aft length of the deck hook is very inconsiderable, compared with its length in a transverse direction, it is not usual to take any notice of the curvature in the sheer, but to simply trim the timber to the round of the beam. It need hardly be remarked, that if it were considered necessary to take the curvature of the sheer into account, the mode of procedure in obtaining the form of the upper surface would be similar to that stated in the preceding Article.

1. *To side the deck hook.* — Cut the after ends of the piece to the length required, and in a direction square to the middle line, and to the sheer of the deck. Next fix a beam mould against these ends, with its centre at the middle line, and sufficiently below the upper edge of the piece to enable the surface to be trimmed to the round up, at the same time leaving enough wood below the edge for the required siding. Hold a straight-edged batten *ab* along the middle line, and bring the surface of the timber at that part in a line with the middle of the beam mould. Then by the aid of another straight-edged batten, trim down spots along the upper surface, holding this latter batten parallel to the one at the middle line, as at *cd*, *ef*, etc., until the two edges are out of winding, while each of the battens is resting upon the surface of the hook and the beam mould in this parallel direction. The opposite side of the hook should then be trimmed parallel, and at the depth of the ekeing, from the upper side.

2. *To mould the deck hook.*—Make the mould to the shape of the space enclosed by the upper inner edges of the ekeings, and take the bevellings at suitable places, say, one at each end, and one at the middle, and one at each side of the throat. In taking these bevellings, the horizontal arm of the bevel should be held square to the curve, and the vertical arm square to the upper edge; also the horizontal arm must be looked out of winding with a line corresponding to the edge of the middle line batten *ab*. Apply the bevellings, in trimming the hook, with the bevel in the same directions as when taking these bevellings. A guide mark (or "square spot") is squared down the side of the hook, say, at the

several bevelling spots, so as to enable the counter-mould for trimming the lower edge to be accurately applied, this mould having been made similarly to that of the upper edge. The piece is counter-moulded, and the back trimmed in the usual manner, after which the inside edge is moulded and trimmed.

243. To Trim a Deck Transom.—It need hardly be stated that a *deck transom*, or after deck hook, is trimmed in a similar manner to the preceding.

244. To Trim a Fore Shift of Thick Waterway (Plate LXXXVII.).—The side of a ship, from a certain height above the water line, usually inclines inboard for a considerable portion of her length; but it frequently happens that at the bow and stern, especially the former, there is as much outward inclination at the height of upper or main deck as there is inclination inwards at amidships.

Now, in every case, the upper inner edge *a*, (figs. 2, 3, and 4), of the thick waterway is kept to a fair curve at a certain constant height above the beams or deck; consequently, owing to the upper side *ab* of the waterway being square to the surface of the timbers, the edge *b* against the latter will be at a variable height from the beams.

1. Before proceeding to trim a fore shift of thick waterway, it is therefore necessary to get in the line b_1b_2 on the inner surface of the timbers. This can be done by placing a piece of mould stuff, of a width *ab*, equal to the thickness of the spirketting, against the timbers, measuring upon it the given height of the point *a* above the beams, and then drawing the line *ab* square to the timber surface. This process followed out at places sufficiently close will give a number of points, such as *b*, through which the line b_1b_2 can be drawn.

2. The curvature of this line must be obtained in the manner described for the ekeing (Art. 241). Then transfer this line to the edge of the timber to be trimmed, also a line coinciding with *b*, when that point is above *a*; and, elsewhere, with a projection of *a* on the ship's side, leaving enough wood below it for the required extreme siding, as at *bf*, fig. 2. Trim a surface to this line, level and out of winding; this will be represented by the lines *bo*, figs. 2 and 3, and *ao*, fig. 4, on Plate LXXXVII.

3. Make a mould against the timbers to the line b_1b_2, choose bevelling spots, also a guide or pitching spot, and mould the piece accordingly, trimming the back *roughly* to bevellings obtained by holding the bevel against the timbers, square to the curve, and with the tongue out of winding with an athwartship level line, stretched across the ship for this purpose.

4. Proceed to line and trim the piece sufficiently near to its required siding or depth from *o* to *c*, to allow the counter-mould to be laid on the lower side; that mould having been fitted against the timbers, and the guide and bevelling spots set off upon it. Counter-mould and trim the back of the piece correctly in the usual manner.

5. Next trim the lower side by bevelling it from the back, the bevellings being the angles *bed*, figs. 2 and 3, between the inside of the timbers and the lower part of the dovetailed score in the beams. In the wake of the ekeing, the angle of bevelling *bec* will be that between the inside of the timbers and the upper surface of the ekeing.

But three processes now remain. *First*, to trim off the side *ba* through the line b_1b_2, square to *eb*; this being to lodge the spirketting upon. *Second*, to round off the upper front of the waterway to the shape of section moulds at the ends, made to please the eye, and fairly between these extremes. *Third*, to trim out the rabbet for the edge of the thin waterway, the section of which, given by the section moulds, will be as close an approximation to an equilateral triangle as the varied shape of the waterway will admit of. Nothing further remains to be done than to lay the waterway upon the beams, abreast its true position, and then mark the sides of the latter for the purpose of cutting the dovetailed stops (see Art. 209).

It need hardly be stated that the foregoing description is equally applicable to an after shift of waterway.

245. To Trim a Cheek (see Plate LXXXI. and Art. 232). —In proceeding to trim this timber, it must be remembered that when in place it has to conform to a given sheer, this curve or sheer being continued forward, and terminating in the *hair bracket*. The cheek is fitted after the plank is put on and the knee of head in place, its position being rased upon the side of the ship. The sheer or *flight* of the cheek is given by a mould, termed the "flight mould" (see fig. 2, Plate LXXXVIII.), provided from the mould loft, having the fore edge of rabbet marked upon it as a pitching spot. The position of the cheek is also generally given on the mould to the knee of head by tacking the flight mould to it in its correct position, and by this means the position of the cheek is transferred to the knee of head and there rased in.

If the flight mould were placed against the knee of head with the fore edge of rabbet, as marked upon the mould, coincident with that point on the stem at the line rased upon the latter for the cheek; also, if the mould were blocked off from the knee of head at its fore end, until it became parallel to the middle line of the ship—the distance blocked off being, of course, the taper of the knee in the length of the mould—then, in this position, the rased line on the knee of head should be the vertical projection of the upper edge of the flight moulds. Hence we proceed as follows:—

1. *To side the cheek.*—Fix the flight mould against the arm of the cheek which is to fit against the knee of head, and block it off from that arm as at *a*, fig. 2, Plate LXXXVIII., so that the point on the mould corresponding to the fore edge of rabbet is opposite the angle of the piece to be trimmed, and distant from it the taper of the knee of head in the length of that arm. The flight mould will then be in a position equivalent to being parallel to the middle line of the ship.

Place a straight-edged batten *bc* on the after end of the flight mould, and trim the top of the piece away until the batten is horizontal, and square to the middle line, while, at the same time, it fays upon both the mould and the piece. Trim spots through at other places on the timber until straight-edged battens *de*, *fg*, etc., held at these places are out of winding with the first batten, while, at the same time, they are parallel to it, and fay upon the piece and the flight mould. In this way the upper surface of the cheek is trimmed to its flight, after which the lower side is set off and the cheek trimmed to the required siding.

2. *To mould the cheek.*—Make a mould* to the angle included between the lines given for the upper side of the cheek on the bow and knee of head, showing the fore edge of rabbet as the pitching spot. Obtain the bevellings for the side against the bow by holding the bevel square to the curve, and looking its horizontal arm out of winding with a straight line drawn from the angle of cheek to the fore end of the latter; and the bevellings for the side against the knee, by looking the horizontal arm of the bevel out of winding with a straight line on the bow, extending from the angle of cheek to its after extremity. Apply these bevellings in a similar manner to that in which they are taken. Counter-mould, for the shape of the under side, in the usual manner.

246. To Trim a Shift of Plank.—The edges of the plank of side are rased upon the timbers before fitting the plank, this being done chiefly in order that these edges shall conform to the sheer of the ship, and thus assist in giving her a graceful appearance. Another reason for lining off the edges is, that the planking of the ship shall be in accordance with the model, or whatever other means are adopted for arranging this portion of the work, so as to ensure a satisfactory shift of butts and general combination of plank.

If a wide batten, termed a "spiling batten," be bent round the ship's side, especially at the bow and stern, it will be found that it will not bend to the curves of some of these lines; the latter being sometimes either convex or concave, with reference to the upper edge of the spiling batten. In the former case, the edge is said to have "sny," and in the latter "hang."

The first operation in "taking account" of a strake of plank, is to determine the amount of "sny" or "hang" in the edge of the adjacent plank, against which we must fit the plank to be trimmed. We will suppose that we are planking the ship's side, from the rail, downwards.

1. Bend a spiling batten fairly upon the timbers, just below, and as near as possible to, the lower edge of the last plank in place, so that the edges of the spiling batten are

* Sometimes this mould is provided from the mould loft, and corrected by putting it in place at the ship, and there fitting it.

unrestrained. Choose a certain number of bevelling and spiling spots, sufficient for the purpose of trimming, say, one at every frame space, and mark these spots both upon the batten and the timbers. Then measure the distance from the upper edge of the spiling staff to the lower edge of the plank above at each of the spiling spots.

2. See which side of the plank is nearest the heart of the tree (which is therefore to fay against the timbers), and set this side uppermost. Transfer the spiling spots to the opposite side of the batten, and place the latter upon the plank, in the best position to aid conversion; transfer these spots to the plank, and set off the spilings from the respective spots, measuring from the edge of the batten. Bend a batten to pass through these points and so draw the line of the inner upper edge of the plank.

3. Proceed to take bevellings at the several spiling spots by holding the stock of the bevel upon the timber, and the tongue against the lower edge of the lowest plank in place, allowance being made for the caulking seam. Copy these bevellings upon a board, and apply them at the respective bevelling spots in trimming the edge lined off.

4. The lower edge is obtained by measuring from the plank in place, the distance to the line of that edge rased upon the timber, at the several spiling spots. Set off these breadths at the respective spiling spots on the plank, pass a curve through the points, and trim to a square bevelling, minus half the allowance for caulking seam.

247. When the Strake is a "Shutter in."—In this case the curvature of the edge is obtained as above; but in order that the plank may fit accurately between those on each side of it, above and below, the spilings for the widths are taken by means of small pieces of stick cut so as to fit tightly between the two strakes, close against the timbers; and the breadths of the plank at the several spiling spots are set off by means of the sticks. The bevellings of the lower edge are obtained in the same way as those of the upper.

248. When the Plank is a Shutter in, Lengthwise; *i.e.*, the last plank to complete a strake. In addition to the above precautions, it is necessary to leave one butt uncut until after the plank is nearly bent and shored in place;

the other butt being driven home closely against its neighbour.

When the plank is nearly in place, bend a slight batten and measure the girth against the timbers, from the last point where the plank touches them, to the butt of the adjacent plank of the strake against which the butt, about to be cut, must fit, and mark the latter point on the batten. Then, still keeping the first end of the batten fixed, let it spring along the inner surface of the plank, and mark the point upon the latter. Cut the butt at this point to the two bevellings obtained by holding a bevel against one of the edges of the planks and the butt to be fitted against; also, against the timber surface and that butt.

PART IV.—IRON SHIPBUILDING.

CHAPTER XVII.

249. Differences between Mercantile and War Ships.—While there are differences in the details of the hulls of wooden ships intended for mercantile as compared with those for war purposes, there is a much greater dissimilarity in the elements of iron ships intended for these respective services. The difference is more marked in armoured than in unarmoured war ships; but even the latter are in many respects very differently constructed to iron ships of the same size intended for commerce.

It must be observed that these differences are chiefly due to the adoption of the longitudinal system of construction in the Royal Navy, a system which has been but little applied to the mercantile marine. Besides this, the provision which has to be made for carrying such heavy weights of armour, etc., and the general adoption of a double bottom, have caused war shipbuilding to become a more distinct branch of the profession than formerly. We, therefore, propose to consider each of the principal elements of an iron ship, under two divisions, viz :—*firstly*, as applied to merchant, and *secondly*, as applied to war ships.

250. Scantlings of Merchant Ships.—So common is the practice of insuring ships engaged in commerce, that the scantlings, etc., of by far the greater proportion of the iron vessels built at the present day for the merchant service are regulated by the rules of the several associations of underwriters; and so well do those rules agree with the experiences of our best shipbuilders, that the majority of the ships not intended to be insured, are built according to the rules laid down by one or other of these associations. Hence the practice of iron shipbuilding is very uniform, and a detailed statement of the dimensions and modes of connecting the several parts of a ship for the mercantile navy would consist of little other than a copy of the rules of the three principal underwriters' societies, viz:—Lloyd's, The Liverpool Registry, and the Bureau Veritas. As a statement in detail of the niceties of difference between the rules of these societies would occupy a much greater space than the limits of this work will allow, it is not intended to enter fully into particulars of scantlings, but rather to state the functions and requirements of the several parts of the ship, and the methods of performing the work in connection therewith. It may further be remarked, that the rules referred to are continually being changed in accordance with the experience which is being acquired with regard to iron ships.

251. The Keel and Keelson of Mercantile Ships.—There are three principal forms of keel in vogue, viz:—*bar*, *flat plate*, and *centre plate* or *side bar* keels. Of these the former is the commonest, being associated with the frames and keelson in several different ways, of which those shown by Plates LXXXIX. and XC. are very usual.

252. The Bar Keel (Plates LXXXIX., XC., and XCI.) is generally of hammered iron, made in pieces as long as can be conveniently forged. The butts are usually scarphed and riveted (see Plate XCI.); but sometimes, though rarely, they are welded. The latter operation must necessarily be performed near the keel blocks, and by means of a temporary hearth. The difficulty of securing a good weld, and the expense of the process, have considerably limited its adoption.

The scarphs are always vertical, similar to the French system for wood keels; they are plain, and in length about eight or nine times the thickness of the keel.

The holes in the keel bars for securing the garboard plates are arranged in accordance with a sketch or template; they are drilled, usually by the contractor who forges the bars.

The holes in the scarphs are not usually drilled until after the latter have been fitted, although, sometimes, only those at the lip ends of the scarphs are left; they include some intermediate holes, smaller than the others, for joining the pieces of keel previous to the garboard plates being riveted, the latter operation completing the connection. (See Plate XCI.).

The holes in bar keels are set off in different ways, the double chain arrangement shown by fig. 3, Plate XCI., being one of the most usual; the double zigzag system, shown by fig. 2 on the same Plate, is also very common, and is recommended by Lloyd's rules. Fig. 1 on that Plate shows an arrangement which has been adopted in the Royal Mail Company's vessels; however, it does not appear to be so satisfactory as the others, in consequence of the way in which the bar is riddled with holes for the sake of rivets which are quite unnecessary. Fig. 2, Plate XCI., is adopted by the Netherlands Steam Ship Co., while fig. 3, on that plate, is found in the vessels of the Pacific Steam Navigation Co. It should be remembered that Lloyd's and the Liverpool Underwriters' rules allow nothing less than double riveting in keels.

The diameter of the rivet used in bar keels is $\frac{1}{4}$ inch greater than is required for plates of the same thickness as the garboard plates (see Art. 328), and the spacing is about five diameters from centre to centre, in order that the joint between the plates and the bar may be caulked.

The garboard strakes form the only connection of this kind of keel to the remainder of the hull (see Plates LXXXIX. and XC.), except in such cases (which are very rare) when intercostal keel plates between the floors are riveted to the bar, with either a rabbet, groove, or plain joint.

253. The Side Bar Keel.—The next kind of keel in order of frequency of adoption is the *centre plate* or *side bar keel.* See Plate XCII., which shows two forms of this kind of keel. The *side bar* system is much superior to that which we have just been considering, but as it is more expensive, and requires more careful workmanship, it is not so common as the bar keel. It consists of a vertical plate, extending from the underside of the keel to the top of the floors, as in fig. 2, Plate XCII., or to the top of the keelson as shown in fig. 1 on the same Plate. On each of the lower edges of this plate another plate is riveted to it, so as to form an external keel of the same depth and thickness as a bar keel for the same class of ship.

The plates are as long as can be procured, and their butts are carefully shifted. The side plates, or bars, are connected to the vertical plate by an openly spaced series of small rivets, termed "tack rivets," marked T in fig. 1, Plate XCII., which are arranged with reference to the holes for riveting the garboard plates in some such a manner as there shown, the latter being spaced about four and a half diameters apart. The Liverpool rules require that the butts of the centre plate shall be "secured by double butt straps, each of a thickness equal to two thirds that of the centre plate, and to be treble riveted."

Great nicety of workmanship is required in riveting the centre, side, and garboard plates together, in order to obtain an accurate correspondence of the holes, the rivets having to pass through five thicknesses, and sometimes, when double side bars are fitted, through seven thicknesses of plating.

254. The Flat Plate Keel is not generally adopted in the merchant service. The early iron shipbuilders used wood keels bolted to the lowest strake of plating. Finding that the wood was very liable to decay, they discontinued its use, and bent plates to a dish form instead. The inadequacy of such a form to bear the weight of the ship when grounding, led to their being substituted by the bar and side bar keels now in use. In a highly efficient form, however, being associated with an internal vertical keel, the flat plate keel is now adopted in iron-clad ships of war. (See Plate XCIV.)

The *hollow* or *dish keel* is a variety of the *flat keel* system, of which examples are given by figs. 1 and 2, Plate XCIII.

Lloyds' rules state that, "when hollow or flat keel plates are adopted, their breadth must be the same as given for the garboard strakes, and their thickness not less than once and a third that prescribed for those strakes, for three-fifths the vessel's length amidships. The butt straps of flat keel plates are to be one-sixteenth of an inch thicker than the plates they connect, and treble riveted."

255. Summary.—In the earlier specimens of bar keels the garboard plates were rabbeted into the former, thereby considerably relieving the riveting when the work was carefully executed; but the expense involved by so doing led to the rabbeting being discontinued, and the garboards are now riveted against the sides of the bars. As already stated (Art. 252), the vertical plates, when fitted between the floors, were sometimes grooved or rabbeted into the bars and riveted. At the present day, it is generally considered sufficient to simply rest the lower edges of these plates upon the bar, and connect the former to the floors only; although when vessels built for the government service have bar keels, a tongue is left on the upper part of the bar to which the vertical intercostal plates are riveted.

The greatest variety of combination, however, has been found in the case of the side-bar system. In some cases the centre plate extends only to the top of the floors (fig. 2, Plate XCII.), at others to a sufficient height above to form a keelson, as in fig. 1 on that Plate; while, again, at others it has been carried high enough to form such a keelson as is shown by fig. 2, Plate XC. In another variety the centre plate projects just high enough to allow a piece of *bulb plate* to be riveted to it, and thus form a keelson.

256. Internal Keels.—This leads us to a more detailed consideration of that portion of the keel which is on the inside of the ship. Judging by the extent of its application, it has only been during late years that the importance of a vertical plate between the floors has been fully recognised.

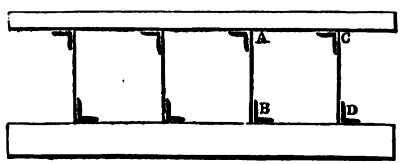


Fig. 28.

It has been a common practice to place no longitudinal tie between the outer keel and the longitudinal combination of plates and angle-irons on the top of the floors, known as the *gutter plate* and *keelson*. Certain accidents to iron ships have called attention to the fact, that the hogging strains peculiar to long, narrow ships tend to produce a tripping of the floors; or an alteration in the form of the space A B C D in fig. 28, enclosed by keel, keelson, and floors (see also

Plate XC., fig. 1) shown by fig. 29. The remedy evidently consists in placing a vertical plate between the floors, and this is usually done. (See Plate LXXXIX.)

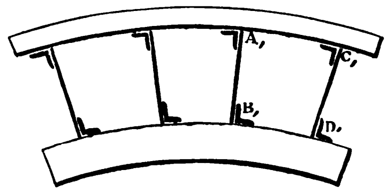


Fig. 29.

It will be seen that by fitting a series of intercostal plates in this way, no more longitudinal strength can be obtained than is given by the rivets connecting the plates to the floors; except such a case as in Plate LXXXIX., where a little additional strength is gained by continuing the plate above the floors to form a keelson. Hence in some cases, especially those of very long ships, a continuous vertical plate has been fitted, the floor-plates on each side being butted against it. A loss of transverse strength results from such an arrangement, which strength is not required to such an extent in long, narrow ships. Generally, the frame or reverse frame angle-iron (usually the former) has been scored through the edge of the keel plate, and thus a portion of the transverse strength has been retained. When the continuous vertical plate has extended above the floors, a scarphing angle-iron two to three feet long is usually passed through a hole in the former and riveted to floor plates, reverse frame and gutter plate on each side; this being required by the Liverpool rules.

The keel shown by Plate LXXXIX. is a very usual form, and although the longitudinal connection is not all that could be desired, yet as it sufficiently provides against the floors tripping, and affords a means for direct communication of the thrust from the keel bars to the pillars; and as the side keelsons contribute considerable resistance to a deflection of this, the lowest part of the girder, the arrangement on the whole cannot be considered unsatisfactory. A great advantage of this mode of combination is the cheapness and facility with which the work of framing can be performed, by crossing the frames over the keel in one piece, and then erecting them, compared with the piecemeal process of building when the transverse frames are not continuous.

257. Box Keelsons.—It is not necessary to do more than just allude to the complex and varied systems of box-girder keels and keelsons which have been adopted from time to time; against the difficulties in the construction of which, their weight, cost, and the impossibility of access to their interiors, to check corrosion, there is scarcely any set off whatever.

258. Keels and Keelsons of Iron-clad Ships.—There has been a marked uniformity in the construction of the keels of iron-clad ships for the Royal Navy; the style adopted in the *Warrior* being very little different to that in vogue at the present day. As will be seen by reference to Plate XCIV., no external keel is fitted, the material which would otherwise be so disposed being employed to greater advantage in the form of a plate and angle-iron girder at this, the lowest part of the ship. Besides this view of the case, it is apparent that the flat keel plates, supported by the internal keel and framing, affords a better bearing surface than a bar keel for such heavy weights to ground upon.

The keel of an iron-clad ship consists of the following parts:—

First—A flat keel plate, which is a continuation of the bottom plating, the latter being so arranged that the flat keel plate is an outer strake. This strake is usually rather thicker than the remainder of the bottom plating; in this respect coinciding with Lloyd's rules for keels of that construction (see Art. 254). This is very necessary for local as well as structural strength, as these plates are more liable to injury from touching the ground, etc., than the remainder of the bottom.

An inner strake of flat keel plate is worked in conjunction with this outer strake, being fitted between the inner edges of the garboard strakes, or strakes next to the keel plates. The edges of the inner strakes are secured to the outer by means of a single row of rivets, the edge of the outer being secured to the garboard strakes by a double row (see Plate

XCV., fig. 1). The butt straps of both strakes are on the inside of the plating; they are generally treble chain riveted, and are in width equal to the width of the plates they connect, minus the space occupied by the keel angle-irons; while their length, in the case of treble chain riveting, is about sixteen diameters of the rivet.

The lengths of these flat keel plates, bear the same ratio to the room and space as those of the bottom generally, being about three or four times.

Second—A vertical keel plate, extending from the inner surface of the flat keel plates to the inner bottom plates, being usually of the same length as the garboard plates, or about three or four times the room and space. Sometimes, however, they are in alternate lengths of four and five times the room and space, so that two plates of these dimensions will give good shift to three plates, each three times the room and space in length.

Plates XCV. and CII. show a rather unusual case, in which the bottom plates are four times the room and space, or 16 feet in length, while the vertical keel plates, which are of steel, are double the lengths of the bottom plates.

The butts are always carefully shifted with regard to those of the continuous work in the neighbourhood, and are connected by double butt straps, treble chain riveted; each of the butt straps being a little more than half the thickness of the plates they connect.

The vertical keel plates are connected to those of the flat keel by angle-irons on each side, in lengths about double those of the vertical plates, except in such an exceptional case as that just mentioned, when they are of the same length. Their butt straps are usually shifted clear of each other, but sometimes they have been placed opposite to each other in the same frame space. They are very carefully fitted, and are sufficiently long to receive two rivets in each flange, on each side of the butt. The rivets in the keel angle-irons are spaced about five to six diameters apart, so as to make a watertight division of the double bottom space. It will be observed that these rivets serve also to connect the outer and inner flat keel plates.

This completes the continuous portion of the keel, the remainder of which consists of an intercostal staple-shaped angle-iron, on each side of the vertical keel at its upper edge, serving to connect the inner bottom (when fitted), also the bracket or floor plates to the vertical keel. The riveting in these angle-irons is also spaced so as to make a watertight division between the two sides of the double bottom space. The angle-irons are often so arranged as to extend down the sides of the vertical keel, and butt against the frame angle-irons alternately, at two different heights above the flat keel plate, as shown by Plate XCIV., thus breaking joint with each other; the difference in the lengths of the arms of the angle-irons being sufficient to receive one rivet.

A consideration of the keel of an iron-clad ship is not complete without a reference to the gutter plate, or the middle strake of inner bottom, in the event of the latter being fitted. This strake forms the upper flange of the **I** girder, the lower flange of which is represented by the flat keel, and the web by the vertical keel plate. In order to obtain a watertight division of the double bottom space, it is necessary to fit these plates with great care, when they form a part of an inner bottom. The angle-irons along the upper edge of the vertical keel, and the continuous angle-irons (to be referred to presently), must be fitted very accurately, so as to form a fair surface upon which to fit the gutter plates, and obtain a watertight joint when riveted and caulked. The rivets are spaced for watertight work, the butt straps are fitted on the under side, and, like those of the flat keel plates, they are in two lengths.

A keelson is not often fitted above the gutter plate of an iron-clad ship; or, if so placed, its primary use is as a support to a boiler flat, or some other purpose not directly connected with the hull. Of course, the structural value of such girders as boiler and engine bearers, especially when disposed in a longitudinal direction, must not be overlooked; nevertheless they cannot be said to constitute a portion of the keel, keelson, or any of the other elements of the hull proper.

259. Keels and Keelsons of Unarmoured War Ships.— The keels of unarmoured iron war ships are differently constructed to those just described. In these ships the flat keel is composed of two thicknesses, as before, unless the bottom is sheathed with wood, in which case it is usually of one thickness only (see Plate XCVI.).

The vertical keel is composed of a continuous plate (in lengths the same as before), and is riveted with a single row of rivets to intercostal pieces of vertical keel, which are the width of the lap deeper than the frames. As the inner angle-irons of the frames do not cross the keel similar to those in armoured ships, the inner angle-irons of the vertical keel are consequently continuous. The vertical keel is connected to the flat keel plate by a single angle-iron, generally on the same side of the plate as the continuous keel plate is riveted. This angle-iron is intercostal, and turns up against the side of the floor plate and vertical keel, until it butts against the inner angle-iron of the frame, or reverse angle-iron, which turns down against the keel. The butts are sometimes extended, alternately, to two different heights, so as to break joint with each other.

As double bottoms are not usually fitted to unarmoured ships, the precautions necessary to obtain watertightness, already referred to, are not needed. Holes are usually cut in the intercostal portions of the vertical keel to serve as water courses.

As in the case of armoured ships, it often becomes necessary to fit longitudinal combinations of plates and angle-irons to serve as boiler and engine bearers, in which case it is usual, when practicable, to connect these bearers to the vertical keel and longitudinal frames; or rather to deepen these to the extent necessary to serve the purpose in question.

260. Stems and Stern Posts of Merchant Ships.—The stems of iron merchant ships are merely continuations of their keels, and preserve the characteristics of the latter throughout, the pitch of rivets and connection to the frames being uniform.

The great curvature in the pieces of stem rendering it very difficult to transport them from place to place, it is usual to supply the stem from the forge in a straight piece, and then to bend it, after being heated in a furnace, on the bending slab, in the same way as angle-irons are bent for the frames (see Art. 271). When so bent the stem is erected by means of tackles, then shored and proved to its proper position, in a similar manner to a wood stem (see Art. 173).

The stern post of a paddle, twin screw, or sailing ship, consists simply of a bar similar to those composing the keel, being bent to the angle between the stern post and keel, then carried along for a short length and scarphed to the latter in the same manner as the pieces of keel are joined together. Sometimes the braces or gudgeons for the rudder are forged to the post, while at others they consist of straps passed through holes in the fore edge of the rudder, and riveted to the post in such a way that the rudder cannot be unshipped without taking off the braces. In any case, the rudder post of a sailing, twin screw, or paddle wheel ship, is much simpler than that of a single screw ship; and, in the latter case, there is necessarily a difference between the stern posts of ships having lifting, and those with non-lifting, screw propellers.

Plate XCVII. shows the stern post of a screw ship of the latter class. If it were intended to raise the propeller, the portion between *D* and *E* would be omitted, and the fore post *BE* would be extended to about the same height as the rudder post *CD*. As will be seen, provision is made for housing the screw shaft by giving a swell to the post, as in a wood ship (Art. 25).

The hole is drilled within about half an inch of the finished diameter before the stern post is erected, so as to leave ample margin for boring out the shaft hole correctly after the ship is built. The stern post is erected by similar means, and with similar precautions to the stem; and the plating of bottom is connected by riveting similar to that in the keel bars.

261. Stems and Stern Posts of Iron-clad Ships.—The stem and stern posts are very formidable items in an iron-clad ship. This is true not only of their size and, therefore, weight, but also of the elaborate, difficult, and therefore expensive character of these forgings.

The provision for ramming, which has become an important feature in modern naval tactics, renders the stem far heavier, and more difficult to forge, than would otherwise be required; but with regard to the stern post of a ship with a single screw, the great massiveness is necessary, not only to give the required form for the large screw shaft to pass through, but also to act, as it were, like an anvil block, and so protect the hull from the great vibratory strains which the application of enormous engine power to screw propulsion must necessarily bring upon the after part of the ship. Twin screws have been fitted to some of our recent ironclads, and in these the stern post is similar to that of an iron sailing ship, as before described.

262. The Stems of Ironclads.—Plate XCVIII. shows the stem of an iron-clad ram, sections being given at different places to explain the form of this elaborate and expensive forging. The stem is usually forged in two or three pieces, which are carefully scarphed, keyed, and riveted together, but sometimes, when practicable, it is forged in one piece (Plate XCIX.). The scarph is arranged so as to simplify the forging, by reducing the curvature of the pieces as much as possible, at the same time keeping the scarph clear of that portion of the stem which would receive the principal portion of the shock, in the case of collision by ramming.

The stem of an iron-clad ship is differently shaped at different positions in its length. From the upper part of the stem to the upper part of armour belt it is formed as shown by the elevation and sections between *A* and *B* (Plate XCVIII). Only one rabbet is cut on each side of this portion, these being to receive the fore butts of the topside plating, which are connected to it by a double row of *tap* or screw rivets. Sometimes the stem is wider at this place than is merely required for riveting the butts of the side plating, in order to secure to it a continuation of the vertical keel, similar to that shown by Plate XCIX.

The portion of the stem in the wake of the armour belt, between *B* and *C*, has rabbets cut in it to receive the fore ends of the plating behind armour, the teak backing, and the armour plates. (See sections at main and lower decks, Plate XCVIII.) A separate stop was prepared for the ends of the teak backing in the stem of the Monitor, represented by Plate XCIX., which was not done in the case shown by Plate XCVIII. The armour shelf is riveted at the lower part of this portion of the stem (Plate XCIX.).

The remainder, to where it joins with the keel at *D*, is the most variable portion of the stem. The bottom plating is rabbeted into this part, the rabbit being of uniform depth; and, in order to obtain a flush surface when the plating is fitted, the laps are chipped thinner to a little abaft the portion which butts on the stem. The plates are secured to the stem by a double or treble row of tap rivets.

At the lower extremity, as shown by the plan at *D*, the several sections and the elevation, the two flat keel plates terminate at different places, so that their butts may give shift to each other. The extremity of the stem is forked, in order to receive, between the forks, the vertical flanges of the lower angle-irons (see *E* in the Plate) of the vertical keel, the horizontal flanges being fitted into a rabbet cut in the underside of the stem.

These angle-irons stop at such a position that their ends shall be well shifted with regard to the ends of the flat keel plates. They are through riveted to the fork, and tap riveted on the underside through the flat keel plates. The vertical keel is continued over the inside of the stem, sometimes to the top of the latter, and at others stopping at a bulkhead, breasthook, or deck flat. In every case it is connected to the stem, either by angle-irons on each side, through riveted, and tap riveted to the stem, or else by riveting the plate to a projecting piece on the stem, as shown in Plates XCVIII. and XCIX.

The preceding remarks describe the general characteristics of the stem of an ironclad; but with regard to further details it may be remarked that these vary in almost every ship.

263. The Stern Posts of Ironclads.—As in the case of merchant ships, the form of the stern post is regulated to a considerable extent by the conditions of a lifting propeller, or otherwise. In the former case the body and rudder posts are not connected above the propeller; but both of them are carried as high as one of the decks, to the beams and plating of which they are firmly united. If the propeller is not intended to be lifted, then the two posts are joined, both above and below the propeller; below by a shoe riveted to the lower part of the body post, the latter being formed so as to be a continuation of the keel; and above by a keyed and riveted scarph, joining two arms, which, when united, form the upper boundary of the screw aperture.

As shown by Plate XCVII., the stern posts of merchant ships, of which the propellers do not lift, are forged in one piece, but the great sizes of such forgings in large war vessels renders it almost necessary to scarph them. It should be observed that in the *Northumberland* the rudder post was not riveted to the body post by a shoe at the foot, but the two parts were welded together while in place on the blocks, by means of a temporary hearth; a V scarph being formed and welded just above the heel of the post. The manner of scarphing and riveting the two pieces composing a body post is shown by Plate C. Four of the rivets in this case are through, and four are tapped.

The adoption of a balanced rudder considerably modifies the stern post arrangements, as no rudder post is then required. This form of rudder is not so much in use now as it was a few years ago, in consequence of its unsuitability to evolutions under sail. The stern post shown by Plate C. is of the kind fitted in ships having balanced rudders; but the portion of the post marked *D* has been usually made much wider and thinner, in order to provide for a greater amount of lateral strain than in the case shown. In the *Penelope*, the shoes* are formed of plates and angle-irons, and in the *Bellerophon*, the construction was very similar. It should be stated that in the *Northumberland* the after spur of the body post was also flanged, but in that case the thickness was maintained, as a portion of the weight of the rudder post and rudder was borne thereby, whereas the weight of the balanced rudder is entirely borne by the upper part of the stern; the flange of the post at the bottom offering resistance to the lateral strains upon the rudder in steering. When a balanced rudder is fitted, there is, necessarily, no after support to the propeller, the shaft of which must therefore have a good bearing provided for it in the body post.

264. Forging Stems and Stern Posts.—The information supplied from the mould loft floor for making a stem or stern post, consists of a batten mould with the shapes of sections of the forging at different parts marked upon it, very similar to Plate XCVIII. The forging is made of slabs of hammered

* This vessel had two rudder posts, rudders, and screw propellers.

iron, carefully "piled" and worked by a "porter bar" in the ordinary manner. In this way, a hammered stem, stern post, or piece of the same is formed as nearly as practicable to the required size, leaving sufficient material for the exact dimensions to be obtained under the planing machine. Sometimes the stem, or each piece of a stem, is forged and planed straight, and then bent to the required shape. This is a very cheap and easy way of doing the work when the stem is not so thick as to make the bending impracticable. The most common plan, however, is to forge the stem or its pieces to something like the required form and shape, and then plane it either by a machine having rectilinear motion only, or else by one, the tool of which works to the required curvature by means of a guide. This latter process has been carried out with great success at Chatham yard. The rectilinear machine, however, is most commonly employed, and consequently a great deal of chipping is necessary, both in cutting clearances for the planing tool, and in finishing.

The scarphs are carefully planed and fitted, but sometimes it is considered preferable to join them by welding. Allusion has already been made to the case of the rudder post of the *Northumberland*, which was welded to the body post when in place on the blocks. The welding together of two pieces of finished forging is a very delicate operation, as, in addition to the careful correspondence which is essential to a satisfactory joint, provision must also be made, in preparing the two pieces, for the stretching or "drawing out of the fibre," as it is termed, which is necessary in order to get a good weld. Besides this, a further allowance must be made for the contraction which takes place in cooling. These precautions are particularly necessary with regard to the rudder post when it is intended to support the after end of the propeller shaft. In that case, a small margin of material must be allowed at the boss, and afterwards a line representing the centre of shaft must be drawn, the correct size set off therefrom, and the surplus iron removed.

265. Rivets in Large Forgings.—A great many of the rivets which are used in the work connected with the stem and stern post, are necessarily much longer than elsewhere in the ship; and it may not be out of place to refer to the precautions which are necessary in clenching these rivets.

In consequence of their length, the contraction in cooling is much greater than in the case of ordinary rivets; hence, if the rivet is heated throughout the whole of its length, a very great strain is brought upon the head and point; so much so, that these latter frequently break off in cooling. The heads and points do not always fall off, owing to the fracture in the rivet taking place within the surface of the forging; hence, the defect is not at all times detected until the vibration of the machinery, or the working of the ship causes the pieces to fall out. Such a defect causes undue strains to be brought to bear upon other rivets, some of which are already in a state of extreme tension; and although sound, yet having been cooled very rapidly by contact with such a large mass as a forging, are often very brittle.

In this way fractures have occurred, which can be and are avoided by adopting the following precautions. Cut a piece of rivet bar, of the required diameter, to the length sufficient for the necessary size of head, and point when hammered down. Heat one end, place the other in the hole for the rivet, and knock a head at the heated end, a "dolly" being held against the other. Then remove the rivet from the hole, heat the other end, taper it slightly, and drive it through the hole from the side opposite to that from which it was first driven, and then beat up the point. In this way, by not raising the body of the rivet to a high temperature, the contraction which ensues upon cooling is not greater than in an ordinary rivet; that being quite sufficient for closing up the work.

CHAPTER XVIII.

266. Framing.—With the exception of a few vessels built on the *longitudinal system* (see Art. 278), and one or two others with frames placed diagonally, iron merchant ships have been, and still continue to be, framed in almost exactly the same way. But while this uniformity has existed in the mercantile navy, a great many modifications and changes have occurred in the framing of Her Majesty's ships.

At the present time there are three distinct modes of framing, only two of which, however, are carried out to any great extent.

1. *The transverse system*, generally adopted in the mercantile marine.

2. *The longitudinal system*, so ably advocated by Mr. Scott Russell.

Very few ships have been built on this principle; but of these the *Great Eastern* is a noble specimen.

3. *The above systems combined*, in two principal forms—viz.:—the *bracket system* in iron-clad ships, and the *solid-floor system* in unarmoured war ships.

267. The Transverse System owes its origin to the early iron shipbuilders combining the new material in the same manner as they had been accustomed to do with wood. The frames cross the keel transversely, being generally evenly spaced, and the skin plating is riveted to them in a manner analogous to the mode of securing the plank of a wooden ship. Indeed, the transverse system, as a whole, bears a far greater similarity to wood shipbuilding than our present knowledge of the relative properties of the two materials, iron and wood, would prepare us for.

268. Its Components.—A frame of an iron ship built on the transverse system is composed of three parts, viz.:—

1. *The frame angle-iron* or outer angle-iron, to which the

bottom plating is riveted (see *A* and *B*, Plate LXXXIX.). This angle-iron rarely crosses the keel, but generally extends from the keel to the topside on each side of the ship.

2. *The reverse frame* or inner angle-iron, the longitudinal flange of which stands in an opposite direction to that of the *frame* angle-iron; the ceiling, foot-waling, lining, etc., being secured thereto (see *A* and *B*, Plate LXXXIX.). From about the turn of the bilge to the topsides these two angle-irons are riveted back to back. The reverse angle-iron is either carried across the keel and stopped at a short distance on the other side at alternate sides of the keel—or else it is butted at the keel, and a connecting strap carried across so as to join the two pieces. In small ships it is sometimes possible to carry the angle-iron across the ship continuously from side to side.

3. *The floor plate,* which extends from the turn of the bilge on one side of the ship to the same height on the opposite side, serving to deepen, and, therefore, strengthen, the frame at that part. The reverse angle-iron is riveted to its upper, and the frame angle-iron to its lower, side. It is connected to the intercostal keel plate by short angle-irons, as shown in Plate LXXXIX. When the keel plate is continuous, as in the side-bar arrangement, the floor plate is in two pieces; but when, as in the above-mentioned Plate, the keel is worked intercostally, the floor plate extends from side to side. For large ships it is difficult to obtain the floor plate in one length; in that case they are supplied in two pieces, which are welded or butt-strapped together at alternate sides of the middle line; welding being the usual method.

Lloyd's rules require that the butts of the frame angle-irons shall be connected by angle-iron straps not less than three feet long; while, by the Liverpool rules, the lengths of these angle-irons vary from four feet to six feet. The reverse angle-irons are not carried to the full height of the frame angle-iron, but stop at different positions according to the proportions and classification of the ship. Lloyd's and the Liverpool rules require double reverse angle-irons to be fitted in the way of all keelsons, hold and beam stringers (see Plate LXXXIX.). It is perhaps hardly necessary to call attention to the circular hole cut in every floor plate on each side of the keel, just above the frame angle-iron, for the purpose of a watercourse, cement being laid upon the bottom plating to that height.

269. Modes of Building the Frame.—It is not easy to describe the methods of framing an iron ship on the transverse system, inasmuch as each of the principal iron shipbuilding centres has a system of its own. We will, however, endeavour to give a brief summary of the chief features of these methods; at the same time it may be stated that if the importance of any system can be measured by the extent of its application, then that practised on the Clyde would undoubtedly carry off the palm.

270. Rivet Holes in Frames.—On the Clyde it is the practice to punch all the holes in the frame angle-iron, except those for the rivets in the plate edges and at the turn of the bilge, before bending them; also, sometimes, the holes in the reverse frames for fastening the ceiling, foot-waling, etc. On the other iron shipbuilding rivers all the angle-irons are punched after being bent. The rivet holes in the floor-plates and reverse bars, by which they are connected to the frames, are always marked from the holes in the latter by laying one upon another after the reverse bars are bent.

In setting off the rivet holes in the frame angle-irons, when building by the Clyde system, a batten is bent to the curvature of the frame on the scrive board (see Art. 144), and the positions of the plate laps, etc., are set off upon it; after this the distances between the laps are divided so as to have a spacing of rivets about eight diameters apart. The holes are always punched from the outer surface of the angle-iron; *i.e.*, the surface against which the plating will ultimately fay. In setting off the rivet holes for securing the frame to the reverse angle-iron and floor plate, care should be taken to avoid placing two rivets in the same section of the angle-iron, so as not to unduly weaken it.

271. Bending Frame Angle Irons.—The frame and reverse angle-irons are bent to their required form upon a large slab of iron, which is cast with a number of square holes in it, disposed like the squares on a chess-board. This is technically called the "bending slab." Adjoining this slab are the angle-iron and plate furnaces, and (in the north of England and Scotland) the scrive board (see Art. 144); while in the south of England the frame moulds are kept conveniently near.

The angle-irons are placed in a reverberatory furnace, and while they are being raised to a bright red heat, the workman transfers the curve of the frame which is to be bent upon the bending slab. When the scrive board is used, a flat rod of soft iron termed the "set iron" is bent to the curvature, the bevelling spots are set off upon it, a line is drawn with chalk upon the slab to the shape of the bar, and the points where bevellings are to be applied are also marked upon the line. Strong iron pins are next driven and wedged tightly into the holes in the slab which are nearest to the chalk line. The angle-iron, when sufficiently hot, is removed from the furnace, laid upon the bending slab close to the iron pins, and one end being fixed at a certain point, the other is bent round, and the whole length wedged and driven tightly against the bars. A "set" or pressure is obtained by means of other pins driven and wedged into holes on the opposite side of the angle-iron.

The flange of the angle-iron to be riveted to the floor plate or reverse angle-iron, is that which is laid upon the slab, and the other flange bears against the pins first placed in position. In applying the bevellings the bevel is held upon the slab, and against the back of the angle-iron, in a position square to the curvature. Great care should be taken in opening or closing the angle-irons being bevelled, in order that their strength may not be deteriorated in the process, or their backs become so bulged or bruised that the plates will not fay well against them.

When the angle-irons are bent to the curves, and before they are cool, their curvatures are proved by laying them upon the scrive board and trying them to the lines there shown, the board being preserved from burning by strips of half-round iron which are nailed upon its surface.

It should be observed that an allowance for the stretching of the angle-iron in punching and bending should be made when working by either of the processes. The final operation at the bending slab is to mark upon the angle-iron the positions of plate edges, harpins, and other important points, and nick them with a cold chisel.

272. Bending Reverse Angle-Irons.—The lines of the insides of reverse angle-irons are drawn upon the scrive board as far from the middle line on each side as the ends of the floor plates, the lines being also the edges of those plates. The reverse angle-iron is bent just after the corresponding frame angle-iron, the line of its curvature being obtained by setting off the depth of the frame, above the floor ends, on the inside of the curves of the frame angle-irons, the said depth being given by the midship section. When the line is set off, the reverse angle-iron is bent and bevelled in a similar manner to that already described. When cold, the frame angle-iron is laid upon it, and the rivet holes set off; the holes for the rivets which connect it with the floor plates are also spaced, and the holes in the floor plate are afterwards copied by placing the reverse angle-iron upon the plate.

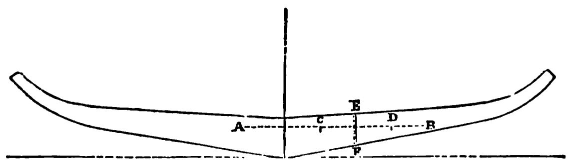


Fig. 30.

273. The Floor Plates are provided by the iron manufacturer with straight edges, and, as already stated, sometimes in two or three lengths. On the Clyde, when the floors are supplied in two pieces, they are bent nearly to their required shape, as given by the scrive board, separately, and then sheared or cut to the exact form. The two pieces are then laid upon the scrive board in their correct positions, overlapping each other about $\frac{3}{4}$ inch, and a straight line is struck upon them (see A C D B, fig. 30); also two marks as C and D with a centre punch, these being about 3 feet apart. When the plates are welded, then A C D B must be a straight line, and C and D the fixed distance of 3 feet apart. The rivet holes are set off very carefully by placing the frame and reverse angle-irons upon the plate.

274. Erecting the Frames.—By the Clyde and Tyne systems the frames, reverse frames, and floor plates, are riveted together either by the side of the blocks or across the keel upon a stage level with the latter, and there they, with the beams of one or more of the decks (according to the size of the ship), are riveted together. It is usual to rivet up a great number of frames in this way before commencing to erect them, the latter operation being commenced aft, and proceeded with towards the bow. The pieces are first "cottered" together, and then a number of frames are riveted up in succession. The rivets usually have *pan* heads, and their points are finished with a *snap tool* (see Art. 326).

By the Mersey system the frames are erected before riveting any beams to them, the two sides being connected by cross spalls and harpins. By this process a great number of harpins and ribbands are required, and the work must be carefully set off and shored, as there is very little rigidity in each of the pieces to keep the structure to the required form without such precautions being adopted. It will be admitted that by the Scotch system, where each of the frames is of itself sufficiently rigid to maintain its form, much less trouble is required, in order to ensure an accurate result. The erection of the frames is generally entrusted to wood shipwrights, who adopt the same or very similar means of proving the accuracy of their positions as in wood shipbuilding (see Art. 178).

275. Stern Frames.—In proceeding to erect the frames, it is usual to commence aft at the last transverse frame that rests upon the keel, and then proceed forward. As the stern post includes a portion of the keel, if that forging is not ready to be erected, several of the aftermost frames are temporarily grouped closely together until the stern post is in place, and then these frames are correctly spaced. Plate CI. shows a very usual method of framing the after part. By this sketch it will be seen that the stern frames are canted, and heel against a deep transverse frame, termed a "transom frame," situated at the fore ends of the rudder post, and connected thereto.

276. Bow Frames.—The iron ships of the merchant navy are not usually sufficiently bluff to render it necessary to cant the bow frames, so that whether the stem is upright or raking, the foremost frames are square to the middle line, and cross the stem the same as if it were the keel.

277. Side Keelsons are the chief source of longitudinal strength in the lower portion of the framing of an iron merchant ship on the transverse system. They are of various forms; but in all the varieties the portion of the keelson from the outer bottom to a little above the inner side of the reverse frames, is worked intercostally (see *C* and *D*, Plate LXXXIX.). Sometimes, however, the keelson is altogether inside the reverse frames (see *E*, Plate LXXXIX). The intercostal portion is connected to the bottom and floor plates by short pieces of angle-iron, as shown. The continuous portion of the keelson consists either of two angle-irons back to back, as at *D*, a piece of plate bulb, an **I** girder, as at *C*, or some other such form. The positions of the side keelsons are nicked upon the angle-irons of the frames when the latter are being finally proved on the scrive board, or by the moulds.

278. The Longitudinal System.—By this system, instead of the frames being arranged in continuous transverse "bends," as in wood shipbuilding, they are disposed fore and aft, and thus better adapted to withstand longitudinal strains. The propriety of building short wide ships on the transverse system is obvious, but for ships of the extreme proportions built for commerce at the present day (often with a ratio of length to breadth of 10 or 11 to 1), it seems very inconsistent to dispose so much of the material in such a manner as to render but scanty assistance in resisting the longitudinal bending forces, which must be considerable in such long ships.

The longitudinal system of Mr. Scott Russell, whose name has been long associated with the subject of longitudinal framing in iron ships, has been thus enunciated by that gentleman :—

"1. To divide the ship by as many transverse bulkheads as the practical use of the ship will admit. I like to have at least one bulkhead for every breadth of the ship in her length. In a ship eight breadths her length, I wish to have at least eight transverse bulkheads.

"2. I have between these bulkheads what I call partial bulkheads, or the outer rim of a complete bulkhead, with the centre part omitted, so as to form a continuous girder running transversely all round the ship, and not interfering with stowage.

"3. I run from bulkhead to bulkhead, longitudinal iron beams or stringers, one along the centre of every plate of the skin, so giving each strake of plates the continuous strength of an iron beam, one portion placed at right angles to another. This longitudinal forms one continuous scarph across all the butt joints of the plates, hitherto their weakest part, and adds, also, to the strength of the rivets of the joint, the help of a line of rivets and angle-irons along the centre of the plate. These longitudinals and the skin are therefore one.

"4. What remains over, after this is done, of the superfluous iron used in the ribs, I make into a continuous iron deck, mainly carried by the bulkheads, and by longitudinals under it; and I believe this iron is infinitely better applied in a deck than in ribs fastened to the skin."

The *Great Eastern*, a part transverse section of the framing of which is shown by fig. 3, Plate XCIII., was constructed by Mr. Scott Russell on this system. Both Mr. Russell and Mr. E. J. Reed claim, with reason, that the framing at the bow and stern is much more readily executed than by the transverse system, chiefly owing to the work being more accessible.

The experience which has been gathered in working by the longitudinal system is so slight that we are unable to state any particular method of carrying out the work which shall have the merit of economy, or any other form of superiority. Indeed, it would appear that it is the lack of knowledge of this kind which has hitherto stood in the way of the adoption of the longitudinal system by many intelligent shipbuilders, who, while fully aware of its great structural advantages, are yet deterred from applying it by the fact that the experience gained by our workmen in the transverse system, and the consequent facility and cheapness with which they perform the work, render competition by a new system comparatively hopeless. We understand that Mr. E. J. Reed, C.B. (late Chief Constructor of the Navy), to whom the profession and country are indebted for the many valuable improvements and developments in iron shipbuilding, which his enlightened foresight has induced him to recognise and adopt, has recently laid down some iron ships at the Earle Company's shipyard at Hull, which are being constructed on the longitudinal system. It remains to be seen whether, by so doing, an impetus will be given to that system. Mr. Russell has admitted that greater skill, intelligence, and accuracy are required in building upon this principle. We fear that these difficulties are more formidable than is generally imagined. Whoever has had any experience regarding the class of workmen into whose hands iron shipbuilding has fallen, will, we believe, share with us the opinion that any deviation from the groove into which the practices of iron shipworkers have been running during so many years, will not meet with pecuniary success for, at least, some considerable time.

279. The Bracket System is the development under the auspices of Mr. Reed of the transverse and longitudinal systems combined, by which iron-clad ships have been built since their introduction.

The framework of iron-clad ships consists of two sets of frames—transverse and longitudinal. These cross each other at right angles, or nearly so; the plates of the longitudinals being continuous, and those of the transverse frames in short pieces between the longitudinals. The plates in the transverse frames, when on the bracket system, consist of a bracket-plate on each side of the longitudinal (see Plate XCIV.).

280. Longitudinal Frames.—These are constructed very similarly to the vertical keel (Art. 258), and consist of—

1. A plate extending from inner to outer bottom plates, in the wake of the double bottom, and a somewhat reduced and tapering breadth before and abaft it. These plates are sometimes disposed in alternate lengths of four and five times the room and space, and at others they are all in either three, four, or even six room and space lengths. The butts are carefully shifted with regard to each other, and to the butts of the outer and inner bottom plates (see Plates CII. and CVIII.). They are connected by double butt straps (similar to the vertical keel), which are double-chain riveted, except in the case of those longitudinals which make a water-

tight division in the double bottom space, the butts of which are generally treble chain riveted. Longitudinals, and the vertical keel, have frequently been made of mild steel plates, carefully annealed, so as to break at about 32 tons to the square inch.

The inner or continuous angle-irons of the transverse frames inside the double bottom, pass through slots cut in the upper edges of the longitudinal plates, thus reducing the effective breadth of these plates to the same as those immediately outside the double bottom space, where the inner angle-irons of the transverse frames pass above the inner edge of the longitudinal plate. The plates are lightened and rendered more uniformly strong by holes, these being of such a size as to leave at least the same effective sectional strength across the hole, as in the line of rivets through the angle-iron joining the longitudinal to a watertight transverse frame. At intervals holes are cut sufficiently large to allow a man to pass through. These holes, in consecutive longitudinals, are placed in alternate frame spaces, so that complete access can be had to all parts of the framing beneath the ceiling, and in the double bottom. Holes are not cut in the frame spaces where the longitudinal butts occur. The man-holes are oval-shaped, the sizes varying between 18 × 12 inches, and 22 × 18 inches. Small circular holes are also cut, similar to those in the transverse frames, to form watercourses. These are, of course, omitted in watertight longitudinals.

2. A continuous angle-iron riveted to the lower edge of the plate, generally on the side farthest from the middle line. The lengths of these angle-irons are generally double those of the plates; their butts are shifted with regard to each other, and to those of the bottom and longitudinal plates (see Plate CII.); they are also carefully strapped with two rivets on each side of the butt.

Generally one of the longitudinals on each side is watertight throughout the length of the double bottom, in order to divide that space into watertight cells. In such case the rivets in the inner and outer angle-irons are spaced about four to five diameters apart so as to get a caulk; elsewhere, about eight diameters is the usual spacing.

It may be noticed in passing that in the *Warrior* class there are two outer angle-irons to each longitudinal, instead of one, as now fitted in such ships.

3. An inner angle-iron which in the wake of the double bottom is in short lengths between the transverse frames; but outside that space it is continuous, in lengths about the same as the outer angle-irons, to the butts of which they give shift. In this case, as before stated, the inner angle-irons of the transverse frames pass over the inside of the inner longitudinal angle-iron.

The longitudinals are always connected with outside strakes of plating, and are placed, if possible, square to the ship's surface, so that the angle-irons do not require bevelling when this end is attained.

Formerly, it was the practice to score the longitudinal plate, and joggle the angle-iron over the butts of the bottom plating; but as it is inconvenient to defer fitting the longitudinal until the bottom plates are brought on, and as it is difficult to butt the bottom plates so as exactly to fit the score, this practice is discontinued, and the butt strap of the plate is now fitted in two pieces, one of which is sometimes made to lap over and is riveted through the outer angle-iron of the longitudinal.

The girth of the ship's bottom being considerably less at the extremities than at amidships, it is impossible to extend all the longitudinals right fore and aft without unduly crowding them together, and thus making the bow and stern framing inaccessible, and unnecessarily heavy. It is usual to stop one of the longitudinals at the extremities of the double bottom, and another at an intermediate position between these points, and the stem and stuffing-box bulkhead; two or three longitudinals generally extending from the former to the latter. At the bow, especially in ships constructed for ramming, the longitudinals on each side meet and form breast hooks, one or more of these being plated across from side to side as far aft as a transverse bulkhead; and so the space before that bulkhead is thus divided into two or more watertight cells. The advantages of this arrangement in a ship intended for ramming are obvious. The modes of framing the bow are very various; that shown by Plate XCIX. being the bow-framing of the Bombay Monitor

Magdala. The same style is carried out aft as forward, but not nearly to the same extent, framing of that kind not being so much needed as at the bow.

281 The Armour Shelf.—Although the armour shelf or recess plate is a part of the longitudinal framing of the ship, it has also other functions which we will briefly consider. Forming the upper boundary of the bottom plating, and making a watertight connection between the latter and the plating behind armour, it at the same time offers a suitable lodgment for the backing and armour.

There have been several modes of constructing the shelf, and of uniting it with the bottom plating. In the earlier iron armour-clads the shelf was formed of a bent plate, which was rolled to one of the shapes shown by fig. 31, and then bent, the point A forming the angle of the shelf. This was connected to the plating behind armour by an angle-iron above and another below the shelf. It also lapped outside the upper strake of bottom plating, thus taking the place of an outer strake the surface being flush with that of the armour.

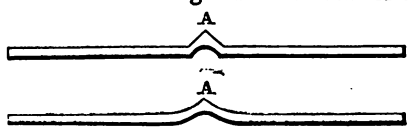


Fig. 31.

The great expense attending this method, and the injury done to the plates by bending, led to others being devised. The first deviation from the preceding was in the case of the *Hercules*, the shelf of which was formed in the manner shown by Plate XCIV. This style has since been retained for ships having *wing passages*, except in the case of the *Captain*, where the outer angle of the armour shelf was wider than in the *Hercules*, and instead of being tap riveted against the shelf plate, it was connected by an edge strip to a narrower plate than in that ship; in other respects the shelf was very similar to that shown by Plate XCIV.

The preceding remarks apply to ships having wing-passage bulkheads, as shown in Plate XCIV. In the *Invincible*, *Cyclops*, and some other recent ships, the wing-passage bulkhead is dispensed with, and the inner bottom is continued to the same height as the armour shelf, the latter being considerably widened in the wake of the inner bottom, in order to form a wide, watertight compartment between the shelf and the next longitudinal below it. The longitudinal referred to is, necessarily, made watertight, and the compartment is divided into a number of cells by watertight transverse frames spaced about sixteen feet apart. The armour shelf of a large ship, when made in this way, is very wide in the wake of the double bottom (see Plate CIII.); elsewhere it is formed similarly to that shown by Plate XCIV. If possible, the whole width is made of one plate, but when this cannot be done, two plates are riveted to each other with a lap-joint, the latter being situated immediately below the angle-iron connecting the shelf to the plating behind armour, so as to receive the same rivets. On the inner edge the shelf plate is connected to the inner bottom by a continuous angle-iron, of much smaller size than that on the outer edge. The riveting of both edges is spaced for watertight work.

In the *Devastation* class of ships the armour shelf differs from those in their predecessors, inasmuch as, owing to the overhang of the armour, the shelf is in two pieces, the outer of which is connected on the outside of the ship to the bottom plating, and is tap-riveted underneath the armour.

The butts of both the plates and continuous angle-irons composing the shelf are shifted with regard to those of the remainder of the longitudinal framing, and the plating in the vicinity. The butt straps are on the underside, being generally double riveted, as also are those of the angle-irons. The points of the rivets in the outer angle-irons are countersunk, so that there may be a flush surface for the armour to rest upon. The armour shelf tapers in width forward and aft to suit the tapering thickness of the armour and backing.

282. The Transverse Frames.—The transverse frames in an iron-clad ship consist of the following components:—

1. The outer or frame angle-iron; in short lengths between the longitudinals, except in the case of watertight frames, where they are made *staple-shaped*, so as to fit against the longitudinals.

2. The inner or continuous angle-iron, termed the reverse angle-iron, which in small ships extends from shelf to shelf,

but is generally in two lengths, butted and strapped at a short distance from, and on alternate sides of, the keel.

3. The bracket plates, fitted in pairs, one on each side of each longitudinal, being riveted to the frame and reverse angle-iron, and connected to the longitudinal plate by a short piece of angle-iron on each side of the longitudinal, but on one side of the frame only. The earliest iron-clad ships, such as the *Warrior*, *Northumberland*, etc., had solid floor plates, pierced with holes fitted between the longitudinals, instead of bracket plates; the latter were first used in the *Bellerophon*.

It is, perhaps, impossible to better describe the advantage of the bracket system than in the words of the gentleman under whose auspices it was first introduced. In his *Shipbuilding in Iron and Steel*, Mr. Reed says:—"The objects of the invention and introduction of this system were to save weight, to simplify workmanship, and to add both to the strength and safety of the ship. The characteristic features of the system are the adoption of an inner bottom, and of short angle-irons connected by bracket plates, in place of staple and other forged angle-iron work. A great increase of longitudinal strength is gained by the use of much deeper longitudinal frames than those of the *Warrior* and other of the earlier ironclads. Another important feature resulting from the employment of deep longitudinals is, that the space between the two bottoms is roomy and easy of access for cleaning and painting operations, which are essential to the preservation of an iron structure. Facilities are also offered by these arrangements for letting in water between the bottoms to serve as ballast, the space being so divided into watertight compartments as to enable the officer to regulate the trim of the vessel by filling the fore or the aft spaces. Provision is, of course, made to pump out any compartment when required."

Allusion has already been made to the difference in the depths of the frames within and without the double-bottom space; a difference is also frequently made in the spacing and construction of the bracket framing. The frames within the double bottom are almost invariably spaced four feet apart, outside those limits they are sometimes four feet and at others two feet apart; although occasionally a three-feet spacing has been adopted. Again, the decrease in the depths of the frames at the extremities often render it impossible to have spaces between the brackets sufficiently large for man-holes, consequently it is found cheaper and just as light to substitute for the bracket plates, solid plates pierced with holes at that part, in a somewhat similar manner to the portion of the frame immediately below the armour shelf in Plate XCIV. The framing before and abaft the double bottom, when the latter is constructed as shown by Plate CIII., is constructed similarly to the corresponding frames of ships of which the double bottom is framed in the manner shown by Plate XCIV. Care is taken to stop the reverse frames, and the frames behind armour, so that they may scarph over each other alternately at different distances from the armour shelf. For instance, in the *Hercules* type of ships, the frames behind armour in the same transverse sections as those of the bottom,* stopped alternately at the second longitudinal below the armour shelf, and three feet below that point; the reverse angle-irons of the same frame extending as high as three feet above the same longitudinal, and to the longitudinal, alternately; thus causing the scarphs of consecutive frames to be shifted three feet clear of each other, the scarphs themselves being three feet long.

A modified form of the bracket system has been adopted in some foreign iron-clad frigates recently designed by Mr. E. J. Reed. Both the frame and reverse angle-irons of these ships are continuous, slots being cut at both the upper and lower parts of the vertical keel and longitudinals for these angle-irons to pass through. The longitudinal plates are continuous, as before, but the angle-irons are intercostal, being in some cases worked staple-shaped, instead of using short angle-irons to connect the bracket plates to the longitudinals; this is often done in ordinary bracket framing in the case of the frames beneath the engines, and always in watertight frames.

The reasons for framing in this manner appear to be two-

* The frames in the double bottom are spaced four feet apart, but those behind armour are two feet apart; hence alternate frames behind armour are connected to the frames of the bottom. The *others stopping at the* first longitudinal below the armour shelf.

fold. *First*, in order to get increased transverse strength, the ships being very wide in proportion to their length; and *second*, for the facilities offered in erecting this kind of frame (see Art. 285).

283. Transverse Framing of Unarmoured War Ships.—Reference was made in Art. 259 to the framing of unarmoured ships of H.M. Navy, which is differently constructed to that of iron-clad ships.

In the midship part of these ships, for rather more than half their length, the transverse frames are of two kinds, placed alternately (see Plates XCVI., CIV., and CV.). In the one case (Plate XCVI.), the frame is composed of a frame and reverse angle-iron, which extend from upper deck to upper deck (the angle-irons being necessarily in two or three lengths), the butts of which give shift to each other (see Plate CV.), and are carefully strapped. There are no floor plates in these frames, consequently they are of uniform depth throughout.

In the other case, the frame is composed similarly to that just described, as low down as about the turn of the bilge (see *A*, Plate CIV.); but below that the frame deepens by stopping the reverse angle-iron and introducing a floor plate, extending to the inner edges of the longitudinal frames, the junction being made by scarphing the floor plate upon the upper reverse angle-iron, and continuing the lower reverse angle-iron as shown.

At the extremities of the ship, throughout the remainder of the length, all the frames are formed as in Plate XCVI.

The floor plates of the frames shown by Plate CIV., are worked in intercostal pieces between the longitudinals and the vertical keel; being pierced with holes to lighten the framing, produce uniformity of strength, and allow ready access through the frames under engines, boilers, bunkers, ceiling, etc. A double angle-iron is riveted to the inner edge of the floor plates, being in short lengths like the latter.

284. Longitudinal Framing of Unarmoured War Ships.—The longitudinal frames below the turn of the bilge are in two portions, one of which, the lower, is worked *intercostally* between alternate transverse frames, *i. e.*, the *frames* shown by Plate XCVI., while the upper portion is continuous. Thus the intercostal portions are twice the room and space in length. The longitudinals are consequently formed of the two sets of plates lapped and riveted together, and three angle-irons—viz., two on the upper and one on the lower edge. It will thus be seen that the longitudinal is constructed very similarly to the vertical keel as described at Art. 259.

The outer angle-iron is intercostal, like the outer plates of the longitudinal. The latter extend to a sufficient height above the shallow frames (Plate XCVI.), to receive a row of rivets connecting them to the continuous plates of the longitudinal. The shift of butts of the latter, and their continuous angle-irons, follow the same rule as already stated (see Art. 280, and Plate CII.). The longitudinal plates are lightened with holes similarly to the floor plates.

By reference to Plate XCVI., it will be seen that two longitudinals are fitted above the turn of the bilge, where the floor plates do not extend. Each of these is worked intercostally between all the frames, a portion projecting sufficiently far on the inside to receive the rivets connecting to it two continuous angle-irons, back to back, running across the insides of the reverse frames, and riveted to the fore and aft flanges of the latter. The longitudinals are connected to the transverse frames of both kinds by short pieces of angle-iron as shown in the Plates.

285. Systems of Building Bracket Framing.—There are several methods of putting together and erecting the frames of iron-clad ships. In describing one or two of the principal of these, we will assume that the angle-irons and bracket plates have been prepared, fit to go into place.

The blocks having been laid and duly sighted, the two thicknesses of flat keel plates are prepared by means of the keel staffs and templates, the butts fitted, the holes punched or drilled, and the whole temporarily secured to the blocks in a correct position. The lower angle-irons of the vertical keel are next laid in place, the holes marked upon them from the flat keel plates, and those to connect it to the vertical keel set off. The holes in these angle-irons are then punched or drilled, and the angle-irons temporarily secured in place. Next, the vertical keel plates are placed in position, their butts fitted, the holes marked on them from the keel angle-irons, and then punched or drilled. The stations are already set off, and the holes for connecting the frame angle-irons to the flat keel plates set off and punched. Next, the lines of holes for connecting these frames to the vertical keel are squared up, the holes set off, also those for the angle-irons on its upper side. Then the slots in the upper side are cut for the continuous or reverse angle-irons to pass through. The angle-irons at the upper edge of the vertical keel are not fitted until the reverse frames are crossed. The pieces of frame angle-iron between the vertical keel and the first longitudinal on each side are now temporarily secured, having first been punched for the riveting.

When this stage is reached, there are at least two modes of procedure. In the Royal dockyards, and on the Thames and Clyde, the reverse angle-irons are next crossed, and are supported by means of ribbands at their upper ends on the inside surface, and then shored. On the Mersey, the first longitudinal and the lower tiers of bracket plates are next put into place, and temporarily secured; after which, the next row of frame angle-irons and their bracket plates; then the second longitudinal, and so on, to the armour shelf; the whole being supported by ribbands and harpins, which are fixed and shored as the work proceeds. After this, the continuous angle-irons are crossed and connected. In some cases the bracket plates and angle-irons have been connected on the ground, and then erected.

The first-mentioned system seems to be the more preferable, as by securing a continuous angle-iron of each frame by ribbands and shores, the whole of the outer frame angle-irons and bracket plates can be hung to it, even if the longitudinals are not quite ready to go into place. Of course, when these portions of the frame are hung to the continuous angle-iron, the latter is quickly relieved of its weight by placing shores under the frames, and then the reverse angle-iron acts as a ribband to keep the frame to its shape.

The framing recently adopted by Mr. Reed, referred to at Art. 282, is very readily erected. The outer angle-irons are *first crossed* in place before the vertical keel is laid upon the *flat keel* plates; these are connected by ribbands and shored.

Next, the bracket plates and longitudinals are placed upon the frame angle-irons and temporarily secured, and then the inner angle-irons are crossed. The short angle-irons (if any) connecting the longitudinals and bracket plates being next fitted, the whole is riveted together.

In every case it is usual to frame the midship portion of the ship first, as high as the armour shelf, or even above; so that the armour plating may be proceeded with amidships, while the more difficult framing at the bow and stern is being erected.

286. Building Frames of Unarmoured War Ships.—The following was the mode of procedure in building the *Active*, the framing of which is shown by Plates XCVI. and CIV. After the flat keel plates were bent, the edges and butts were lined off and sheared. Lines were also struck upon them, for the centres of the rivet holes at the edges and butts, and along the centre for the angle-iron connecting it to the vertical keel. The rivet holes were then set off and punched. The plates were fitted together upon the blocks, temporarily united, and butt straps fitted, the holes being marked upon them from the plates, and then punched.

The outer angle-irons were next erected, and temporarily secured to ribbands prepared for that purpose; the reverse angle-irons were then crossed and secured to the flat keel plates. The intercostal floor plates were also got into place and temporarily fastened to the outer angle-irons until the longitudinals were ready, when some of them were removed to facilitate the fixing of the longitudinal plates. All the frames were inclined slightly forward of their true position at their upper extremities, but were kept well to their correct stations on the keel plates. This was done to allow for the usual tendency to set aft as the work proceeds. The whole of the plates forming the keel, both continuous and intercostal, were put in place singly after the frames and reverse frames were in position. At each intermediate frame one of the floor plates adjacent to the keel was removed, being taken from each side alternately, for greater convenience when getting the continuous plates of the keel into place, and were replaced as soon as possible after these plates were got up. The butts of the latter were then fitted, their holes set off and punched. The longitudinals were next fitted, similar means being adopted as when fitting the vertical keel.

287. Frames behind Armour.—In the earlier ironclads the frames behind armour consisted of a $\frac{5}{8}$-inch plate, 10 inches wide, connected to the plating behind armour with two angle-irons, a single angle-iron being riveted on the inner edge. The plate was reduced in width to 7 inches at the framing of the bottom, and, with the angle-iron on the inner edge, was continuous from gunwale to gunwale.

In the *Bellerophon*, and succeeding ships, the frames behind armour consist of a reverse angle-iron 10 inches wide, which is connected with two angle-irons to the plating behind armour. When a wing passage bulkhead is fitted, this reverse frame extends down as far as about the second longitudinal from the armour shelf, being reduced in breadth to about 5 inches, and scarphing with the continuous angle-iron of the bracket framing. The two outer angle-irons of the frames behind armour extend to about midway between the shelf and the adjacent longitudinal; both are riveted to the solid plate, and stop at about 18 inches from each other.

When the armour shelf is constructed as shown by Plate CIII., then the frames behind armour in the wake of the double bottom are connected in the manner shown. In this case, the union is aided by means of the bracket at *B;* sometimes, however, when the lower deck beam is above the level of the shelf, a bracket plate is fitted so as to connect the beam, shelf, and frame behind armour.

288. Frames above Armour.—At the present day, when the armour plating is being concentrated in a belt at the water line, and the ship's side above that belt is left unprotected, except from bullet fire, a great proportion of the framing above the water line is included under the above heading. These frames are necessarily very slight, being made sufficiently strong that, with the side plating and pillars, they may efficiently support the weight of the decks above, together with their armaments, and altogether give the necessary structural strength. They are usually of two kinds, placed alternately, about two feet apart. The larger *size consists* of an angle-iron about $7 \times 3\frac{1}{2} \times \frac{7}{16}$ in., with a *reverse* angle-iron about $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}$ in., while the other is an angle-iron about $4 \times 3\frac{1}{2} \times \frac{7}{16}$ in. The feet of both are bent down and connected to the plating of the deck immediately above the armour belt (generally the main deck), the junction being effected similarly to that shown by *B*, Plate CIII. In the wake of the explosion of the heavy guns, as at the embrasures, etc., the whole of the frames are of the larger size.

CHAPTER XIX.

289. Outer Bottom Plating.—Independent of its primary purpose to keep the ship afloat, this is perhaps the most important part of the structure, especially so in merchant ships. By far the greater portion of the material worked into the hulls of the latter is in the form of bottom plates. Indeed, a merchant ship is little other than a shell of iron plates stiffened by transverse ribs. The bottom plating being, then, such an important item in the construction of the ship, so much of the weight put into the hull being necessarily required in order to obtain a watertight and comparatively impenetrable bottom, it becomes a matter of considerable moment to so arrange and secure these plates, as to obtain their maximum efficiency.

The bottom plates are always arranged in longitudinal strakes, like the planks in wooden ships. The plates in all cases are riveted to the frames, and connected to each other by straps at their butts, and by either lap joints or strips at their edges, lap jointing being by far the more common method.

There is scarcely any variety in the connection of the plates to the frames, this being done with a single row of rivets in the frame angle-irons, spaced seven to nine diameters apart by Lloyd's, and eight diameters by the Liverpool, rules.

290. Flush Plating.—In the early days of iron ship-building, several systems of combining the bottom plates were adopted before builders were agreed, as it were by common consent, to the form now in vogue. Among these early systems was that of *flush* or *jump* joints and butts connected by edge strips and butt straps on the inside surface. These edge strips were themselves, in some cases, connected at their butts by straps. In some instances the butt straps were fitted between the edge strips, and in others were made the full width of the plate, by joggling them over the strips so as to receive some of the rivets in the edge fastening. Liners, the width of the frame angle-irons, were fitted between the strips behind the frames, the strips being continuous behind the angle-irons.

291. The Clinker System.—Again another, termed the *clinker*, arrangement was sometimes adopted, the connection in this case being by lapping the edges one upon another, after the fashion of boat planks. In this case tapered liners were required, thus rendering the system rather expensive, notwithstanding that less riveting and material were required than by the preceding method.

292. Lamb's System.—A system just the reverse of that in Art. 289, was patented by Mr. Lamb in 1856. This consists in fitting the edge strips on the outside surface, and thus rendering liners unnecessary. Like the first-named system, this has the advantage of the resistance to vertical shearing forces offered by adjacent edges which rest upon each other. It has a disadvantage as regards cost of riveting compared with the system now practised (Art. 293). Lamb's system has been adopted in the ship *Inconstant* of H.M. Navy, the strips being made thick in order to receive the screw fastenings of the plank with which that ship is sheathed, in order that the bottom may be coppered, to prevent fouling (see fig. 38).

293. The Raised and Sunken Plate System is that at present practised; and we will now proceed to consider the differences in the arrangement of butts, riveting, etc., which are adopted in plating the bottoms of ships in this way.

294. Shifts of Butts.—The bottom plates being butted either at the middles of the frame spaces or at some other constant distance from the frames, generally the former, it consequently follows that the lengths of the plates are multiples of the room and space. In order to get an even and simple arrangement of butts, the bottom plates extend over the same number of frame spaces throughout, with the exception of those at the extremities of the ship. By both Lloyd's and the Liverpool rules, the bottom plates are never less than five frame spaces in length, and as these spaces range between 21 and 24 inches, it follows that the minimum limits range between 8 feet 9 inches and 10 feet in length. As a matter of fact the lengths usually employed in large ships are between 10 feet 6 inches and 12 feet, although it is not at all unusual, especially in H.M. ships, to find lengths of 16 feet and upwards employed.

Lloyd's rules further require that butts in adjoining strakes shall not be nearer to each other than two frame spaces, and the butts of alternate strakes are not to be under each other, but shifted not less than one frame space. These restrictions are not very exacting, as it is neither difficult nor expensive to provide even a superior arrangement to that demanded. Plate CVI. shows the *diagonal arrangement*, such as is now commonly adopted at the principal iron shipbuilding establishments, including the Royal dockyards; also Plate CVIII. shows the shift of butts of one of H.M. ships arranged by this system. In the former disposition it will be seen that there are no butts in alternate frame spaces, and in both the Plates consecutive butts in the same frame space are alternately on outer and inner (or *raised* and *sunken*) strakes.

Before the improvements in the manufacture of iron had enabled the makers to supply plates of such lengths as have just been named, the iron shipbuilder was considerably limited in the disposition of the butts of bottom plating. The *brick* arrangement was very common, and even now is sometimes adopted, although never in classified ships. By this system the butts of alternate strakes are in vertical lines, each butt being placed at the middle of the lengths of the plates immediately above and below it. Consequently, one line of butts are all those of outer strakes, and the next those of inner strakes. When the plates are arranged so as to have the same apparent breadth, and therefore the inner are wider than the outer strakes by twice the width of the edge lap, then on the supposition that the butt, even when strapped, is a place of weakness, it necessarily follows that a ship plated on this system is weaker across a line of butts of inner than of outer strakes. This can be, and is, sometimes prevented, both when plating by this and other systems having the same defect, by making all the strakes of the same *width*. By the *diagonal* system, shown on Plate CVI., the *relative* widths of the strakes is almost immaterial. It should be remarked that the garboard strakes are shifted clear of the keel scarphs, and are never nearer each other on opposite sides of the ship than two spaces of frames, as shown by Plate CVI.

Plate XCV. shows the disposition of butts in the bottom plating of an iron-clad ship, where the plates are 16 feet long, and the room and space 4 feet.

The butts are disposed on a half block model, from which also the edges are transferred to the scrive board or mould loft floor. In ordering the plates from the manufacturer, the lengths are measured from the model and the breadth from the scrive board or mould loft floor. After the frame angle-irons are bent and adjusted, the positions of the plate edges are nicked upon them with a centre punch or cold chisel, so that the plates can be "pitched" in the positions indicated by these marks; care being taken that the edges are in fair lines, got in by the aid of shearing battens.

295. Fitting the Plates.—The ship being framed, and the beams and stringers riveted in place, the plating is proceeded with; the plates received from the manufacturer, when for high class ships, having been first tested and proved sound, and of good quality. The stations of the several plates are sometimes indicated to the foreman in charge of the work, by a duplicate of the model, or by a sketch showing an expansion of the bottom plating; but on the Clyde, a copy of the book by which the iron is ordered, is all the information afforded. It being usual to mark the strakes alphabetically, and to number the plates in each strake, the workman is thus guided in pitching them.

296. The Inner Strakes (or sunken strakes) are, necessarily, the first to be fitted; generally commencing with those next to the garboards, the latter being outer strakes (see Plate LXXXIX., and fig. 2, Plate XCII.). Sometimes the fitting of the outer strakes is commenced directly two inner strakes are fitted, but very frequently the whole of the inner strakes are fitted in place before commencing the outer.

Templates are used for taking account of the rivet holes in the inside strakes corresponding to those in the frames, when the plates are too heavy to be held in place, and there *marked. Some* builders use templates very sparingly, preferring rather to fix a plate, weighing as much as half a ton, temporarily in place, in order to mark the rivet holes. These templates are of several kinds, but that most commonly in use consists of two battens, of $\frac{1}{4}$-inch fir (see fig. 32), representing the edges of the plate, with a cross batten nailed at every frame space corresponding with the frame angle-irons.

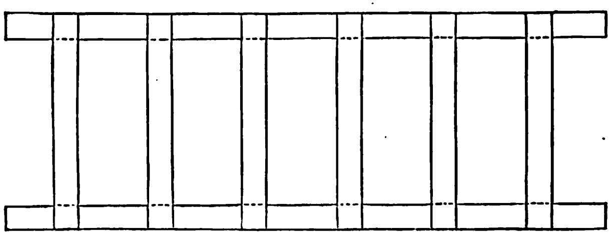


Fig. 32.

This template or batten mould is fixed by means of "hutch hooks" against the frames, at the place where the plate is to be fitted, and the lines of the butts and edges are marked upon it. At the same time the positions of the rivet holes in the frames are copied upon the template, by dipping a hollow cylinder of wood or iron in whiting, and putting it through the holes in the angle-irons. The template is then laid upon the plate, and the lines of edges and butts, also the frame rivets, are copied upon it, the latter being performed by means of a "marker" or reversing tool (see Plate CVII.). This is done by dipping the projection *A* in whiting, and then holding the reversing tool as shown by the Plate; the hole *B* being immediately over the whiting mark for the rivet in the template. Then by pressing the lower fork down upon the plate, a circular mark is made, which, when punched out, gives the rivet hole in the correct position.

The edges and butts of the plates are lined off, the edges being sheared when for inside strakes, while both the edges of outside strakes and all the butts are generally planed to the lines. Sometimes the butts are also sheared, in which case they are fitted by chipping and "jumping" them; that is, by hammering the butt of the plate until it fits against the butt of the next plate. "Jumped" butts, now disallowed by Lloyd's rules, are obviously inferior in quality of workmanship to those which are prepared under the planing machine. Indeed, the jumping system is now rarely adopted, and only in small yards where there is a lack of planing machines. When the butts are jumped, the Liverpool rules require that "the ridge formed by jumping shall be chiselled off the inside, in order that the butt straps shall fit closely; the ridge outside to be hammered into the seam."

The edges and butts of a plate of an inside strake having been cut, and the holes for the frame rivets transferred from the template, the centres of the holes in the edges and butts have next to be lined off. The holes are usually set off by means of patterns or templates, a pair of which serve for the edges of that portion of the bottom in which the plating is of the same thickness. One of these templates is made to suit the rivets of the portion of an edge in a frame space where there is no butt on either of the adjacent plates, and the other for the case where a butt occurs. The reason for this will be seen by reference to Plate XCV. When the plates are of the same breadth, a single butt strap template will suffice; but, in any case, a template suited for the butt of a wide plate can generally be utilized for setting off the rivets in the butts of all plates of the same thickness. The rivet holes marked on these templates are bored out, and thus the holes are easily transferred to the plate by means of the hollow cylinder and whiting.

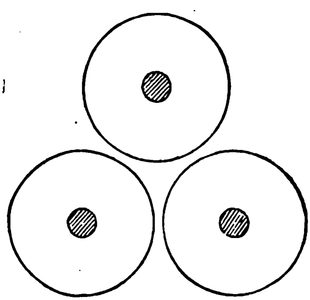


Fig. 33.

Should it be necessary to give great curvature to the plate, the latter is bent between iron rolls, the exact shape of the plate being obtained by the aid of section moulds having straight edges, which are out of winding when the plate is to the required form, the moulds being held in their proper positions. There are various kinds of plate-bending machines; a sectional view of one variety is shown by fig. 33. It consists of three iron rollers, each about 16 feet long and 20 inches in diameter. The upper roller rests in bearings, being free to revolve, but not turned by the machinery which causes the two lower rollers to revolve. It can be raised or lowered to suit the circumstances of the case, this being done by the aid of a lever. When being bent, the plate is lifted by a number of men, under the direction of the "plater" in charge, who hold the plate in the necessary position for obtaining the required curvature and twist. The plates are bent cold, unless very considerable curvature is required, as at the boss. Generally, when the plate is forged to its shape, a skeleton mould is made for it, constructed of small iron rods bent and welded together. In this way the inner strakes are cut, bent, punched, and fitted, after which they are temporarily secured in place by means of nut and screw bolts, "cotters," etc., until the outer strakes are brought on.

297. The Outer Strakes (or raised strakes).—The garboard strakes are the most difficult to prepare of the outer strakes of bottom plating, when either the bar or side bar system of keel is adopted. The difficulty referred to arises from the furnacing which these plates must undergo, before they can be bent to the angle between the bottom of the ship and the side of the keel (see *A*, fig. 2, Plate XCII.). This bending is very carefully performed, the plate being usually bent on a cast-iron slab, and then proved by section moulds. In order to get a satisfactory set of rivet holes for connecting the garboard strakes to the keel and adjacent plating, it is advisable to shore the plate in place, and mark the rivets in that position.

Templates are generally used in taking account of the rivets in the edges of the inner strakes, above and below the outer strake to be fitted, for the purpose of setting them off upon the latter; except in the case of light plates, which are held up or shored in place, and the holes marked upon them. As already mentioned, some builders prefer holding up or shoring, and then marking the holes on heavy plates in this way. The template employed for outside strakes is similar to that shown by fig. 32, and the holes are transferred from them to the surface of the plate by means of the reverser, shown by Plate CVII.

A patented template has been used on the Thames, having a number of revolving tongues of zinc working on its edges, with holes in them. These tongues can be set in any direction, so as to indicate the position of the rivet holes in the inner strake of plating. No reverser is required with this template. The template commonly in use on the Thames is similar to that shown by fig. 32, except that the two extreme cross battens are connected to the upper and lower battens with working joints, and the remaining cross battens are of thin iron, which can be set to the positions of the frames. The holes for the butt straps of the outer strakes are set off similarly to those of the inner strakes; also the butts are fitted and the edges sheared as before stated.

298. Sheer Strakes.—As every precaution should be taken in building a ship to have the material most efficiently disposed, it necessarily follows that the greatest longitudinal strength should be given at the upper and lower parts; being where the greatest tendency to extension and compression occur. The vertical keel, side keelsons, and the other longitudinal connections in their vicinity, when properly arranged, afford the required strength at the lower part: we have now to consider one of the principal modes of providing corresponding resistance at the upper part of the ship.

Sheer strakes are the strakes of the plating (generally *outer*) which are adjacent to the principal decks; the strake in the wake of the main deck being that to which attention is chiefly given. In vessels of extreme length this strake is doubled for a considerable distance amidships, and in all cases it is thicker than the adjacent strakes (see Plate LXXXIX.), and should be connected to the deck-stringer plate. No holes should be cut in these strakes without compensation, this being effected either by doubling the plates above and below, or by strengthening the stringers; the former being the most effectual method.

It may be remarked that the plates at the bilges are thickened, and frequently doubled, for a considerable length amidships in very long ships; the extent to which either of these is done being laid down by Lloyd's and the Liverpool rules. In the latter case the butts of both thicknesses are carefully strapped, and the two thicknesses riveted together between the frames.

299. Riveting in Bottom Plating.—Reference has already been made to the riveting of the bottom plating; we will now consider this subject somewhat more in detail. It will be obvious that since the bottom plating occupies such an important position in the structure, the riveting upon which the efficiency of the plating entirely depends must be deserving of careful attention.

There are three sets of rivets in the bottom plates of a ship, viz., those in the edges, butts, and frames (whether transverse or longitudinal). Unless the frame is watertight, the rivets connecting the bottom plating to it are openly spaced, generally from seven to nine diameters of the rivet from centre to centre; but at the watertight transverse and bulkhead frames the rivets are spaced about six diameters apart, while in the watertight longitudinals the spacing is about five diameters.

The rivets in the edges are sometimes in a single, and at other times in a double, row. Lloyd's rules require, that "in all vessels the edges of the garboard strakes and the lower edges of sheer strakes are to be double riveted. When the remaining outside plating is $\frac{6}{16}$ of an inch in thickness, or less, the edges may be single riveted; when the plating is above that thickness, the edges must be double riveted, from the keel to the height of the upper part of the bilges, all fore and aft. In all vessels the edges of the plating above this height (excepting the lower edges of sheer strakes) may be single riveted if the plating is $\frac{8}{16}$ of an inch, or less, in thickness; but if above that thickness they must be double riveted." The Liverpool rules also require the same conditions. In the Royal Navy double riveting is always adopted in edges, except in cases of ships sheathed with wood, which are single riveted at the edges, the plates being thinner than those in ships of the same size which are not sheathed. The narrow lap for a single row is shown by Plate XCVI.

Double riveting is of two kinds, viz., *chain* and *zig-zag*. The former is shown in Plate XCV., and fig. 3, Plate XCI.; while the latter is shown by fig. 2 on the same Plate. The *Liverpool* rules require chain riveting for all double and treble riveted joints and butts, but Lloyd's rules merely recommend its use, without enforcing the same.

Again, the Liverpool rules permit the rivets in the edges of the sheer and garboard strakes to be of the size corresponding to the thickness of the adjacent strakes (Art. 327), but that the rivets in the butts shall be the size required for plates of equal thickness.

By both the rules it is required that the widths of the laps of the plate edges shall not be less than six diameters of the rivet, when double chain riveting is adopted; and three and a half diameters when single riveting is worked. The Admiarlty practice is rather less than the above.

As a general rule rivets should never be nearer the butt or edge of any plate, angle-iron, edge strip, or butt strap, than a space equal to its own diameter, a little more being preferable; and in edge or butt riveting the space between two consecutive rows of rivets must not be less than one and a half times their diameter, one and two-third times being preferable.

Butt straps of bottom plating are always, at least, double riveted, and sometimes treble riveted. The butt straps are the same thickness as the plates they unite, and the strap is cut with the grain of the iron in the same direction as in these plates. Lloyd's rules require a length equal to thirteen diameters of the rivet for double-riveted straps, and nineteen diameters for treble. The requirements of the Liverpool rules vary from thirteen to fourteen diameters for double, and demand eighteen diameters for treble, riveted straps. In both these rules the lengths of the straps have been increased by one or two diameters during recent years. The Admiralty practice is about twelve diameters for double, and sixteen and a half diameters for treble, riveted butts.

Lloyd's further stipulate that the rivets in both edges and butts shall be spaced not more than four and a half times their diameter from centre to centre; and this is the Admiralty practice. By the Liverpool rules, however, the spacing is four diameters apart. In treble-riveted butts both the rules permit alternate rivets to be omitted on the farthest rows from the butt; this practice is not observed in plating the *bottoms of iron ships.*

The rivets in edges, butts, and angle-irons should be punched *from the faying surfaces;* that is, the faying surfaces are to be uppermost when the plates are held to the punching machine; as by this means the conical form given to the hole by the punching tool is such that when the plates are in place and the holes coincident, the latter are the shape of two frustrums of cones joined at their small ends. The extra binding effect of the rivet by this arrangement need hardly be pointed out. The holes for the frames, and those in the edges of the raised strakes, also those in the butt straps, are countersunk on the outer surface; the countersink generally extending through the thickness of the plate. The outside or point of the rivet is chipped flush, or nearly so, after it is hammered up; the usual practice being to chip the rivet points slightly convex beneath the water line, but flush above. The rivets should be of a conical shape under the head, in order to fill up the conically-shaped holes in the angle-irons and inside strakes of plating.

300. Liners.—The raised and sunken system of bottom plating requires *liners* to be fitted between the outer or raised strakes, and the frames. Except in the watertight frames these liners are about the same width as the frame angle-irons, and the rivets connecting the frames to the plating necessarily pass through the liners.

In the preceding article it was remarked that, while the rivets connecting ordinary frames and bottom plates are seven to nine diameters apart, those in the watertight frames are only six diameters. Although this is a wider spacing than is adopted in watertight joints at other parts of the ship, yet it will be observed that a row of rivet holes so arranged reduces the strength of the ship at a line passing through them by one-sixth, and even more than this if we take into account the deterioration in the quality of the iron in the remainder of the section caused by punching these holes. In order to bring up the strength of the ship at this section to the same as at an ordinary frame, the liners at these watertight frames in H. M. ships are made wide enough to take two additional rows of rivets on each side of the frame, and thus serve as butt straps to join the portions of the plate on both sides of the line of rivets. (See the watertight frame in

Plate XCV.) Lloyd's and the Liverpool rules require that the liners shall extend from the fore side of the frame before the watertight frame or bulkhead, to the aft side of the frame abaft it. It should be remarked that in the ships of the Royal Navy the longitudinal frames afford a connection between the portions of the plates on both sides of a line of rivet holes, which is altogether wanting in ships built on the transverse system (see Art. 278). Besides this, the frame space is so small in merchant ships, compared with the length of the butt strap, that a double row of rivets on each side of the angle-iron is nearly tantamount to the requirements of the rules alluded to.

301. Stealers.—As already stated (Art. 138), the great difference between the girth of the ship at amidships and the extremities renders it necessary to end some of the strakes of bottom plating before reaching the bow and stern, particularly the former. Plate CVIII. shows an expansion of the forward portion of the bottom plating of an ironclad. It will be seen by reference thereto that the two uppermost strakes terminate before reaching the bow at the points *S*, *S*; two strakes in each case blending together so as to form one. This union is effected in different ways, that shown by Plato CIX. being very satisfactory. It will be seen that *X* strake is a stealer finishing at its fore end flush with *IX* strake. The manner in which this is done is shown by the section at *A*, *B*, and *C*. The edges of the plates are rabbeted together, the rabbet being 7 feet long. The edges of the plates are strengthened at the joint by an edge strip, as shown; the latter being formed to serve also as a butt strap at the end of the stealer. *E E E* represent tapered liners in the wake of the frames.

302. Frame Spacing in Relation to Butt Fastening.—Uniformity of strength in the connection of the bottom plates at their butts and edges is of the highest importance; and, as we have already seen, the butts should be carefully shifted and strapped in order to insure this result.

The weakness at a section passing through a line of frame rivets in the bottom plating is evidently unavoidable; and the best practice has been to take the tensile strength of such a *section* as a standard in calculations for regulating the fastenings at the butts. Mr. W. H. White, Professional Secretary to the Admiralty Council of Construction, in an interesting and instructive paper read by him at the last (1873) annual meeting of the Institution of Naval Architects, has shown that the frame spacing is an important element in such a calculation; and that the advantages of long plates and a careful shift of butts have frequently been neutralized by the close spacing of frames now adopted in the merchant navy, and required by Lloyd's and the Liverpool rules.

The author in his paper says:—

"Supposing the butt of any particular strake to be that under consideration, it would be proper, according to the ordinary method, to consider this butted strake to be associated with and helped by two out of the four passing strakes which on either side intervene between this butt and the next butt falling in the same frame space with it. If the shift gave only two passing strakes between consecutive butts, then the butted strake would be supposed to be helped only by one strake on either side, and so on. Having settled this important condition, the strength of the strakes associated together is calculated for the weakened section adjacent to the butt; and this strength is made the standard of comparison for breaking strengths corresponding to other less direct, but not improbable, modes of fracture, which would lead to the rupture of the passing strakes, and the tearing asunder either of the butt, or of the butted strake, at some section near the butt. The plan, however, is principally useful as a mode of analysing cases when the frame space and shift of butts are both determined upon; and for our present purpose some further assumptions are necessary. These will be briefly summarised, and then applied.

"First, it will be taken for granted that the maximum amount of succour which a *butted* strake can receive from the adjacent *passing* strakes, is determined by the shearing strength of the edge rivets lying between the necessarily weakened section of the plating nearest to the butt, and some line across the butted plate, or the butt strap, made unusually weak by being pierced to receive the butt fastenings. This is really only equivalent to saying that the passing strakes are far more likely to yield at their weakened sections in wake of the frames than at their practically unpierced sections intermediate between the frames; and that the question whether the butted strake will yield at the same section, or have its edge fastenings sheared and its butt torn asunder, depends mainly upon the strength of the edge fastenings between the butt and the weakened section at the frame.

"Secondly, since the utmost help which can be given to the butted strake by any shift of butts is limited by the shearing strength of these edge rivets, it follows that when the number of passing strakes between consecutive butts lying in the same frame space has been made sufficiently great to secure the fracture of those passing strakes at their weakened section, all further additions to the number of passing strakes are comparatively useless.

"It will be obvious that the number and shearing strength of the afore-mentioned edge rivets is practically governed by the frame space; and it is on this account that frame space has such an important influence on the arrangement of the butt fastenings.

"This departure from the ordinary method of calculation will be seen to lead to a considerable saving of labour; besides enabling the effects of frame space and shift of butts to be considered separately, and determining the shift of butts that should be made use of in association with a certain frame space and edge riveting. The butted strake is, in fact, treated far more independently, although not dissociated from the passing strakes."

Having given some specimen calculations to illustrate his arguments, Mr. White further states in his paper :—

"Apart from quantitative results, however, it must be admitted that the easiest and best way of securing proper strength for the butts is to increase the spacing of the transverse frames, and thus to succour the butt fastenings by the edge riveting to a greater degree than is now possible. This conclusion, supported as it is by numerous calculations, furnishes another argument against the ordinary system of framing iron ships; and although not worthy to be named in comparison with the more weighty arguments based upon a consideration of the strength of the ship as a whole, it is not without force. There can be little question but that a considerable loss of strength in the skin plating, at present resulting from the close spacing of the transverse frames, would be avoided if these frames were spaced more widely; and it is to be hoped that before long some change of the kind will be initiated. With a frame space of say 3½ or 4 ft., and with plates from 10 to 12 ft. long, the present defective butt fastenings might easily be made all that could be wished, without incurring any additional cost or involving any additional weight on the skin itself."

Further calculations made by the author,

"Show that *one* passing strake between consecutive butts would suffice (with the experimental data employed) to secure all that is needed; and that, with the 22 or 24-inch frame spaces, all other shifts of butts, giving a greater number of passing strakes between consecutive butts in the same frame space, are of practically no greater use in succouring the butted plates than the common *brick* shift. With the transverse frames placed further apart, say from 3 to 3½ feet, the number of edge rivets to be sheared is of course greater, and it would undoutedly be desirable to have two passing strakes between consecutive butts, just as has been the practice for many years past in the iron ships of the Royal Navy, where the frame space is from 3½ to 4 feet. With a still greater frame space three or four passing strakes might be advantageously employed; but extremely long plates would then be required, if the assumed conditions of the previous cases were made to hold, and the arrangements would really resemble very closely those of a longitudinally-framed ship—a case to which we shall refer hereafter."

The conclusions at which Mr. White arrives are as follow:—

"1*st*, For longitudinal-framed ships.

"I. In such special vessels it is most advantageous to make use of long plates, and to adopt a shift of butts enabling one to associate a good number of passing strakes with a good 'step' between the nearest butts of adjacent strakes.

"II. Necessarily weakened sections must exist near the butts in order to receive the closely-spaced rivets required for caulking the joints; and the utmost efficiency of the edge-riveting with any particular shift of butts is reached, when the shear of the rivets in the 'steps' brings up the breaking strength for indirect fracture to that for fracture along a line passing directly across the plating through a series of the weakened sections of the butted strakes.

"III. The shearing strength of the rivets on one side of the butts should never fall below the breaking strength of the butted plate along its necessarily weakened section. Consequently, with the ordinary pitch of rivets for watertight work, single riveting ought never to be adopted for the butts.

"IV. Single-riveted edges need not be sources of weakness, if associated with certain shifts of butts and lengths of 'step.'

"2*nd*, For ships in which the ordinary conditions are fulfilled, and the transverse frames occupy a prominent position, it would appear that very different conclusions must be drawn respecting the arrangement and the fastenings of the skin plating.

"I. So far as strength under tensile strains is concerned, the use of long plates is not specially advantageous, except when the frame space is unusually great—say from 5 or 6 feet upwards. Some saving of weight in butt straps would, of course, result from the use of such plates.

"II. The frame space, regulating as it does the amount of succour which passing strakes can give to butted strakes, practically governs the arrangement of the butt fastenings and affords a means of determining upon a suitable shift of butts.

"III. Double edge riveting is always a source of strength in such vessels, as compared with single edge riveting; but its adoption may, in some cases, necessitate a modification of the shift of butts. Single riveting for the butts is objectionable in these vessels for the reasons given above for longitudinally-framed ships.

"IV. It appears that an increase in the spacing of the transverse frames favours the more satisfactory development of the strength of the skin plating, without any increase in cost of workmanship or weight of material. A change in this direction has been repeatedly enforced on weightier grounds than the above, but has been long postponed. There can be little doubt, however, that nothing but advantage, so far as strength in proportion to weight of hull is concerned, would result from modifying the present system of framing, widening the frame space, and combining with the reduced transverse framing some well-considered system of longitudinal framing."

These statements and conclusions require no comment, but show clearly that notwithstanding the great experience and skill which have been brought to bear upon this important subject, both in framing underwriters' rules and in building up the practice of our best shipyards, there is still very considerable scope for progress in the art of iron shipbuilding.

303. Plating behind Armour.—The armour and backing of iron built armour-clad ships are secured to a skin of iron plating, which is riveted to a system of frames as referred to at Art. 287. This plating is generally very thick, varying from 1 to 2 inches, and both for facility of workmanship and strength of combination, as well as economy of cost, it is usually worked in two equal thicknesses, the edges and butts of which give shift to each other. The plates are butted upon the frames, being single riveted through the frame angle-irons. A stronger butt connection than this is unnecessary, as each thickness of plating is a butt strap to the other. The edges are also single riveted, and, in order to reduce the number of perforations in the plates, and leave as much flush surface as possible on the inside for heaving up the nuts and washers of the armour bolts, one of these rows of rivets sometimes serves to connect an angle-iron girder to stiffen the plates (see Art. 304, and Plate CX.). The outer edges and butts are made watertight, and consequently the rows of rivets in them are spaced sufficiently close for caulking. Such precautions are not necessary for those of the inner strakes.

The points of the rivets are usually countersunk, in order to give a flush surface against which to fit the backing. Great care should be taken in fitting these plates, and templating the holes, to insure that the latter may correspond in the two thicknesses. For this reason the holes in the outer thickness should be marked from those in the inner, although they are sometimes both marked from one template, and punched and fitted almost simultaneously.

304. Girders behind Armour.—The girders are formed of angle-irons, the deep flanges of which are about an inch less in width than the thickness of the backing, the flange riveted to the plating being about 3½ inches wide. They are in lengths as great as can be procured, and their butts are carefully shifted and strapped. If the girder is near the water line of the ship, the edge of the angle-iron upon the plating is chipped and the joint caulked, although the riveting is not more closely spaced than usual for this purpose. This is done in order to keep any water between the backing and plating from getting under the angle-iron, and then by means of a rivet hole, not properly filled, circulating between the two thicknesses of plating. These girders are disposed so that they may be clear of the armour bolts, and generally placed so that there are two girders behind each strake of armour plates. In the case shown by Plate CX. there is only one girder behind each strake.

305. Side Plating above Armour.—The plating on the sides of war ships above the armour is usually flush, being connected by single riveted edge strips and double riveted butt straps, the former being in short pieces between the frames. The spacings of the rivets in edges, butts, and frames, are similar to those in the bottom plates (see Art. 299); also the butts are disposed by similar rules (see Art. 294).

CHAPTER XX.

306. Beams.—Of the many sectional forms of beams that have been adopted in iron ships, there are five principal varieties still in use. In fig. 34, A represents the section of a T bulb beam, a very usual form, as it combines lightness with the necessary shape to afford good security for the deck fastening, and resisting vertical and lateral bending forces.

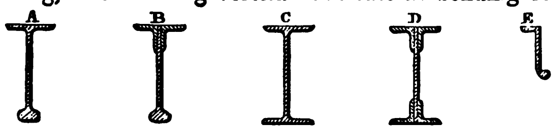


Fig. 34.

B is a variety which is more in use than any other, especially for deep beams, as the T bulb, when rolled to a large size in one piece, is very expensive. This beam consists of plate bulb, with an angle-iron riveted to it on each side, and is therefore heavier than the beam at A when of the same depth and width of flange. It should be stated that the beam at A was, until recently, rolled in two pieces, viz., a T piece and a piece of plate bulb. These were welded together, the joint being situated along the line of the *neutral axis* of the beam, *i.e.*, the part of the beam which, when the latter is bent, is neither extended or contracted. The Butterly Company had the patent right to manufacture these beams, which were known as the "Butterly Patent Welded Beams." Recently, however, beams have been rolled, in one piece, to this section. C shows a form of section which has been strongly recommended and sometimes adopted; it cannot, however, be rolled in long pieces, consequently that shown at D is generally used in cases where a long, strong beam is required. In this latter form of section the upper angle-irons are larger than the lower, as the former have to receive the deck fastenings.

The section at E is that of a beam termed angle bulb, often used in the decks of small vessels, and for the light decks such as poop and forecastle in larger ships.

307. Sizes of Beams.—Lloyd's rule for beam plates requires that their depth shall be "one quarter of an inch for every foot in length, and to be in thickness one-sixteenth of an inch for every inch in depth." The Liverpool rule is almost identical with the preceding. Lloyd's rules further require that "the sizes of all beams which are not less than three-fourths of the length of the midship beam may be in proportion to their lengths, all other beams must not be less than three-fourths the depth and thickness of the midship beam, excepting at hatchways exceeding in length four spaces of frames, mast and pall bitt beams, and beams under the heel of bowsprit, which must not be less in size than the midship beam."

The Liverpool rules require greater uniformity in the dimensions of beams, as may be seen by the following extract:—"The full depth and thickness of the beams to be carried over three-fifths of vessel's length amidships; and may be reduced thence to ends as follows:—main deck beams one-sixteenth of an inch in thickness, and, at after end only (except in vessels having three tiers of beams), one-sixth of their depth. Lower and orlop deck beams one-sixth of their depth, and one-sixteenth of an inch in thickness at both ends when the thickness is nine-sixteenths, and two-sixteenths of an inch when the thickness is ten-sixteenths, and over. Beam knees to be the same depth all fore and aft."

In war ships, the sizes of the beams are governed by the weight of the armament, and sometimes a shallow beam is fitted in order to get as much space as possible between decks; in such a case the strength is made up by increasing the number of the beams, or some other such expedient.

The beams of merchant ships are usually rolled in one length; but for wide ships it is necessary to weld the plates and angle-irons; the butts of those in each beam being well shifted with relation to each other, and to those of the adjacent beams, so that the pieces of alternate beams are similarly arranged. The made beams for H.M. ships (see D, fig. 34), are generally formed in this way; sometimes as many as four plates and twelve lengths of angle-iron entering into the construction of each beam.

308. Spacing of Beams.—The spacing of beams in merchant ships is of a very variable character, depending upon the ratio of the length to the breadth, also upon the number of decks to the ship. In all cases the beams are fastened to frames, and placed immediately over each other. The usual spacing of beams in H.M. ships is 4 feet, being placed at alternate frames, which are generally 2 feet apart above the armour shelf.

309. Beam Arms.—These are very important parts of the beam, as the efficiency of the latter entirely depends upon its connection with the ship's side. There have been many forms of beam arm, but that shown by Plates LXXXIX., XCIV., and XCVI., is now almost universally adopted. The shape of this arm is obtained in two or three different ways. To make the arms of the Butterly beams, already referred to, the welding of the two portions of the beam is omitted for a short distance from each end of the beam as supplied from the maker, and the lower half is heated and bent down to the required curve of the arm, while the upper is left straight. The form of the arm is then completed by welding a piece so as to join the upper and lower parts, sometimes leaving a triangular hole rounded at the angles, for the purpose of reducing unnecessary weight. This method is also sometimes employed in forming the arms of plate bulb beams, but in this case, the end of the beam must be heated, cut, and the lower part bent. The arms of the **I** beams as shown at C, fig. 34, also of the angle bulb shown at E, are made in the same manner. On the Clyde, however, the arms of the section shown by B in that figure (which is the pattern usually employed), are often made by bending the whole of the end of the beam plate to the required shape of the arm as shown by ABC, fig. 35, and then welding a piece of plate at the upper corner of each end of the beam, as shown by D in the figure; the bottom of the arm being finished off as shown by the line DE. At Messrs. Elder's yard, Govan, the beam is cut to its length at A, fig. 36, the portion of the bulb between A and C is chipped off, and a short piece of bulb plate DE is welded on to form the arm, its upper end being curved as at C. A piece G is welded on, and the arm cut to the line AF. This mode of forming the arm does not appear to be so satisfactory as that shown by fig. 35. The arms of made beams, such as shown by D, fig. 34, are made by cutting the plate to the required shape of the arm, and bending the lower angle-irons to the curve of the arm and riveting it thereto.

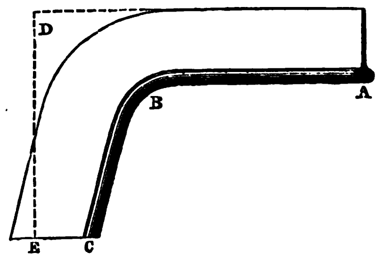


Fig. 35.

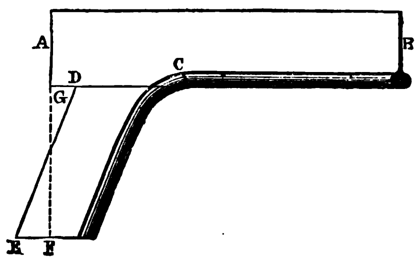


Fig. 36.

Among the many other modes of joining the beam with the ship's side, we may call attention to that shown on Plate CIII., where it will be seen that the upper deck beams and the frames behind armour are of one piece of bulb plate, or rather two lengths welded together, the welds of consecutive beams being situated on alternate sides, at about 6 feet from the middle line.

Both Lloyd's and the Liverpool rules require that the length of the arms shall not be less than two and a half times the depth of the beam; in the Royal Navy, however, the arms are generally three and a half times that depth.

The riveting is generally arranged upon a template by which the holes in both the frame and beam arm are set off simultaneously; but sometimes the holes are set off in either of these, and from thence transferred to the other. The former is the practice adopted on the Clyde.

310. Bending Beams.—When the beams are set to their round up cold, the operation is performed by means of a screw press, or a beam-bending machine. They are, however, frequently bent hot; sometimes upon the bending slab similarly to the frames, and at others by resting the beam, when heated, upon blocks laid to the required curvature, and allowing it to settle down to its shape. The first named method is the most usual.

The plate bulb of beams, such as B, fig. 34, should be bent before the angle-irons are riveted to their upper edges, after which it is necessary to check and adjust the curvature, which alters slightly in the process of riveting. It may be remarked that the riveting of both beams and frames is now frequently performed by means of a riveting machine. The beams are proved by a beam mould, and are generally cut to the lengths given by the scrive board, or mould loft floor; by reference to which, also, the angles of the arms are determined. Sometimes, however, the beam arms are cut to the angles given by moulds which are themselves made from the floor, the lengths of the beams being given by a mould, as shown by fig. 1, Plate LXV. This latter is the practice of the Royal dockyards, while the former is peculiar to the northern shipyards. The processes of bending, adjusting, and cutting the beams, also riveting the angle-irons to the plate bulb, are usually carried out simultaneously with the riveting up of the frames. On the Clyde, all the beams of small vessels are riveted to the frames before the latter are erected; but in vessels of more than about 1000 tons burthen, the upper and main deck beams only are so riveted, and the remainder are fixed and secured afterward. The reason for this difference is, that the collective weight of the beams and frame of a large ship being so great, renders it very difficult to erect without straining and loosening the riveting. On the other principal shipbuilding rivers, the beams are not riveted until the frames are erected, the two sides of the latter being in the meantime connected by cross spalls.

311. Half Beams and Carlings have the same functions as when of wood. They are usually of smaller size than the beams, except when the carlings form the sides of long hatchways, when they are often of larger sectional form than the beams; and the half beams are then frequently made of light angle bulb, especially when the hatchway is also very wide. The connection of beams and carlings is by means of angle-iron corner pieces, when the beams are of a rolled section; and by turning down the upper angle-iron of the carling against the beam when it is of the section shown by B, fig. 34. Carlings made of the section shown by D on that figure, are made of a plate and two box-shaped angle-irons, the latter being riveted to the adjacent beams.

312. Watertight Bulkheads are a peculiar feature of iron ships, as the manner of framing the ship and the materials employed afford special facilities for the construction of such water-tight divisions.

Iron transverse watertight bulkheads are constructed in several ways. In H.M. service the plates are generally arranged horizontally, while in some private yards, especially on the Clyde, they are arranged in vertical strakes. In the Royal Navy the bulkheads at the extremities of the smaller compartments are connected by single-riveted lap joints and butts (see *A*, Plate CV.), the bulkhead being stiffened by angle-irons about 24 to 30 inches apart (see *B*). The bulkheads of larger compartments, such as the engine and boiler spaces, are generally built with flush joints connected by T bars, the edges of the plates being closely fitted upon the middle of the flange, which thus serves as an edge strip, while the web of the T bar stiffens the bulkhead; the butts are strapped and double riveted. In this case also, the bulkhead is stiffened with angle-irons on the opposite side to the T bars; the two sets of angle and T bars thus form a rectangular lattice work of stiffeners.

The bulkheads of large merchant ships often have single-riveted lap joints and butts, and are stiffened by horizontal angle-irons at the middles of the plates on one side, and by vertical angle-iron stiffeners about the same distance apart on the opposite side, the butts of the plates being brought to the middles of the spaces between the vertical stiffeners. The shift of butts is not very important, the *brick* arrangement being usually considered quite sufficient.

When both the edges and butts are lapped, the corners of the plates that come between two others are beaten down thin, so as to bring the thickness of the three plates to about the same as that of two plates elsewhere, and to allow the joints to be caulked. As will be supposed, liners are required behind the stiffeners by the lap-jointed system. The rivets in the butts and edges are spaced as for watertight work elsewhere, while those in the vertical stiffeners are spaced about ten to eleven diameters apart.

313. Connection of Bulkhead to Ship's Side.—Great difficulty has been experienced in connecting the transverse watertight bulkheads to the ship's side. This is due to the close spacing of rivets which is necessary in order to obtain a watertight joint between the frame angle-iron, which connects the bulkhead to the side, and the bottom plating, whereby the bottom plating is pierced by a line of holes, producing considerable local weakness. One of the earliest methods of connecting the bulkhead to the bottom plating was by a single frame angle-iron; the defect of this method has just been alluded to. At the present time there are two modes of performing this work adopted in the merchant navy, both of which are sanctioned by Lloyd's and the Liverpool rules. One of these consists in connecting the bulkhead with a double frame angle-iron, and by the other method the bulkhead is connected with a single frame angle-iron (sometimes with double zig-zag riveting), and with horizontal bracket or knee plates riveted to the bulkhead and outside plating. The brackets are placed on alternate sides of the bulkheads, and at or near the centres of the strakes of bottom plating upon which they come. It may be remarked that sometimes these brackets are fitted together with double frame angle-irons, although such is not required by either of the above rules. Wide liners are fitted between the bulkhead frames and bottom plating, as described at Art.

300, which serve also as straps to butts of bottom plating in the frame spaces adjacent to the bulkhead.

In ships with double bottoms, the bulkheads in the wake of the inner bottom are connected to the plating of the latter, generally by a single angle-iron. The watertight division is completed to the outer bottom by means of watertight frames, which have already been alluded to. Before and abaft the double bottom, the bulkheads are lapped upon and riveted to the floor plates, and continuous reverse angle-irons of the frames.

Great care is taken to preserve the continuity of strength of the longitudinal framing, such as keel and keelsons in ships as ordinarily framed, and the keel, longitudinals, armour shelf, inner bottom, etc., in armour-clad ships, where these pass through the transverse bulkheads; and at the same time to obtain watertight joints. Plate CV. shows a method of covering these joints, the particular form of the angle-iron being of course governed by that of the longitudinal frame or other longitudinal connection.

314. Longitudinal Bulkheads occupy a subordinate position compared with those just considered. Both the Underwriters' rules enforce the fitting transverse watertight bulkheads, in number according to the size and character of the ship; but no reference is made to longitudinal bulkheads. In steam ships the longitudinal bulkheads of the coal bunkers are sometimes made watertight, also the bulkheads of the shaft passages. Great prominence is given to longitudinal bulkheads in ships built by Mr. Scott Russell's longitudinal system, as in the *Great Eastern*. The engine and boiler spaces of several twin screw iron-clad ships of the Royal Navy, now in course of construction, are divided by longitudinal bulkheads, extending as high as the main decks. It is evident that the two sets of engines required for twin screw ships, afford opportunities for fitting these bulkheads in the engine room not found in single screw ships. The statical and structural advantages derived from them are of course considerable.

A great many small iron bulkheads are fitted in H.M. ships to enclose magazines, shell rooms, spirit rooms, chain lockers, etc., all of which, while essential to the internal economy of the ship, are in most cases of service considered structurally and statically. The details of their construction are unimportant.

There are a great many fittings, such as water-tight doors, sluice valves, etc., inseparable from a detailed description of water-tight bulkheads, but which require more space for their due consideration than can be spared in this work.

315. Pillars.—The beams of iron ships being riveted to the frames, and thus arranged in vertical tiers, an efficient system of pillaring is easily obtained. This is very important, as the pillaring of a frame adds considerably to its strength, by acting both as a strut and a tie; consequently the strength of the whole structure is correspondingly augmented. A pillar at the middle line increases the strength of a beam by about one half; and the resistance to transverse bending is increased by connecting the beams with the floors.

Lloyd's rules require "all beams for at least one-half the length of the vessel amidships, the alternate beams before and abaft this length, and all hatchway carlings, to be pillared; the pillars to have not less than two rivets in each of their ends, so as to form a continuous tie from the keelson to the upper, spar, or awning deck."

The Liverpool rules require pillars on every beam for one-third the length, and agree with Lloyd's regarding the number of pillars before and abaft that space.

Formerly, in war ships, it was not considered necessary to secure the pillars at both the head and heel; but since the introduction of the present heavy guns into naval armaments, it has been found requisite to give due attention to the pillar as a tie, in consequence of the great tendency of the deck to lift, which is experienced when these heavy guns are fired over it. In addition to this, it is evident that the working of the ship must at times bring a similar strain upon the pillars, which should therefore be secured at the heels.

Solid wrought-iron bars are commonly used for pillars in the merchant navy (see Plates LXXXIX. and CXIX.), these being generally riveted by means of a palm to the side of the beam, and secured through the deck plank to the beam below by means of nut and screw bolts, which are made watertight by means of grommets. Similar pillars in H.M. ships are connected in the same way.

Tubular pillars are very commonly used in the Royal Navy in preference to the solid bars, as the former possess greater lateral rigidity with the same weight of material. The tubular pillars are welded or riveted to solid heads and heels, by means of which they are secured, similar to solid bar pillars. When pillars are fitted under an **I** beam, the heads are made and secured in the same way as the heels.

Around capstans, and in similar positions, it is necessary to fit portable pillars. These are sometimes made to revolve on a pin at their head, and to tighten by driving the heel over a wedge-shaped shoe, the same as described at Art. 229. A better method, however, is to tighten the pillar by means of a brass nut with a hemispherical bottom, screwed on its heel, the convex part of the nut resting in a hollow deck plate secured to the deck. The pillar is tightened by turning the nut with a spanner. It is hardly necessary to state that the hole in the head of the pillar, about which it revolves, is made oval, in order that the pillar may rise to the necessary extent, as the nut is hove up, in order to take its proportion of the weight of the deck.

316. Mast Holes.—The deck framing around the mast hole of an iron ship, consists of the beam adjacent to the mast, a carling on each side between the beams, and a plate riveted upon these beams and carlings, with sometimes another plate riveted underneath. In this way a cubical space is enclosed that is sometimes filled in solid with wood, through which a hole is cut for the mast, in the manner shown by Plate LXXVIII. The most usual mode is to fit and secure an iron tube, as shown by Plate CXI. In both cases the mast is kept firmly in place by wedges driven between it and the iron tube.

The Liverpool rules require "mast partners at decks, where wedged, to be plated over twice the width of the hole cut out of them, and to take three beams in length."

Lloyd's requirements are equivalent to the preceding, with the addition that the plating is not to be less in thickness than is required for stringer plates. Of course, these rules apply only to sailing ships, and are not strictly adhered to in steam vessels.

317. Stringers.—Stringers are of two kinds, viz., *hold* and *deck stringers.* The deck stringer consists of a strake of plating, fixed in a direction about square to the surface of the side plating; and it serves the double purpose of a longitudinal tie and to stiffen the bottom plating, while, at the same time, it tends to keep the frames and beams in their correct relative positions, giving rigidity to the structure in its vicinity.

Hold stringers sometimes consist of plates and angle-irons, and at others of angle-irons only; they are connected to the ship's bottom by brackets, which are riveted to alternate frames, the stringer being connected to both the bottom plating and bracket by pieces of angle-iron worked intercostally.

Deck stringers (see Plates LXXXIX., XCIV., and XCVI.) are the strakes of deck plating riveted upon the top of the beams against the ship's side, being generally connected by angle-irons to the outside plating. The longitudinal strength of the stringer is necessarily limited to the tensile strength of the plate and connecting angle-iron, consequently an ordinary stringer does not offer very considerable resistance to the strains due to bending moments. But it is in their connection with the beams and sheer strakes that the efficiency of the stringer is developed, for in this way a girder is formed at the sides of each of the decks, which resists longitudinal alteration in the ship's form, whether she be at rest upon an even keel or rolling in a seaway. It will also be noticed that when the ship is working at sea, great racking strains are set up, tending to alter the relative positions of the beams to each other and to the ship's side; to resist all of which the stringers, by their position and form, are eminently adapted.

Lloyd's rules require stringers of upper decks when the ship has two, and main deck when three, tiers of beams, to be "in width one inch for every seven feet of the vessel's length, for half her length amidships, and from thence to the ends of the vessel they may be reduced to three-fourths the width amidships; in no case, however, is the width to be less than eighteen inches." The same rules further require that "the stringer plates on all tiers of beams are to be fitted home and riveted to the outside plating fore and aft, with angle-irons." Also that "the objectionable practice of cutting through the stringer plates for the admission of wood roughtree stanchions will not be allowed."

The Liverpool rules require much wider stringers than Lloyd's for small, and rather narrower for large, vessels. For instance:—By Lloyd's rules the main deck stringer of a ship 100 feet long is 18 inches, and by the Liverpool rules it is 25 inches, whereas, for a ship of 500 feet in length the former require 71½ inches wide, and the latter 65 inches. It will thus be seen that on the whole the Liverpool rules require the widest stringer plate.

The butts of stringer plates should be shifted clear of those of the sheer strakes, also cargo ports and all openings in the side adjacent to the decks. Wherever it is necessary to cut holes in the stringer for scuppers, etc., the strength should be made up by fitting straps around the hole, or by doubling the sheer strake on the inside in the vicinity. The butt straps of stringer plates are generally treble-chain riveted. As a water-tight joint is not required it is very usual to omit alternate rivets in the row next to the butt, thus increasing the strength of the connection.

318. Tie Plates, sometimes fore and aft, and at others fitted diagonally, are required by both Lloyd's and the Liverpool rules (see Plate LXXXIX.). They serve to connect the beams, and thus relieve the deck fastenings of the strains brought upon them when the ship is working. The deck fastenings are not so efficient in iron as in wood beams, and hence both stringer and tie plates are of service in opposing the first tendency of the deck to elongate.

However, Mr. E. J. Reed and other eminent authorities call attention to the fact that tie plates are not a satisfactory form in which to work iron into a ship, as they give but little aid to the vertical plating, such as sheer strakes, etc.; whereas, if the same amount of material were added to that already worked in the form of stringer plates, it would be much more advantageously disposed (see *F*, Plate LXXXIX). Even as at present worked, tie plates would be of much greater service if deck fastenings were placed through both the deck planks and tie plates, between the beams, as by this means the longitudinal strength of the deck plank, an important item in the hull of a wood ship, could be utilized; whereas, when the fastenings are through the beams only, very little of the strength of the plank is developed.

Mr. Nathaniel Barnaby, the Admiralty Chief Naval Architect, in a paper read before the Institute of Naval Architects in 1866, on "Economy of Material in Iron Decks and Stringers," proposed a novel mode of lightening stringers and tie plates without reducing their strength; on the contrary, he stated that the tensile power of the plates will be increased when thus lightened. "The principle on which this arrangement rests is, that when strains are suddenly applied to the plates, it is necessary to consider not only the number of tons required to break the weakest sections, but the amount which it would stretch before breaking, in other words, the work done in producing rupture. In order, therefore, to make the amount of work done as great as possible, it is necessary to reduce the strength of the plate between the weak sections, at the butts and beams, to the strength at these sections, or even to less than this, in order to obtain long spaces of uniform strength to give elongation. If these long spaces of uniform strength are not provided, and the plate is consequently left with strong parts between the beams, no practical elongation will take place in these strong parts under the action of a sudden strain; but the stretching will be thrown almost entirely on the weak points, and if any one of these is weaker, in any sensible degree, than the rest, it will be confined to that point. The author states that the fact that the strains of greatest magnitude in a ship are sudden makes the principle above stated of no slight importance to naval architects, because by its application the time is increased during which a given force must be applied in order to produce rupture."*

319. Gutter Waterways associated with stringers are often fitted in ships of the Royal Navy (see *G*, *G*, Plates XCIV. and XCVI.). Their construction is simple, while, at the same time, they constitute a very efficient longitudinal tie, and serve the twofold purpose of conveying water from

* *Shipbuilding in Iron and Steel*, by E. J. Reed, C.B. Pp. 164 and 165.

the deck of the ship to the scuppers, and connecting the beams and stringer to the framing. Lloyd's rules recommend that these gutters be cemented, and that practice is always carried out in H.M. ships.

320. Deck Plating.—But although the importance of the stringer, especially when efficiently connected to the side plating and frames with angle-irons, cannot be doubted, yet something more than this is required on the upper or main decks of long ships. The practice of plating over the greater portion or the whole of the beams of the upper or main decks of merchant ships is becoming more common of late years than formerly, this being, no doubt, due to the great length which is given to the high-powered steamers required for the ocean traffic of the present day. It is not usual, however, to plate the whole of the surface, it being evident that there is very little, if anything, gained by laying plating near the middle line, where it is pierced with large holes for hatchways, etc. Hence, when decks are plated for structural purposes only, it is usual to do so in four strips, viz., two wide stringers and a belt on each side of the hatchways, the belt and stringer on each side being sometimes joined at their edges.

In this arrangement, when each strake is aided by those adjacent to it, it is usual to connect the butts by double-riveted straps, although the stringers sometimes have treble-riveted straps as in other ships. The edges of deck plates are usually connected by single-riveted edge strips, both these and the butt straps being usually fitted on the upper side, and consequently the deck planks are scored over them. The riveting is countersunk on the upper surface of the plating to simplify the fitting of the deck planks.

When no wood deck is laid, as, for instance, in steam colliers, where the constant loading and unloading of such a cargo would soon damage a wood deck, the beams are covered with iron plating, in order to form a deck flat. In this case the joints are made watertight, and the edge strips and butt straps are fitted on the under side.

The upper and main deck beams of iron-clad ships are often covered with thick plating, chiefly for the purpose of resisting explosive missiles (see Plate CIII.). The plates vary in thickness from one to two inches, and sometimes as much as three inches. In order to reduce the weight and maintain a uniformity of resisting power, the thickness is made up with two or three thicknesses or layers of plates, generally two. The butts and edges of these give shift to each other, the former being brought upon beams and the latter on the middles of the other thicknesses of plates. Hence each thickness performs the function of butt strap and edge strip to the other. The riveting in the butts and edges of upper strakes is closely spaced, to enable the joints to be caulked; that in the other edges and butts is not spaced closer than about six to seven diameters apart. The holes are countersunk on the upper side of the upper strake, so as to give a flush surface.

In fitting this plating the holes in a plate should be marked from those already punched in the opposite plate, this method being preferable to marking both by the same template, as it is very difficult by the latter system to get the holes in the beams and the two thicknesses of plating to sufficiently agree for good riveting.

321. Deck Flats.—In Art. 223 reference was made to the mode of fitting deck flats to iron decks in wood ships, which description is equally applicable to those of iron ships. The shift of butts is the same as when secured to wood beams, except when an iron deck flat is laid, in which case the arrangement of the butts is not of so much importance.

When an iron deck is not fitted, the butts are brought upon the beams and fastened to the flanges with galvanized iron nut and screw bolts, except in the wake of the stringers or tie plates, where the fastenings should be off the beams, the flanges of the latter being already sufficiently cut by the riveting. As remarked at Art. 318 sufficient deck fastenings should be placed in the stringers and tie plates to enable the wood flat to communicate as much as possible of its longitudinal strength to the structure, besides keeping the plates from buckling.

When an iron deck is fitted, the butts of the deck plank are generally placed midway between the beams. It is not usual to fit an oak flat upon an iron deck, as the acids in that wood have a deteriorating influence upon the iron.

Teak has now, to a great extent, supplanted oak as a material for deck flats, especially for ships intended for service in hot climates, as, in addition to the absence of any such corrosive acid as is contained in oak, teak is very free from shakes, and shrinks but very little when exposed to heat.

In the Royal Navy, Dantzic crown deals, varying from 2½ to 3½ or 4 inches in thickness, are employed for the lighter decks; whereas teak is generally used when there is considerable wear, exposure to the sun, or when required to co-operate with a thick deck plating in forming a shell-proof flat.

In flush deck Monitors, as shown by Plate CIII., it is necessary to rivet thick pieces of iron plate upon the surface of the deck plating, near the edges of the deck, which, when let up into the plank, serve as dowels to keep the deck flat from sliding off the plating under the pressure of the caulking.

Yellow pine is generally used for deck flats of high class passenger ships, in consequence of its superior appearance. It does not, however, especially as fitted, contribute much to the strength of the ship.

Care is taken to make the fastenings of the decks of iron ships watertight, by fitting wooden end grain plugs over the heads of the bolts, these being likewise coated with lead paint.

It may be remarked in passing, that in war ships it is usual to fit heavy shell-proof gratings, composed of deep bars of iron, to the hatchways of decks which are elsewhere plated with thick iron, as described in Art. 320.

322. Coamings to Hatchways are sometimes of wood, and at others of iron. In the latter case the construction is very simple, and consists of a deep angle-iron riveted to the upper side of the beams, or of a plate connected to the beams by an angle-iron; short pieces of angle-iron being used to connect the corners of the hatchway. If a grating is fitted, a ledge is prepared for it to rest upon by riveting a narrow strip of plate against the inside of the coaming. Plate CXII. shows the method of fitting a hatchway to an iron deck. In the case of a watertight scuttle to a watertight iron deck flat, an angle-iron is riveted around the upper edge of the iron coaming, to which the hinges of the plate cover are riveted, the cover being secured by wedged buttons worked with a spanner, or some other such artifice.

323. Topsides.—The topside of an iron ship admits of great variety of construction. In the early specimens of iron ships, the topsides consisted simply of wood stanchions lapped against the frames and bolted thereto, the frames being stopped at the height of the upper deck. Deals or thin plank were secured to the outside of these stanchions, and the whole was surmounted by a rail of some kind. As stringers were not usually fitted to these ships, the method was not at all objectionable. On the introduction of stringer plates, these stanchions were for some time retained, the connection being obtained by cutting holes in the stringers to allow the stanchions to pass through and scarph with the frames. The objection to this is evident, and hence the clause to that effect in Lloyd's rules, referred to in Art. 317.

A method nearly as objectionable is sometimes adopted. This consists in continuing the iron frame to the height of the topside, and then connecting a rail to them by means of an angle-iron running fore and aft upon the top of the frames. It is evident that, in order to continue the frames, it is necessary to cut slots in the stringers, and although only alternate frames are continued above the upper deck, yet the loss of strength due to cutting only one slot in the stringer is as great as if the whole of the stringer were reduced in breadth by the width of the frame. It should, however, be noticed that, as the size of the angle-iron frame is less than that of the wood stanchions required for a topside of equal strength, the stringer is not weakened so much as by the other method. In this case the topside is usually plated up with thin plates as high as the rail. The topside shown by Plate XCVI., is formed by continuing the frame above the upper deck stringer, first reducing it in depth by 3 inches, the breadth of the outer angle-iron. Pieces of teak, the breadth of the frame, are secured to these, and the inner and outer plank of the topside are fastened to them. In the wake of the ports and channels, extra strengthenings, in the form of internal stanchions or struts, are fitted; also plating connecting the frames, and thus distributing the strains. A very common form of topside is made by continuing the side plating to the rail, and supporting it by angle-iron or rod stanchions similar to those just referred to. The most approved method, however, consists in continuing the side plating to a short distance above the stringer, connecting it thereto by an angle-iron, and then fitting a thick piece of waterway in the angle so formed. Wood stanchions are then let down into the waterway, and the whole secured with horizontal bolts through the stanchions, waterway, and side plating; also, with up and down bolts through the stringer and waterway (see Plate CXIX.). There are several varieties of this style; in some cases, a gutter waterway is fitted on the inside of the stanchions, the wood waterway being between the side plating and gutter waterway; also, several other methods differing in detail only.

In H.M. ships, wood topside stanchions are sometimes fitted, these being let down into a thick waterway or covering board, and through bolted thereto. In several of the iron-clad ships the topside wood stanchions have been extended down behind the armour plating, thus partially taking the place of the backing; a strong connection is obtained in this way. A very usual method, however, is to fit light angle-iron frames, turned down and riveted to the deck plating, thin plating being riveted thereto to complete the topside.

A great advantage of wood framing over iron for a topside is found in the superior facilities for connecting the topside fittings, such as cleats, bolts, racks, etc.; hence, when the framing is of iron, it is frequently found necessary to secure wood stanchions thereto for that purpose.

In the merchant navy, it is a very common practice to carry up the topside and fit a light deck over what would otherwise be the upper deck of the ship. This light deck is then termed the "spar deck," and the deck beneath is termed the "main deck." The spar deck is nearly flush (see Plate LXXXIX.), a piece of waterway being around its boundary, to which iron guard stanchions are secured by palms at their feet. Either guard rods or chains are passed through holes in these stanchions; and in the former case, a rope netting is generally fitted outside all for the safety of the passengers and crew.

324. Rudders.—The rudders of iron merchant ships are very simply and uniformly constructed, the only variety existing in the manner of fitting the gudgeons or braces. This statement does not include the steering apparatus, into the details of which it is not our intention to proceed. The rudder consists of an iron frame covered with thin plates, the spaces between the plates being usually filled up with fir or some other light material. The pintles are sometimes forged with the frame and filed to shape, or turned in a lathe, or else they are made independently and secured to the rudder by nuts. The rudder frame is forged similarly to the stern post, a mould being provided for the purpose, it is afterwards planed to size, and the head turned in a lathe. It is a very common practice to forge the rudder frame in two pieces, turn the main piece in the lathe; then weld the two together, and plane to the required thickness where necessary.

Plate CXIII. shows an ordinary rudder frame for an iron ship, in which the pintles *P* are forged with the frame. The space *A* is left to allow the engineers to remove and replace the packing around the after bearing of the screw shaft in the boss of the rudder post. The lower pintle, marked *B*, rests in a bearing prepared for it, marked *F* in Plate XCVII. Sometimes, however, the weight of the rudder is borne by the first or second pintle from the top.

The ordinary form of rudder frame for H.M. ships is similarly constructed to that shown by Plate CXIII., although usually differently shaped. The space *A* is never required in H.M. ships; nor are all but the lower pintle of the same length as shown. The weight of the rudder is taken by the first or second pintle from the top, which is shorter than the others, and has a hemispherical steel point that bears upon a corresponding hemisphere of steel fitted in the brace, thus reducing the friction considerably. The rudders of large ships have two such bearing pintles. The rudder is covered with thin iron plates, connected to each other with edge strips, and tap or through riveted to the frame. The plates composing each side are generally fitted, and then taken to pieces and riveted together on the ground; one side is then partially secured to the rudder, the spaces between the arms of the frame filled up with the wood or other material determined upon, after which the plating is laid upon the opposite side and the whole riveted together. It need hardly be stated that the outer surface of the plating is thus made flush.

A locking plate is fitted to the upper pintle, as in the case of a wood rudder. In the Breastwork Monitors, where all the pintles are underneath the surface of the water and always inaccessible except by diving, it is necessary to keep the rudder from lifting, either by causing its head to bear in a socket fitted beneath portable beams, or by fitting a piece of T bulb beneath the counter, just abaft the rudder, extending through an angle of forty-five degrees each way, and in this way the rudder must be turned through that angle before it can be lifted sufficiently to allow the pintles to clear the braces. A locking plate on the inside of the ship prevents the paul plate from revolving more than forty-five degrees, and so keeps the neck of the rudder immediately below the T bar until the locking plate is removed.

Balanced rudders have been occasionally fitted for many years in ships of the mercantile marine; and during the past eight or nine years the difficulty experienced in steering large ships of war has resulted in their adoption in ships of our own and several foreign navies. The balanced rudder revolves about an axis so situated that about two-thirds the area of the rudder is on the aft, and the remaining one-third on the fore side of the axis. The advantage of this form consists in the ease with which they can be put over to large angles; but the suddenness with which they stop the speed of the ship has caused them to be disused of late, chiefly in consequence of the difficulty of performing evolutions under sail with vessels so fitted. The weight of the balanced rudder is borne upon rollers on the inside of the ship, there being only one pintle, viz., at the bottom of the rudder, which revolves in a socket prepared for it on a projection from the stern post (see Art. 263). The limits of space preclude a more detailed description of this form of rudder, full particulars regarding which will be found in Mr. E. J. Reed's *Shipbuilding in Iron and Steel.*

325. Bilge Keels are made either of wood or iron; in both cases they are connected to the bottom plating by angle-irons. The earliest form of bilge keel consisted of a plate connected by two angle-irons, and stiffened on the outer edge by two strips of half-round iron riveted thereto. This style of bilge keel is still frequently adopted, sometimes in the modified form of plate bulb connected by two angle-irons.

An ordinary form of wood bilge keel is shown on Plate XCIV.; the angle-irons being riveted to outer strakes, and the bilge keel fitted beneath longitudinals, to resist the thrust in the event of the ship grounding. The wood bilge keel is in two pieces, viz., a *main* and *false* piece, the former being secured to the bottom by bolts through the two angle-irons, and the latter by nails driven into the main piece.

In one or two of the Indian troop ships a peculiar form of bilge keel, having a V-shaped section, has been fitted. This has been made of two plates of iron riveted to the bottom, also riveted together at the lower part of the V, the triangular space between the two plates and the bottom being filled in with wood or other light material. A bilge keel of this form has been proposed for the sheathed ships of H.M. Navy, the bottoms of which are covered with zinc sheets (see Art. 337).

It is usual in the Royal Navy to connect the angle-irons of the bilge keels to the bottom plating with tap rivets, which have nuts hove upon them on the inside surface of the plating. A portion of the thread of the screw is in the angle-iron, so that upon grounding violently the tap rivets will break off outside the plating, and leakage is prevented by means of the screw in the plating and the nuts on the inside.

The advantages of bilge keels have probably been overrated; nevertheless, they no doubt offer some resistance to rolling and leeway, besides which their structural efficiency, especially when made wholly of iron, must not be lost sight of.

In fitting bilge keels, care must be taken to minimise the resistance offered by them to the speed of the vessel. To effect this the projection of the bilge keel upon a plane, perpendicular to the longitudinal vertical plane of the ship, should be of the smallest possible dimensions. In lining off the keel in the body plan, the same process is followed as in getting the sight edge of a longitudinal by the method at Art. 166, taking care that the line joining the two rabbets therein referred to is parallel to the load water line.

CHAPTER XXI.

326. Rivets and Riveting.—In the course of the preceding remarks on iron shipbuilding, frequent reference has been made to the character and spacing of the rivets at the several parts of the ship. It is now proposed to consider this important branch of the subject a little more in detail.

327. Forms of Rivets.—Rivets are of two kinds, *clenched* and *tapped*, the former being secured by beating up the point or "clenching," and the latter by screwing the rivet into a screw hole previously prepared for it by means of a "tap tool."

Considering first the clenched rivet, which is the great uniting agent in the ship: By referring to Plate CXIV., it will be seen that there are several different ways of forming both the head and point of this rivet. *A* on that Plate represents the *pan head* rivet, which is the commonest form in use. As will be seen, it is slightly conical under the head, in order that the rivet may fill the hole of that form made by the punching tool. There are three principal modes of forming the point of this rivet. *B* represents the *boiler point*, so named because it is the form used in boiler making when hand riveted. This is the most efficient form of rivet point, not so much in consequence of its shape as the nature of the hammering it receives in being beaten up. It is not usual in shipbuilding to give this rivet point the exact conical form which is customary in boiler making, as it is not often employed in riveting work exposed to view. The *boiler point* is chiefly used in riveting transverse and longitudinal frames. *C* represents the *snap point*, which is formed by first roughly beating down the point, and then finishing it by holding a snap tool thereon, and striking the latter. This snap tool consists of a hollow cup of steel welded to a punch head for striking upon. Snap points are chiefly employed for work in sight, as, for instance, bulkheads, beams, etc., and sometimes for frames. It cannot be depended upon like the boiler point, as, unless the rivet is carefully beaten down before applying the snap tool, it will probably be defective, either by not filling the hole or by looseness. This is caused by the snap tool finishing off the edge of the clench, while it does not press upon the rivet so as to squeeze it into the hole. It is a very common practice in private shipyards to let out the frame riveting by "piece work," allowing the rivets to be snap pointed; the result is, that when the frame is erected (especially if by the Scotch system), a tap with a small hammer upon each rivet reveals the fact that a large percentage is loose, and, therefore, inefficient. When carefully performed, however, snap riveting has a very neat appearance, and is found to give watertight work when tested by water pressure. *D* represents the *flush* or *countersunk point*, which is used for bottom and side plating, deck plating, plating behind armour, etc. Below the water line the point is generally chipped slightly convex, but above water it is generally made flush.

At *E* is shown the *snap head* rivet, used in machine riveting of beams, boilers, etc. It is not often employed for hand riveting. *F* shows a rivet which is only used on rare occasions, when both surfaces are required to be flush; as, for instance, in the case of the nut and washer of an armour bolt being in the wake of a rivet in the plating behind armour, it is found necessary to form the rivet as thus shown in order to give the washer, nut, etc., a fair bearing surface.

The last form which we will consider is the *tap rivet*, shown at *G* and *H*. This rivet is employed in cases where it is impossible to clench the point, either because it is put into solid iron, or because the point side of the rivet is at an inaccessible part of the ship.

The hole is first drilled, and then a steel "tap" is inserted and turned by a spanner until it cuts a thread in the side of the hole to fit the thread on the rivet which is to be placed therein. The rivet is hove up with a spanner by means of a projection on the head, as shown at *G*; when the rivet is screwed up tightly, the head is chipped off flush, or nearly so. Tap riveting is employed in securing plates to forgings, such as the stem, stern post, etc, and to armour plates. It should be stated that it is important that the whole of the screw thread should be beneath the surface of the forging, etc., as, if above, the rivet will readily break at the first turn of the screw thread above the forging. In riveting the angle-irons of bilge keels to the bottom plating tap rivets are used, and so placed as to readily break off in this way (see Art. 325).

328. Sizes of Rivets.—In connecting iron work with rivets the object is to get a uniformity of strength between the plates, or angle-irons and rivets, so that the former may not be so strong as to cause the latter to break first, nor *vice versâ*, but that the two may be on the point of yielding simultaneously; hence the sizes and spacing of the rivets must be regulated accordingly. Calculations made in order to determine the diameters of rivets which should be used in connecting different thicknesses of plates have shown that the former should never exceed twice the latter; while with thick plating it would appear that the rivet should be but slightly thicker than the plate. The requirements of Lloyd's and the Liverpool rules, also the practice of H.M. dockyards, are given by the following table, where the sizes are stated in sixteenths of an inch:—

TABLE OF DIAMETERS OF RIVETS OF DIFFERENT THICKNESSES.

Thickness of Plates.	Diameter of Rivets.		
	Lloyd's Rules.	Liverpool Rules.	H. M. Dockyards.
5	10	8	8
6	10	10	10
7	10	10	12
8	12	12	12
9	12	12	14
10	12	13	14
11	14	14	14
12	14	14	16
13	14	15	16
14	16	16	18
15	16	17	18
16	16	18	18

It will be seen from the above that unless for the thinnest plates, the Liverpool rules and the practice of H.M. dockyard (especially the latter), require larger rivets than Lloyd's rules. The sizes required by the Liverpool rules were larger a few years since. Where plates of more than one inch in thickness are used, the diameters of the rivets are from $\frac{1}{8}$ to $\frac{3}{16}$ inch greater than the thickness of the plates; and when two plates of unequal thicknesses are riveted together the diameter of the rivet is estimated from the lesser thickness. As already stated, the rivets connecting plating to stem, stern post, or keel, are $\frac{1}{4}$ inch larger in diameter than for the same thickness of plating elsewhere. Tap rivets are usually about $\frac{1}{8}$ inch greater in diameter than ordinary rivets for the same thickness of plating.

329. Spacing of Rivets.—The spacing or pitch of rivets required by Lloyd's rules is "four and a half diameters apart, from centre to centre, excepting in the keel, stem, and stern post, where they may be five times, and through the frames and outside plating, and in reversed angle-irons of frames, where they may be from seven to nine times, their diameter, from centre to centre." The Liverpool rules require "rivets to be four diameters apart, from centre to centre, longitudinally in seams and vertically in butts, except in the butts where treble riveting is required, when the rivets in the row farthest from the butt may be opened eight diameters apart, centre to centre. Rivets in framing to be eight times their diameter apart." The Admiralty practice is four and a half to five diameters in edges and butts of bottom plating, and five to six diameters in watertight work elsewhere. The rivets in the frames are spaced about eight diameters apart. Again, Lloyd's rules state that "in chain riveted butts, a space equal to twice the diameter of the rivet to be between each row; where treble riveting is adopted, a space equal to twice the diameter of the rivet to be between each row, with half the number of rivets in the back row. The overlaps of plating, where chain riveting is adopted, are not to be less than six times the diameter of the rivets, and where single riveting is admitted, to be not less than three and a half times the diameter of the rivets." The Liverpool requirements for breadths of overlap are almost tantamount to the preceding, while the Admiralty practice is rather less. The breadth of butt strap for double riveting is about thirteen times the diameter of the rivet by Lloyd's rules, and from thirteen to fourteen and a half times by the Liverpool rules, while the practice of H.M. dockyards is eleven and a half to twelve diameters. For treble-riveted butt straps, nineteen diameters in breadth are required by Lloyd's, and about eighteen by the Liverpool rules, while sixteen to sixteen and a half diameters is the Admiralty practice.

330. Testing Iron.—The most carefully arranged combination of plates and angle-irons, and the most satisfactory spacing of rivets, are altogether useless unless the materials so combined are of good quality. Hence a very important branch of the iron ship-surveyor's duty, whether for Lloyd's Register, the Liverpool Underwriters, H.M. service, or private shipowners, consists in examining and testing the quality of the iron supplied for the ships.

The tests required for H.M. ships are of a very searching character, far more so, we believe, than for any other class of vessels. These tests are laid down in a code of rules which are too lengthy for insertion here. The tests are of two kinds, *tensile* and *forge*. The former are performed with the aid of a powerful machine; the latter, which are of two kinds, "hot" and "cold," are made by a smith. It may be remarked that in addition to these a preliminary test is made by striking the plate with a hammer and listening to its "ring;" blisters are also sought for in the same way.

331. Tensile Tests are made by means of a compound lever machine, sometimes worked with a hydraulic or oil pump. Strips are cut from the plate selected for testing, both *with* and *across* the grain of the iron, *i.e.*, with and across the direction in which the plate issued from the rolls in the process of manufacture. These strips are reduced in breadth towards the middle, as shown by *A*, Plate CXV.—a parallel breadth being left for a length of several inches. The area of a section of this strip at this part is generally about one square inch. The strip is placed in the machine in such a way that it is between the motive power and a balance in which weights are placed, representing the tension upon the piece being tested. The machine is often so constructed, by an arrangement of levers, that a one pound weight placed in the scale represents a ton pull upon the piece of iron. Weights are placed in the scale until the iron breaks, and then the strength of the latter is measured by the weights in the scale. Two marks, six inches apart, are made in the test piece with a centre punch before it is put into the machine, and, when broken, the two pieces are fitted together and the distance between the centre punch marks is measured; the excess of this above the six inches being a criterion of the ductility of the iron. The fractures are then examined, and by their appearance an experienced eye can judge the quality of the material.

Pieces of the flanges of angle and T irons, beams, etc., are planed or slotted off, and tested in a similar way, only that no cross test can be made of these pieces.

The Admiralty regulations require for B.B., or first-class iron, a tensile strength of 22 tons per square inch, lengthways, and 18 tons crossways. Second class, or B. iron, is required to stand 20 and 17 tons respectively. Bar iron is tested in a similar way to the plate strips, except that it is not usual to reduce the diameter unless the bar is too stout to be broken by the machine.

332. Forge Tests are of two kinds, "hot" and "cold;" the iron being tested with and across the grain by each. *B* and *C*, Plate CXV., show the nature of these tests. Two pieces are cut from the selected plate, and one is heated in a smith's fire, while the other is kept for the cold test. They are bent upon a cast-iron slab, with rounded corners, having a radius of half an inch each; each piece being bent in the two directions by repeated blows with a large hammer. B.B. plates of one inch thick are expected to bend cold, without fracture, to an angle of fifteen degrees with the grain and five degrees across the grain; half-inch plates to thirty-five and fifteen degrees respectively; while three-sixteenth inch plates and under must bend to ninety degrees with the grain and forty degrees across the grain.

The hot forge tests of plates of one inch thick and under are one hundred and twenty-five degrees with the grain and ninety degrees across.

The cold forge tests of B. quality plates are ten and five degrees, with and across the grain, respectively, for one-inch plates; thirty and ten degrees for half-inch plates; and seventy-five degrees and thirty degrees for plates three-sixteenths inch thick and under.

The portion of plate tested both for hot and cold tests is to be 4 feet in length across the grain, and the full width of the plate with the grain. The plate should be bent at a distance of 3 to 6 inches from the edge.

D, *E*, *F*, *G*, *H*, *I*, and *J* show various forms of angle-iron, and *K*, *L*, *M*, and *N* of beam iron forge tests, all but *J* and *N* being made when hot. The former is a cold bending test with the grain, and the latter is the result of nicking and bending, in order to determine the fibrous quality of the iron in the beam. As will be seen, these tests are very exacting; but they are none the less necessary, as the smithing operations these angle, etc., irons have to undergo are frequently very distressing. The greater number of these tests are to detect "reediness," lamination, or looseness in the fibrous structure of the iron, these defects occurring more frequently in angle, T, and beam irons than in plates.

Armour bolts and rivet iron (see *O*, *P*, *Q*, *R*, and *S*) are both submitted to the same kind of forge tests, which consist in bending the iron double, when cold, and in punching holes of the same diameter as the iron at right angles to each other, the iron being red hot. Neither of these tests should show any fracture. The fibrous character of the iron is frequently examined by cutting a nick on one side, and then doubling the iron; the character of the fracture, whether fibrous or otherwise, determines the quality of the material (see *T*). The malleability is determined by beating up the point when cold, as shown at *U*; also by beating down the head when hot, as shown at *V*.

Mention may be made, in passing, of the percussive tests to which armour bolts are submitted, after manufacture, by letting a "tup" of about one ton weight fall a distance of about 30 feet upon the head in such a way as to cause elongation of the bolt. The number of blows before breaking, and the appearance and position of the fracture, are criterions of the quality of the material.

CHAPTER XXII.

333. Backing behind Armour.—It is proposed to devote a small amount of space to a consideration of certain details peculiar to armour-clad ships, viz.:—*backing* and *armour plates*.

The backing behind armour is usually of East India teak, although oak is sometimes fitted, being rarely used alone, but generally in combination with the first-named material. The backing is generally fitted in horizontal strakes between the girders, being butted on frames; but sometimes, when two thicknesses are fitted, the inner is longitudinal and the outer vertical. It is secured to the plating behind armour with iron nut and screw bolts, spaced about 2 to 3 feet apart, so as to be clear of the armour bolts, and with two bolts in the butts (see Plate CX.). These bolts have flat heads; they are driven from the outside, and made watertight by wrapping a piece of tow, dipped in lead paint, under the head, and by placing grommets under the nuts which are hove up against the plating behind armour.

The backing is first trimmed and fitted, and the holes for the bolts bored through from the inside of the ship; the holes having previously been set-off on the plating and drilled. The backing is then removed, and hempen grommets are tacked round the bolt holes on the faying surface of the wood; the piece of backing is next payed over with a mixture of white and red lead paint, after which it is put into place and secured. End grain teak plugs, dipped in Hay's glue, are driven over the heads of the bolts. It has been the practice to caulk the backing, but recent orders direct that the joints are to be closely fitted and the caulking omitted.

334. Armour Plates.—The armour plates on the ship's side are arranged in horizontal strakes; those for pilot towers, and, sometimes, turrets, being arranged vertically. They are in lengths averaging about 16 feet, while the breadths are usually from 3 to 4 feet; the butts are generally arranged upon the "brick" system (see Art. 293), and are brought upon the frames (see Plate CX.), taking care that they give good shift with those of the plates behind armour.

As the armour plates have to conform to the curvature and twist of the ship's side, they have to be bent after leaving the rolls. This is sometimes done by the manufacturer while the plates are in their hot state, immediately after rolling, the required form being given by moulds supplied from the building yard. More frequently, however, they are bent in the shipyard. When much curvature is required, the plate, if not just from the rolls, is heated in a reverberatory furnace until of a bright red colour, in which state it is placed in a "bending cradle," and there bent to the required form. The "bending cradle" is composed of a pair of stout iron vertical frames, between the bars of which transverse beams of iron, bent to the necessary curvature, are secured, so that together they constitute a bed of the required form. The plate is removed from the furnace and laid upon this bed, where, by means of a series of transverse and two longitudinal iron beams above the plate, the latter is shored down until it fits closely upon the bed, when it is allowed to cool. In cases where great curvature is not required, the armour plate is bent in a Bramah press.

Reference has been made to the moulds for bending an armour plate to its shape. Before making these moulds, the surface of the backing is trimmed fair and to the required thickness, so that when the armour plates are fastened in place the outer surface shall be flush. The armour plating is of varied thickness, the thickest plates being worked at the load water line amidships, and tapering towards the extremities of the ship. These thicknesses are previously determined by the designer, and shown upon an expansion drawing and sections of the ship at amidships and elsewhere. Consequently, the backing has to be trimmed accordingly, and at the places where variations in the thickness of the armour plates take place there are sudden discontinuities in the thickness of the backing, for each armour plate is of uniform thickness throughout its length.

In taking account of an armour-plate with a twisted surface five moulds are required, viz., two sectional moulds to the butts, two sectional moulds to the edges, and a mould made of three or four battens nailed together at the corners, giving the developed shape of the surface of the plate which fits against the backing. The outer edges of the sectional battens at the butts are planed, so as to be out of winding when the moulds are in their proper position against the backing; by this means the exact amount of twist in the surface is determined. Sometimes the outer edges of the other sectional moulds are treated in a similar manner, so that by nailing the four together the form of the plate is at once seen. It should be observed that the ends of the butt moulds are cut to the bevellings at the extremities of the edges, and those of the edge moulds to the bevellings at the extremities of the butt of the plate. Sometimes additional bevellings are provided for intermediate positions in an edge, when it has to fit against the edges of two plates, already in place, which have different bevellings. It is necessary to strike straight lines on these sectional moulds as a check in case of warping (see Art. 85, etc.), also to mark which is the upper, lower, fore, or after extremity of each mould. The bed of the bending cradle is readily prepared to the required form by the aid of such complete data as that which we have just briefly described. It need hardly be mentioned that cases at times occur when more elaborate information must be provided than that stated above, but the limits of this work do not allow of a more detailed description.

The edges and butts of the plate having been carefully lined off, they are planed by machine to the required bevelling. The plates being very expensive, and paid for by the ton, the shipbuilder orders them as nearly as possible to the exact size, so as to leave not more than about a half or three-fourths of an inch to be removed by the planing machine. The plates for the straight parts of the ship are generally ordered the exact size, and planed by the manufacturer. When planed to the required form, the centres of the armour bolt holes are set off, drilled, and countersunk. The armour plates of ships of the Royal Navy are secured by conical-headed nut and screw bolts, such as shown in fig. 37.

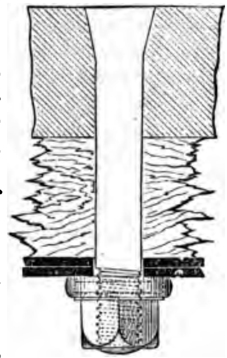


Fig. 37.

The chief peculiarity of these bolts is the "elastic cup washer" against which the nut is hove up. This consists of a hexagonal cup, made of either wrought or malleable cast-iron, into which an india-rubber washer fits, being in thickness about an eighth of an inch less than the depth of the cup on its inside. A hexagonal plate washer about a quarter of an inch thick, is fitted over the india-rubber, and the whole being put on over the point of the bolt, an iron nut is hove up against the plate washer. The object of this simple contrivance* is to act as a buffer when a sudden elongatory strain is brought upon the bolt by the impact of a projectile upon the armour plate, and thus to prevent the bolt from breaking, as it probably would, at a screw thread. Various other modes of attaining the same end have been proposed, of which Sir William Palliser's deserves consideration. It consists in reducing the diameter of the shank of the bolt, for a portion of the length, to about an equal size with the smallest diameter in wake of the screw thread; an ordinary plate washer is put under the nut, and the screw thread is cut rather finer than usual. A sudden jarring or tensile strain results in an extension of the bolt at the reduced part, and thus prevents the fracture at the screw thread already referred to. Experiments made with bolts of this kind have proved satisfactory, and the objection raised to them at first in consequence of their not filling the bolt holes, and, hence, not being watertight, have been overcome by the inventor in bringing up the bolt to a uniform size with a coating of lead. The expense of this

* This invention is due, we believe, to Mr. W. B. Baskcomb, the teacher of Shipbuilding at the Royal School of Naval Architecture, who has rendered valuable services in the experiments upon armour plates almost ever since their first application to ships of war.

system, and the difficulty of carrying it out successfully, have led to its not being adopted except for land fortifications, where considerations of watertightness do not occur.

The subjoined table gives the proportions and dimensions of bolts for the several thicknesses of armour between 4 and 14 inches:—

TABLE OF DIMENSIONS FOR ARMOUR BOLTS.

Thickness of Armour.	Diameter of Bolt.	Diameter of Head of Bolt.	Length of Cone.	No. of Threads per Inch.	Depth of Nut.	Width of Nut across sides.
ins.	ins.	ins.	ins.	No.	ins.	ins.
4	$2\frac{3}{4}$	$3\frac{7}{8}$	$3\frac{1}{8}$	$5\frac{1}{2}$	$2\frac{3}{4}$	$4\frac{11}{16}$
6	3	$4\frac{1}{4}$	$3\frac{3}{8}$	5	3	$5\frac{1}{16}$
8, 7, & $6\frac{1}{2}$	$3\frac{1}{4}$	$4\frac{9}{16}$	$3\frac{5}{8}$	5	$3\frac{1}{4}$	$5\frac{7}{16}$
9	$3\frac{1}{2}$	$4\frac{7}{8}$	$3\frac{15}{16}$	4	$3\frac{1}{2}$	$5\frac{13}{16}$
10	$3\frac{3}{4}$	$5\frac{1}{4}$	$4\frac{1}{4}$	4	$3\frac{3}{4}$	$6\frac{3}{16}$
11 & 12	4	$5\frac{5}{8}$	$4\frac{1}{2}$	$3\frac{1}{2}$	4	$6\frac{9}{16}$
13	$4\frac{1}{4}$	6	$4\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{1}{4}$	$6\frac{15}{16}$
14	$4\frac{1}{2}$	$6\frac{5}{16}$	$5\frac{1}{16}$	3	$4\frac{1}{2}$	$7\frac{5}{16}$

The centres of the bolts to be 10 inches from the edges, and 12 inches from the butts. The above sizes apply only to armour plates 3 feet wide, having but one bolt in each frame space; narrower plates have bolts $\frac{1}{4}$ inch less in diameter. In Plate CX. there are two bolts in a frame space.

The positions of the armour bolts should be set off on the outer surface of the plating behind armour, so that all rivets happening to be in the way of nuts* may be flushed on the inside; the bolt holes, however, are not bored until subsequently. The armour plate being in place, the hole in the backing for the armour bolt is bored about $\frac{3}{16}$ or $\frac{1}{4}$ inch less in diameter than that in the plate, the two holes being made perfectly concentric by means of a guide on the auger, which fits accurately in the armour plate hole. A hole about $\frac{3}{4}$ or $\frac{7}{8}$ inch in diameter is then drilled, concentric, with the others, through the plating behind armour, a guide being placed upon the drill, similar to that on the auger, to ensure that

* The rivets and bolts should be, if possible, carefully set off, so as to be clear of each other; nevertheless it sometimes happens, especially at or near the extremities, that some rivets must be flushed as here stated.

result. The hole in the plating behind armour should be a little larger than the bolt, so that the screw thread may not be injured when driving it. The diameter of the hole in the plating being thus about $\frac{1}{4}$ inch greater than that in the backing, it is necessary that the cutter of the riming tool should work on the inside surface of the plating. It will be at once seen that the small hole already drilled in the plating serves as a guide to this tool. The latter is sometimes worked on the inside of the ship by means of a ratchet brace, but some prefer to drill from the outside of the ship by tightening a nut on the brace against the surface of the armour plate, and thus drawing the cutting tool towards the driller. The latter method is very convenient at places not readily accessible on the inside of the ship.

Before driving the armour bolt, the following precautions are taken in order to ensure watertightness if near or below the water line. The joint of the two thicknesses of plating behind armour in the bolt hole is iron-caulked, and oakum is driven in between the backing and plating just referred to; also the bolt hole is payed with a mixture of white and red lead paint. The bolt is driven with an iron sliding ram, termed a "monkey," an operation usually requiring four men; and when in place the hole is caulked around the bolt on the inside of the ship, a hempen grommet steeped in a mixture of red and white lead paint is put around the point, after which the cup-washer is put on, and then the nut hove up by means of a large spanner. When the armour plates are fastened, all unevenness in the surface, as at the edges and butts, also the projecting heads of armour bolts, are chipped flush, and the edges and butts caulked.

The French secure their armour plates with screw bolts having raised threads. These bolts do not pass through the plating behind armour, and in this respect are superior to our own system, which covers the inside surface of the plating with a number of nuts that become formidable projectiles, if suddenly broken off by the impact of shot on the armour plating.

This was seen in the experimental firing of the *Hotspur* upon the turrets of the *Glatton*, the interior of which gave evidence of the destruction of life which would have resulted from these nuts alone, if men had been in the turrets. In the armour-clad ships now being built this has been prevented by placing the bolts in such positions that the nuts on them may be cased in with stout iron plates. It may be remarked with regard to the French system, that the results of experiments made upon armour plates secured in that manner, although to a great extent satisfactory, have not been such as to warrant the Admiralty in adopting it in ships of the Royal Navy.

PART V.—SHEATHED AND COMPOSITE SHIPBUILDING.

CHAPTER XXIII.

335. Sheathed Ships.—A great disadvantage which has always attended iron ships, has been the rapidity with which their bottoms have become incrusted with sea-weed, shells, etc., thereby impeding their progress through the water. Many schemes have been devised for counteracting this tendency, the greater number of which have consisted in coating the bottom with a substance intended to prevent the growth of such bodies. Although these "compositions" are successful in keeping the bottom clean for a short time, and to temporarily prevent oxidation of the iron, yet they are quite ineffectual in the case of ships which have to keep the sea for a considerable time on a distant station, like those of the Royal Navy. The only satisfactory mode yet arrived at of keeping the bottom free from fouling for any lengthened period, is to sheath it with wood, and then with copper or zinc outside all, in this way reverting to the old practice adopted for many years in wood ships. Certain precautions are, however, necessary, which are not required in coppering the bottoms of the latter, unless iron fastened. It is well known that a galvanic current is set up between copper and iron when immersed in sea water, if either actually in contact, or both exposed to the water. The result of this galvanic action is a chemical decomposition of the iron; hence the precaution already alluded to consists in perfectly insulating the iron work in the ship from the copper by means of some non-conducting material, such as wood, pitch, etc. When zinc is employed these precautions are not necessary, as the galvanic action set up between zinc and iron results in the decomposition of the former. Indeed, this property is utilized for the ship's benefit, as the decomposition of the zinc causes a substance to form on its outer surface, which is washed off by the motion through the water, carrying the weeds, etc., with it. Hence, when zinc sheathing is fitted on the wood covering the iron bottom, the wood is not caulked, nor are the fastenings and plating insulated, but rather a free communication is allowed between the zinc, iron, and sea water. It may be remarked that the property in copper that causes it to be used for sheathing, is that of exfoliating when under the action of sea water, and thus carrying with it the substances collected upon the surface. By the preceding remarks it will be anticipated that the wood sheating is differently fitted according as copper or zinc is used for coating the outer surface.

336. Coppered Sheathing.—Copper was the substance employed for covering the wood in the earlier sheathed vessels of the Royal Navy—as, *Inconstant*, *Volage*, *Swiftsure*, etc. When copper is used the bottom is sheathed with two thicknesses of wood, instead of one only, as when zinc is fitted.

The method adopted in the *Inconstant* (see fig. 38) is somewhat peculiar, and has not been carried out in later vessels. The bottom plates are connected by thick edge strips on the outside; the plating being fitted in the manner described at Art. 292.

The inner layer of sheathing, $3\frac{1}{4}$ inches thick, is fitted vertically, and secured to the bottom plating with $1\frac{1}{8}$ inch galvanized iron screws, tapped into $1\frac{1}{4}$ inch edge strips $5\frac{1}{4}$ inches wide, and into intermediate narrower strips of iron riveted at the middles of the bottom plates. These screws are carefully fitted and hove up, so as to compress the wood under their heads, after which the holes are filled with a composition of Portland cement and Hay's glue.

The outer layer, $2\frac{3}{4}$ inches thick, is fitted longitudinally, and fastened with $\frac{3}{4}$-inch yellow metal screw bolts, in the manner shown by fig. 38. Great care is taken to perfectly insulate the iron plating and framing from the copper sheathing, and, consequently, every precaution is adopted to make the fastenings and the joints of the plank watertight. Teak plugs, coated with Hay's glue, are driven tightly over the heads of the outer fastenings, the latter being hove up to a depth of $\frac{3}{4}$ of an inch beneath the surface. All the faying surfaces are well payed with Hay's waterproof glue.

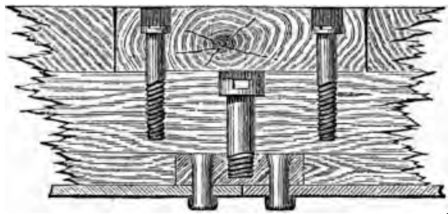


Fig. 38.

In the *Volage*, *Swiftsure*, etc., both the thicknesses of planking are fitted horizontally, the edges of the two layers breaking joint with each other. Plate CXVI. shows in elevation, also in section at the keel, the mode of wood sheathing in the unarmoured iron corvettes *Volage* and *Active*, which is very similar to that adopted in the *Swiftsure* and other sheathed armoured ships; see also Plate XCVI., which shows the material employed at the several parts of the bottom. The strakes are about 10 to 12 inches wide, tapering to a lesser width towards the extremities; the inner skin is 3 inches thick on the outer strakes of plating, except the garboards, which are about an inch thicker. The outer strakes are of varying thickness, as shown by Plate XCVI., and are the same widths as the inner.

The inner thickness is fastened to the bottom plating with galvanized iron screw bolts, tapped through the bottom plating, and further secured by means of nuts hove up on the points at the inside (see fig. 2, Plate CXVI.). In fitting the wood sheathing to the *Volage* and *Active*, the screws are spaced about $10\frac{1}{2}$ inches apart on alternate edges, so that those on each edge are 21 inches apart. Thus, in one frame space, there are four bolts* to each plank, and so

* In some recent sheathed ships the number of bolts has been reduced to three in each frame space.

arranged that all upper edge fastenings are in one line, and all lower edge in another line (see fig. 1, Plate CXVI.). The holes in the plating were first drilled, care being taken to bore them square to the surface. The positions of these holes were set off from the lines for the plank edges previously drawn upon the ship's side and bottom. When the inner planks were fitted, small holes were bored through from the inside of the ship, after which the former were removed, and the faying surfaces of both planks and plates were payed, first with Hay's protective varnish, and, when dry, with Hay's waterproof glue. Next, the holes in the plates were tapped, and those in the planks rimed, care being taken to make them concentric with those in the plates; the holes were then ring-bitted for the bolt heads. Next, the bolts having been dipped in Hay's glue, were driven and hove up in the plating by means of slots in their heads; grommets dipped in red lead were placed round the points of the bolts, and the nuts hove up upon them. Great care was taken in caulking so as not to strain the fastenings. After the outside was faired, the heads of the bolts were examined, and all that were not at least $\frac{5}{16}$ of an inch beneath the surface were removed, and the holes for the heads deepened; the bolts were then replaced by others slightly larger in diameter. The holes outside the heads were then stopped up with a mixture of Hay's waterproof glue and Portland cement.

The fore hoods end at a rabbet cut in the wood stem (see Plate CXVIII.), and the after hoods end at a rabbet prepared in the yellow metal body post. The fore hoods are fastened to the bottom plating as elsewhere; but in the stem they have, for each plank, one bolt on the upper edge, driven through and clenched upon an iron ring; and on the lower edge one screw bolt. The lower strakes have a second through bolt instead of a screw, as they are wider than the other strakes. The after extremities of the after hoods stop at a rabbet $6\frac{3}{4}$ inches broad, cast in the yellow metal post, and they are secured to the latter with $\frac{5}{8}$-inch metal screw bolts tapped into the metal post. In the wake of the aperture the planks stop at a rabbet cut in a mahogany chock, similarly to the ends of a deck plank against a piece of thin waterway. This chock is fastened to the bottom plating, and forms the base of the teak framing of the aperture, being, of course, strengthened by the bottom plating, and a framing of angle-irons beneath it. The aperture is formed of $\frac{1}{2}$-inch Muntz metal plates, secured to the deck framing above, and the wood chock below.

The outer thickness is fastened to the inner with metal screws, of such a length that, when properly hove up, their points shall be about half an inch from the iron skin, while their heads are three-eighths of an inch within the surface, after the bottom is faired. The butts are arranged to give shift to those of the inner thickness, and are fastened with two screws on each side of the butt. The planks range in length from 28 to 42 feet. Both the faying surfaces were payed with Hay's waterproof glue, and the plank pitched as quickly as possible before the glue hardened. The fastenings were next set off and put in (see Plate CXVI.), care being taken to make them perfectly tight, the heads being about $\frac{3}{4}$-inch beneath the surface, and the hole filled with a composition made of tallow, bee's-wax, and white lead, in equal parts, this being found very suitable for receiving the nails of the copper sheathing. The fore hoods end in a rabbet on the stem, and are fastened with one through bolt on the upper edge, and one screw on the lower edge, except in the wider strakes, which have a second through bolt instead of a screw. The after hoods are fastened to the yellow metal post with $\frac{5}{8}$-inch tap bolts.

The manner of fitting the stem, and scarphing the pieces together, are shown by Plate CXVIII.

The limits of space prevent us from considering the further details of this mode of sheathing. But before leaving the subject, attention is called to Plate CXVII., which shows the mode of securing the sheathing in an unarmoured frigate recently built. The general features of this arrangement are the same as those just described.

337. Zinced Sheathing. — As already stated, when zinc sheathing is employed, only one thickness of plank is fitted, and the many precautions in order to obtain perfect insulation, of which we have stated some in the preceding Article, are no longer necessary.

In the ships of the Royal Navy, the difference in the wood work consists in entirely omitting all relating to the outer thickness, and fastening the inner as already stated.

There is, however, a considerable difference in the work at the bow and stern, involving a great saving in the cost of the ship, inasmuch as costly brass castings are no longer necessary for the stern posts, rudder, etc., these being forged as in ordinary iron ships of the same class. Although it is imperatively necessary for the safety of the ship that the fastenings should be watertight, yet no oakum is driven into the seams, the latter being left open, so that there may be free galvanic action, by means of the sea water, between the zinc and iron. It should be stated that it is important that the former should be of good and uniform quality, as otherwise it will be eaten out in a honeycomb fashion, instead of by uniform surface decomposition.

338. Mr. Daft's Plan.—Before discussing the subject of zinc sheathing for iron ships, a slight reference should be made to the plan proposed by Mr. Daft, and described by him in a paper read before the Institution of Naval Architects in 1865. Mr. Daft proposes to connect the bottom plates on the flush system, as described at Art. 290, with this difference, that he leaves a small space between adjacent edges and butts, which space he afterwards fills up with strips of wood, the latter becoming tight by swelling in the sea water. He proposes to lap the zinc sheets over each other opposite these strips of wood, and nail them thereto. By driving a nail slightly longer than the thickness of the bottom plating, its point, striking against the edge strip or butt strap, will turn up, and so hold the zinc plate more securely.

339. Composite Ships.—But while the several methods of preserving an iron ship's bottom from fouling, referred to in the preceding pages of this chapter, have been adopted for large ships of such high engine powers that anything less than an iron bottom would not offer the necessary resistance and rigidity, a great number of sailing ships in the merchant service, and small steamers in both that and the Royal Navy have been built upon a system aptly termed "Composite." The general features of the composite system are as follows:—

1. Iron transverse framing as in ordinary merchant ships.

2. Iron longitudinal ties, such as vertical keel, flat keel, gutter plates, side keelson, sheer strakes, stringers, etc., and, sometimes, diagonal tie plates, or riders, outside the frames.

3. A wood watertight bottom, composed of one or two thicknesses of plank, the outer surface of which is sheathed with copper, Muntz metal, or zinc.

Many methods have been proposed for combining the wood and iron in such a way as to obtain the peculiar excellence of a composite ship in the highest degree with the requisite strength. Up to the present time, however, none of the methods has been successful in producing a ship having the necessary rigidity for an ocean steamer of full engine power. Just previous to the opening of the Suez Canal, the sailing clippers trading between Great Britain and India, China, and Japan were built upon the composite system, in order that by means of the copper sheathing their bottoms might be kept clean enough not to greatly retard their speed. The famous "tea clippers" were of this construction. With the opening of that canal the demand for such vessels ceased, and hence it has become a rare thing to see a composite ship being built for the merchant service. The small vessels of the Royal Navy, such as sloops and gun vessels, are built on the composite system, as these vessels are intended for lengthened service in the rivers of China, the coast of Africa, and such like duties.

340. Mr. M'Laine's System.—Among the proposals for the construction of composite ships that have been made from time to time, that by Mr. M'Laine, described by him to the Institution of Naval Architects in 1865, is worthy of passing notice. That gentleman proposes to retain the iron plating of the bottom, in consequence of its great structural importance; for, as he justly says, the bottom plating is the chief feature in an iron ship, the transverse frames serving only to stiffen and prevent it from buckling. Instead, however, of putting the plating on the *outside* of the frames, he would fit it on the *inside*, in lieu of ceiling, and secure a wood bottom on the outside in the manner shown by fig. 39. In this way he obtains the structural advantage of the iron and the anti-fouling advantage of the wood when sheathed with copper or

Muntz metal. Mr. M'Laine further proposes to utilize the spaces between the frames marked *a* as channels for ventilation, the air being pumped through by a small engine. The proposal was more particularly intended for war vessels, in which case the spaces could be filled in solid, to act as backing if thought proper. When lightness of framing is an object, the alternate frames could be constructed of a plank about one-half the thickness of the principal timbers. One of the chief objections to this proposal is the impossibility of access to the outer surface of the plating and to the angle-irons of the frames, so that there is every probability that rapid corrosion would take place, causing a loss of strength, which could not be arrested without removing the bottom plank.

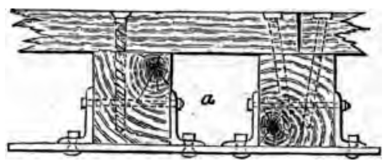


Fig. 39.

341. System Sanctioned by Lloyd's (see Plate CXIX.).—Lloyd's committee have published, with their rules for wood and iron ships, a number of suggestions for the building of composite ships, stating under what conditions vessels so built will be classified by them. The iron framework, according to these suggestions, consists of the following parts:—*

Floor plates, frame, and reverse angle-irons, as in an iron ship; a flat keel plate; vertical keel (generally intercostal), associated with either a gutter plate or a bulb plate and angle-iron middle line keelson; and sometimes a middle line box or I keelson is fitted, instead of an intercostal or continuous vertical keel (see Plate CXIX.). In addition to the preceding, the iron framing consists of side keelsons, hold stringers, a bilge strake of plating on each side, deck beams, stringers and tie plates, sheer strakes, and diagonal plates on the frame similar to riders.

It will be thus seen that the iron framing is similar in

* The following particulars, as far as Art. 348, are extracted by permission from Lloyd's rules.

character to an iron ship, except as regards the strakes of bilge plates and the diagonal plates, which, with the sheer strakes and the flat keel, are the only bottom and side plates riveted to the frames.

342. Wood Keels, Garboards, Stem, Stern Post, etc.—The wood keels are connected by either vertical or horizontal scarphs, tabled similar to the keel of a wood ship (see Art. 172), and bolted with copper or yellow metal bolts (varying in number from six to ten, according to the size of the ship), driven and clenched on rings of the same material. Their lengths are five times the mean of the siding and moulding of the keel. A vertical bolt is driven through the keel and keel plate between each pair of frames. The garboard strakes are not less than two-thirds the depth of the keel, and their butts shifted not less than 4 ft. 6 in. from the butts of the garboard strake on the opposite side, nor less than the same shift clear of the keel scarphs.

The scarphs of stem are required to be flat, in length not less than seven-tenths that prescribed for keel scarphs.

The apron, inner stern post, and deadwood are to be of sufficient siding and moulding for the knight heads and counter timbers, respectively, to be secured to them, and to take the fastenings in the hooding ends. These parts of the ship are through fastened in all cases, and the bolts spaced as in the keel.

343. Flat and Vertical Keels, Keelsons, etc.—The flat keel plate extends right fore and aft, and is made continuous up the apron and inner stern post, as high as practicable above the lower deck or hold beam stringer angle-irons. The butt straps are to be shifted clear of the keel scarphs. The width of the plate is uniform for three-fifths the length amidships; before and abaft this it is gradually reduced to the width of the flange of the angle-iron on the keel plate, forward and aft. The keelsons and internal keels are similar, except as regards scantling, to those of the several varieties of iron ships.

344. Frames, Reverse Frames, and Floor Plates (see Plate CXIX.).—The frame angle-irons extend from the keel to the gunwale, being in as long lengths as possible. They are required to be fitted and riveted to the keel plates, the union being further aided by a piece of angle-iron the same size as the frame, 4 ft. long, riveted to the floor and flat keel, back to back with the frame. The narrow flanges should be of parallel thickness, that the nuts of the screw bolts may fit closely.

The floor plates extend up the bilges not less than a perpendicular height of twice and a half the depth of floor amidships, from upper side of keel at middle line. A floor plate is to be fitted and riveted to every frame, and to be extended across the middle line; but when a continuous vertical keel is adopted, then the floor plates are to be efficiently connected to it on each side by double vertical angle-irons of not less size than the reverse frames. When floors extend from side to side and are made in two lengths, the butts are to have double butt straps, one on each side of the floor plates, and three-fourths the thickness of the floor plates, or else the floor plates must be lapped and treble riveted.

The reverse frames are to be secured to the floor plates and frames, with rivets spaced nine diameters apart; and the butts of the reverse frames are to be connected by butt straps.

345. Sheer and Bilge Strakes.—The iron sheer strake is required to be one inch in breadth for every six feet of the vessel's length for half her length in midships, being reduced to three-fourths the breadth and thickness at the ends. The butts are shifted at least three spaces of frames clear of those of the stringer plate on the beam ends; and the plates are required to be not less than 9 ft. long where practicable; the butt straps in all cases to be in one piece, whether fitted outside or inside; and in no case to be in two pieces by being cut at the stringer plates.

The bilge strake plates to be two-thirds the breadth of the iron sheer strake, for three-fifths the length of the keel in midships, and reduced gradually to one-half their midship breadth at the ends of the vessel. The middle of the bilge strake is to be at the height of the floor head. When the planking is worked in two thicknesses diagonally, transversely to each other, the bilge strakes are dispensed with.

346. Diagonal Plates on Frames are to be not less than one-third of the breadth of the iron sheer strake, and fitted in pairs transversely, all fore and aft, at an angle of 45 degrees, with the butts of each pair meeting between the frames. They are to be connected to the sheer and bilge strake plates by butt straps double riveted, and to be efficiently riveted to each other, and to each frame they cross. These also are omitted when the plank is worked as stated in Art. 345.

347. Stringer and Tie Plates, Gutter Waterways, etc., are fitted similarly to an iron ship, the only difference being in the scantlings required for ships of the several dimensions.

348. Planking (Plate CXIX.).—We now come to the characteristic of the composite ship, viz., the substitution of wood sheathing for iron plates on the bottom and sides. The wood planking is fitted in either one or two layers, the total thickness required varying from 4 inches in the side of a ship under 100 tons, to 8 inches in a ship of between 3000 and 3500 tons. The fastenings may be of copper, yellow metal, galvanized iron, or plain iron. When galvanized or plain iron bolts are used, the butt fastenings, also those in the fore and after hoods to a certain height, those which fasten the planking to the deadwood, the lower edge of the garboard strakes, and the wood keel and stem scarphs, must be of wrought copper or yellow metal. Also all iron-fastened composite ships, previous to being sheathed with copper or yellow metal, must be sheathed with wood $1\frac{1}{4}$ inches thick.

The shift of butts is similar to that of a wood ship, and the butts are secured to "butt plates" of the breadth of the plank, extending from frame to frame on each side of the butt, and efficiently riveted to them. Each butt is secured to the butt plate with two metal bolts.

The planks (except the garboard strakes) are not to be more than 12 inches broad; but when a double thickness is fitted, that on the outside should not exceed 10 inches in breadth.

Teak is preferred for the planking of composite ships, but American rock elm may be used to two-fifths the depth of the ship, set up from the keel plate, without reduction of classification. Whenever any of the oaks, or other woods of an acid nature, are used for any part of the ship adjacent to iron work, the best hair felt, canvas, or other approved material, in addition to paint, is to be placed between them and the iron plates and angle-irons.

The garboard strakes are required to be cross bolted from side to side as in a wood ship.

The bottom plank is connected to the frames with nut and screw bolts of the materials already mentioned. When for planking less than five inches thick, the bolts are to be of such a form under the heads as will prevent them from turning, their heads are to be one and three quarter times the diameter of the bolts, and two-fifths their diameter in thickness. Hexagonal nuts are preferred, to be of the same material as the bolt, and in thickness equal to their diameter.

The planks (when in a single thickness) 10 inches broad and above, to be double fastened; $8\frac{1}{2}$ inches and under 10 inches, double and single fastened alternately; and under $8\frac{1}{2}$ single fastened. All butts to be double fastened as already stated. When the planking is composed of two thicknesses, the outside thickness of planking should not exceed 10 inches in breadth, and may be single fastened, but the fastenings are not to exceed 20 inches apart on an edge; if, however, planks are used in the lower part of the bottom more than 10 inches, but not exceeding 12 inches, in breadth, their fastenings are not to exceed 18 inches apart on an edge.

The bolt holes in the outside planking to be enlarged with a dowelling machine for the bolt heads, which, in the bottom up to one-fifth the depth of hold set down below the upper deck stringer plate, are to be sunk within the surface of the planking $1\frac{1}{4}$ inch when dowels are intended to be used; from thence to the planksheer, they need not be sunk more than $\frac{3}{4}$ of an inch; the bolts to be properly driven with oakum and white lead, putting marine glue or other suitable composition under their heads, and in the bottom they are to be carefully covered (after the seams of the bottom are all caulked) with turned, well-seasoned wood dowels, the fibre of which must be in the same direction as the planking, and be driven with white lead, marine glue, or any other approved composition. Where copper or yellow metal bolts are used, the sinking of them within the surface of the planking to be optional to the above extent.

When the strakes of planking are worked in two thicknesses, diagonally, a longitudinal strake of plank must be rabbeted into the garboard strake on each side, and the ends of the diagonal planks butted against them. One or two such longitudinal strakes must also be fitted at the upper boundary of the planking for the same purpose. In all cases of a double thickness being fitted, both are caulked, and the outer wrought hot on the best hair felt.

349. Admiralty Composite System.—Plate CXX. shows the framing of a composite sloop built on the Admiralty system. As already remarked, only the smallest vessels of the Royal Navy are built in this way, as it is not sufficiently strong to resist the vibration caused by powerful engines, nor for a ship of large dimensions carrying heavy weights.

350. The Vertical Keel and Flat Keel.—The vertical keel is worked intercostally between the floors, almost to the stem, and from there it is continued up inside the latter to the upper deck. The intercostal plates extend to about 3 inches above the floors, and angle-irons about $3 \times 3 \times \frac{7}{16}$ in. are riveted to it back to back. Sometimes these are omitted in the wake of the boiler room, in order to get additional space, in which case the intercostal plates are the same depth as the floors, and a gutter plate riveted to the latter, and to an angle-iron at the upper edge of the vertical keel. Holes are cut through each intercostal plate, just above the height to which cement is laid, in order to form watercourses. The flat keel plate is fitted and secured in the usual manner, and, like the vertical keel, extends up the inside of the wood stem and stern post, and receives their fastenings.

351. Floors, Frames, Reverse Frames.—The floors are continuous from bilge to bilge, and are connected to the intercosal keel plates by short pieces of angle-iron $3 \times 3 \times \frac{7}{16}$ in., bent so as to secure the floors to the vertical keel, and the latter to the flat keel (see Plate CXX.). Holes are cut in the floors just above the level of the cement, in order to form watercourses.

The frames in the wake of the guns are deeper than elsewhere, and are formed by continuing the floor plate to the topside, and riveting the frame and reverse angle-irons to it as at the lower part. The remaining frames above the floor plate (which stops at the turn of the bilge), are formed by riveting the frame and reverse angle-irons back to back in the usual manner.

352. Side Keelsons, Stringers, Sheer Strake, etc.—Side keelsons and stringers are fitted intercostally, as shown in section and plan by Plate CXX. The side keelsons are associated with a strake of plating on both the inside and outside of the frames, thereby considerably increasing their efficiency as longitudinal ties.

The manner of fitting the stringers, both at and between the upper and lower decks, is shown in plan and section on the above-mentioned Plate. The upper deck stringer acts in conjunction with angle-iron watercourses, as already described; also with a sheer strake on the outside of the frames, the whole forming a highly efficient combination for preserving the shape and giving rigidity to the iron framework of the ship at such an important position as the junction of the beams with the side.

The angle-irons for connecting the bilge keels, that connecting the heads of the frames beneath the rail, also the longitudinal bulkheads on the inside, all contribute to the longitudinal strength of the ship, considered independently of the side and deck planking.

353. Plank of Bottom.—Composite ships built for the Royal Navy have always two thicknesses of plank from the keel to about 4 feet above the load water line; above this height only one layer is fitted, tapering in thickness from about 4 inches to 2 inches at the upper part. The inner thickness is of teak, as also is the outer, except from the keel to the bilge on each side, where English or Canada elm is fitted; and the fore and after hoods, which are generally of oak. The inner plank is 3½ inches thick, and the outer 2½ inches, tapering to a collective thickness of about 4 inches where the single thickness commences (see Plate CXX.) Both are fitted horizontally, and the edges and butts give shift to each other in the manner shown by Plate CXXI. The planks, from about 9 to 12 inches in width, are mostly double fastened, as shown by the Plate; but where the planks are only 8 inches wide they are single fastened. The shifts usually average about 24 feet in length.

The inner thickness is secured to the angle-irons of the frames with malleable yellow metal nut and screw bolts, usually about $\frac{7}{8}$ of an inch in diameter. These are composed of 63 parts of copper and 37 of zinc, and are tested to a tensile strain of 22 tons to the square inch, and are required to be capable of bending cold to an angle of 78 degrees after the screw threads are cut in them and the nuts on. Like the fastenings in the inner thickness of sheathed ships already described, these screw bolts are tapped into the angle-irons and further secured with a nut on the inside. The points of these screws are sometimes slightly "upset," to prevent the nuts from coming off. Great care is taken to make these bolts thoroughly watertight, and they are hove up so that the shoulders compress the wood about $\frac{1}{8}$ of an inch. It should be observed that the screw bolts are reduced one-sixteenth of an inch in diameter at the screw thread. The heads are set in a mixture of white and red lead, or Hay's waterproof glue. The holes over the bolt heads are filled with a mixture of Portland cement and Hay's glue, in the proportion of three to one; or else with a mixture of white and red lead.

The outer thickness of sheathing is fastened to the inner with $\frac{1}{2}$-inch copper bolts, the heads of which are previously formed; these are driven and clenched upon metal rings, the means of obtaining watertightness being as just stated. The arrangement of the fastenings is shown by Plate CXXI., the bolts being about 20 inches apart.

The butts of the inner thickness are formed as shown at *A*, Plate CXXI., the scarphs being 4 inches long, and secured to the angle-irons of the frames. The butts of the outer thickness are arranged to give good shift to those of the inner. The former are brought about midway between the frames, and are fastened with two copper bolts on each side of the butt, as shown. The heads of these bolts, like those in sheathed ships, are filled in with a suitable composition to receive the nails of the copper sheathing; a mixture of white lead and tallow, in the proportion of three to one, is sometimes used. (See Art. 336.)

354. Topside Planking.—The topside planking is in one thickness, being principally of teak on the outside and Honduras mahogany on the inside. The former is secured to the frame angle-irons with galvanized iron nut and screw bolts, in diameter suitable to the several thicknesses of planking, which tapers at this part from the double thickness to about $2\frac{1}{2}$ or 3 inches. These nut and screw bolts are tapped through the angle-irons, and nutted on the inside. Where the planks are above three inches thick they are scarphed in a similar manner to the inner thickness of bottom plank; but when less than three inches thick the butts are secured to iron plates riveted to the frames, and sufficiently wide to receive the butt bolts. The butts in this case are brought to the middle of the frame angle-iron. The inside planking at the topside is from $2\frac{1}{2}$ to 2 inches thick, and fastened with $\frac{1}{2}$-inch galvanized iron nut and screw bolts.

355. Wood Keel, Stem, Stern Post, and Deadwood.—The flat and vertical keel plates extend from the stern post to the under side of the upper deck, and to this the wood keel and stem are secured. The keel is of teak, usually about $5\frac{1}{2}$ or 6 inches thick, and about 18 inches broad. A rabbet, $2\frac{1}{2}$ inches deep, is cut out of it on each edge to house the outer thickness of bottom plank (see Plate CXXII., fig. 4). The several lengths are connected by tabled scarphs.

As already stated, the flat and vertical keels extend to the height of the upper deck; it should be remarked, however, that the latter is worked continuously, and not intercostal, before the fourth or fifth station from forward. The wood stem is secured to this framework, being in two sets of timbers, the scarphs of which give shift to each other. The inner thickness is of teak, the upper outer piece usually of oak, and the lower of elm.

The scarphs of the inner thickness of stem are dowelled and the outer tabled; each is fastened with five $\frac{7}{8}$-inch yellow metal through bolts.

Various methods have been adopted for securing the pieces of stem to the stem plate. The inner piece of stem is connected with two sets of bolts. (1) With $\frac{3}{4}$-inch iron through bolts, from side to side, passing through iron straps riveted to the side of the flat plate, the heads of the bolts being countersunk in the straps. Formerly, a plate was riveted up and down on each side, but this has been given up in favour of straps placed at intervals (see fig. 2, Plate CXXII.).

(2) With $\frac{7}{8}$-inch galvanized iron nut and screw bolts, as show by fig. 1 on that Plate, which are secured with nuts hove up on the inside of the angle-iron. These bolts have sometimes been omitted, in which case the only bolts securing the inner piece of stem, prior to the outer piece being fitted, were the metal scarph bolts, and those through the side straps.

Two different methods of fastening the outer stem are shown by figs. 1 and 2, Plate CXXII., the bolts in both cases being $\frac{3}{4}$-inch in diameter, of copper or yellow metal.

It should be stated that the two pieces of stem are dowelled together.

The stern post is in two or three pieces, tabled together, and tenoned to the keel in the same manner as for a wood ship. The after piece is usually of oak and the others of teak. The stern is formed by bolting two post timbers, one on each side of the post, with a third between them abaft the post, boxen being left on them to house both thicknesses of bottom planking.

The pieces of deadwood are dowelled together, and the whole is fastened with malleable yellow metal bolts, the longest being $1\frac{1}{4}$ inch in diameter, and the others, when above 2 feet, are $1\frac{1}{8}$ inch, and below that length 1 inch in diameter.

The remainder of the construction of the hull on the composite principle very closely resembles that of an ordinary iron ship. The deck framing and plating, bulkheads, and all the details of the fittings remain unaltered, care being, however, taken to preserve the insulation of the iron work on the interior of the ship from the copper sheathing on the outside, and so prevent galvanic action.

INDEX.

PART I.—LAYING OFF WOOD SHIPS.

PART II.—LAYING OFF IRON SHIPS.

PART III.—WOOD SHIPBUILDING.

PART IV.—IRON SHIPBUILDING.

PART V.—SHEATHED AND COMPOSITE SHIPBUILDING.

WILLIAM COLLINS AND COMPANY, PRINTERS, GLASGOW.