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THE MODERN PRACTICE

OF

SHIPBUILDING

IN

IRON AND STEEL.

BY

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PREFACE.

The Work on *Practical Naval Architecture*, contributed by myself to this Series thirteen years ago, was prepared chiefly with a view to supply the requirements of the Examinations set by the Science and Art Department and the Admiralty at the time. The favourable reception which was accorded to that book, and the extent of its use, encourage me to believe that it fulfilled the purpose for which it was intended. But during recent years wood shipbuilding has practically ceased to be a British industry; and so many improvements have been made in the construction of iron and steel ships as to render it necessary that an additional volume should be prepared to meet the altered circumstances of the present day. All that was written in *Practical Naval Architecture* thirteen years ago upon wood and composite shipbuilding, and the laying-off of ships, may, however, still be consulted by students of those subjects witb undiminished advantage.

In preparing this treatise an attempt has been made to describe in detail the several processes involved in the Modern Practice of Shipbuilding in Iron and Steel at both our Royal and Private Dockyards, and it is hoped that this has been done in a sufficiently clear and explicit manner to meet the requirements of those desiring an acquaintance with the subject.

S. J. P. T.

GREENOCK, *October*, 1886.

PREFACE TO SECOND EDITION.

During the five years which have elapsed since the publication of the first edition of this work, steel has almost entirely replaced iron in ship construction, so that such a term as "angle iron" is no longer correctly applicable to the materials ordinarily used in shipbuilding. Moreover, it has been found necessary to, normally, specify scantlings in twentieths of an inch; tbe former scale of sixteenths being applied only in the unusual cases in which iron is employed. In revising this work the scantlings and dimensions have been altered in accordance with the present Rules of Lloyd's Register for steel ships, and tbe usual practice of the trade; but, in order to save as many as possible of the stereotype plates from which the text of the first edition was printed, the term "angle iron" has been retained in many cases where "angle bar" would be the more correct designation. Some additions have been made to both the Text and Plate Volumes in order to describe and illustrate the developments of recent years in web-frame and cellular bottom construction, as well as other important details.

S. J. P. T.

GLASGOW, *July*, 1891.

PREFACE TO THIRD EDITION.

It was upwards of ten years ago that this work last underwent revision, and during that interval great advances have been made in the art of shipbuilding. Steel has long since wholly replaced iron as a material for ship construction, except for such purposes as decks and double bottoms, where iron is occasionally used because of its lesser liability to wasting by corrosion. The dimensions given to vessels have continued to increase at a rapid rate, and the increase in size has been attended with important developments in the modes of combination, and in the means of affording the necessary additional strength. Besides these, there has all the time been an increasing tendency to provide more roomy cargo spaces, with unbroken stowage, by omitting decks and tiers of beams, and substituting for these other combinations of materials intended to furnish equivalent structural efficiency.

It has been considered desirable to incorporate, in the form of an Appendix, the additional matter necessary for describing the most important of these recent developments in the details of ship construction, and to illustrate the same by means of additional drawings in the Plate Volume.

The scantlings required by Lloyd's Rules have been altered in some particulars since the issue of former editions, but it has not been thought necessary to correspondingly amend the Text, as by a reference to the current issue of these Rules, which are used in every shipyard, the modifications in question may readily be found.

S. J. P. T.

London, *January*, 1902.

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THE MODERN PRACTICE

OF

SHIPBUILDING IN IRON AND STEEL.

CHAPTER I.

1. **Materials.**—Before explaining the many processes involved in the Art of Shipbuilding in Iron and Steel, as at present practised, it is desirable that something should be said regarding the materials of which a ship is built.

From the earliest period of the world's history, until comparatively recent times, wood was the principal material employed in the construction of ships; and metals, such as iron, copper, lead, and zinc, were used only for their fastenings, fittings, or sheathing. It was not until the second decade of the present century that men ventured to embark upon the seas in vessels built of wrought iron; but so strong was the prejudice against the use of that material, probably on account of its high specific gravity, that nearly the middle of the century was reached before much advantage was taken of the satisfactory results which followed the first employment of iron in shipbuilding.

During the past fifty years, however, enormous strides have been made in this industry, so that it is now very unusual to see a mercantile vessel being built of wood, and ships of war are often cased with iron and steel armour of from eighteen to twenty-four inches in thickness.

After the superiority of wrought iron over wood as a material for ships was established, the attention of some shipbuilders was directed to steel, with the view of still further adding to the strength of ships, and diminishing the weights of their hulls.

For a long time, however, steel was found to be very untrustworthy on account of the great variability in its ductility and tenacity; and although a few steel vessels were built with satisfactory results, the failures in working with the steel then being supplied were so frequent, that both in the Royal Navy and the mercantile marine a considerable timidity was felt in bandling and working it.

In the year 1874 it was found that the French Government was largely using steel manufactured by the Bessemer process in the construction of ships and boilers for their navy, but their experience showed that great care was still necessary in working the material, in order to avoid failure.

In 1875, Mr. N. Barnaby, Director of Naval Construction at the Admiralty, stated his willingness and desire to "build the entire vessel, bottom plates and all, of steel," provided a really trustworthy quality of that material could be supplied. It was doubtless in response to that challenge, that some of the principal steel makers of the country turned their attention particularly to the production of a homogeneous mild steel, containing only a small percentage of carbon, and possessing high ductile qualities with a comparatively moderate tensile strength. Before a year had elapsed, the required material was produced, and in 1877 steel was approved by the Committee of Lloyd's Register of Shipping for the construction of vessels intended to be classed in their Register subject to certain conditions of testing, which included an ultimate tensile strength of not less than 27, and not exceeding 31 tons per square inch of section.

The Admiralty had shortly before accepted a similar material for the construction of H.M. ships, the steel being produced by the Siemens-Martin process. But so rapid was the development in the manufacture, that in the course of a few months steel of the desired quality was

being supplied from many parts of Great Britain, and at the present time it is being imported both from Germany and America.

This mild steel which, by improvements in the manufacture, is now quoted in the market at a lower rate than a few years ago was given for wrought iron, has largely supplanted the last named material in the construction of ships.

When possessed of an ultimate tensile strength up to about 32 tons per square inch of sectional area, it is found to have considerable ductility, and to be free from that brittleness and variability of quality which characterised the Bessemer and puddled steel of thirty years ago. To such an extent is this the case, that shipbuilders, as a rule, prefer working with it rather than with iron, and often employ steel for some of the parts of an iron ship which require much curvature or bevelling.

Although this is the case, yet, up to the present time, it has been felt prudent to adopt certain precautions when working with steel plates of half an inch in thickness and above.

Experiments which were made under the directions of Lloyd's Register Committee in the year 1877, showed that the punching of steel plates was in all cases attended with a depreciation of the tenacity of the steel, and that in the case of thick plating the reduction of strength was fully 33 per cent. The experiments showed, moreover, that by annealing them after punching the full tenacity of the material was restored. It was further found that riming the holes with a drill had a similar effect. From these results it was inferred that the process of punching altered the molecular condition of the steel in the immediate neighbourhood of the holes, and that riming removed the portion of the steel in a state of molecular tension, and with it the tendency of the material to rupture at these holes when submitted to lower stresses than it was capable of enduring before being punched. As already remarked, the operation of annealing effected the same result.

Lloyd's Register Committee, therefore, in sanctioning a reduction in the thickness of steel plates and angles, as compared with those of iron, have insisted upon all butt straps of half inch in thickness and upwards being annealed or rimed; and they further insist upon similar conditions being observed in the case of sheer strakes, garboard strakes, and stringer plates of that size and above. In the following pages it will be assumed, unless otherwise stated, that the material is mild steel that has been found, when tested, to fulfil the requirements of the Committee of Lloyd's Register.

It may here be remarked that all steel worked into classed ships is tested at the steel works by the Surveyors to Lloyd's Register, and when found satisfactory it is stamped with a brand thus:—

The test requirements for steel, according to Lloyd's Rules, are as follows:—

Tests.—Strips cut lengthwise or crosswise of the plate, and also angle and bulb steel, to have an ultimate tensile strength of not less than 28, and not exceeding 32 tons per square inch of section, with an elongation equal to at least 16 per cent. on a length of 8 inches before fracture. Steel plates intended for cold flanging, if specially marked for identification, may be tested to within the minimum limit allowed for boiler plates, viz.:—26 tons tensile strength per square inch.

Steel angles intended for the framing of vessels, and bulb steel for beams, may have a maximum tensile strength of 33 tons per square inch of section, provided they be capable of withstanding the bending tests, and of being efficiently welded.

Strips cut from the plate, angle or bulb steel to be heated to a low cherry-red, and cooled in water of 82° Fahrenheit, must stand bending double round a curve of which the diameter is not more than three times the thickness of the plates tested.

In addition to this, samples of plates and bars should be subjected to cold bending tests at the discretion of the Surveyors.

Rivets.—The steel used for rivets to be of special quality, soft and ductile, and samples of the rivets should be tested by being bent both hot and cold, by flattening down the heads, and by occasional forge tests, in order to satisfy the Surveyors of their thorough efficiency.

With regard to the quality of the iron which is wrought into mercantile vessels, it may be stated that Lloyd's Rules

require it to be of good malleable quality, capable of withstanding a tensile strain of 20 tons per square inch with, and 18 tons across, the grain, and to be subjected to tests at the discretion of the Surveyors.

Brittle or inferior material is to be rejected.

All plates, beam, and angle iron are further required to be stamped with the manufacturer's name or trade mark, and the place where made.

CHAPTER II.

2. The Plans.—The work of the shipbuilder commences with the preparation of the drawings of the vessel he is about to build. These drawings consist of:—1st, The lines showing the dimensions and form of the vessel; and 2nd, The elevations, plans, and sections, describing the modes and details of her construction, and the character and extent of her principal fittings.

The first-named drawing is known as the *Sheer Draught*, and is illustrated by Plate I, which is the sheer draught of an iron sailing ship.

The other drawings comprise—

(*a*) The *Midship Section*, and any other transverse sections of the vessel which may be necessary in order to show the arrangement and sizes of the materials used in her construction. Midship sections of several types of vessels are shown by Plates II., III., IV., and V.

(*b*) The profile, or longitudinal vertical section of the vessel, showing arrangement of decks, bulkheads, etc. See Plate VI.

(*c*) The deck and hold plans, such as are shown by Plate VII.

It will be assumed that these drawings have been prepared, together with a specification describing in greater detail what the intended ship is to be.

3. Scantlings.—It is desirable to remark here that the sizes of plates, angle bars, etc., shown upon the midship sections, and stated upon the specifications of vessels built in the British islands, and, to a large extent, in other countries, are in most cases fixed in accordance with the Rules of Lloyd's Register of British and Foreign Shipping. Moreover, the structural arrangements in the vessels are

to a like extent similarly determined. This is due to the fact that about 90 per cent. of the tonnage of iron and steel vessels built in this country is surveyed by Lloyd's Surveyors, with a view to being classed in Lloyd's Register; whilst the scantlings of the remaining tonnage are very often regulated to a greater or lesser extent by the same rules. It is not intended in this volume to attempt to explain the causes which have led to these results; it is sufficient to point out that such is the case. It will therefore be found in the course of the following pages that frequent reference is made to the requirements of Lloyd's Rules; for these, to a very considerable extent, regulate the practice of iron and steel shipbuilding all over the world, and certainly constitute the almost universal practice in the British islands. In quoting these rules, it will be understood that reference is made to those in operation at the date of publishing the present edition of this work.

4. Lloyd's Numbers for Regulating Scantlings.—In order to regulate and graduate the scantlings and arrangements considered suitable for vessels of different dimensions the Committee of Lloyd's Register have for many years past discarded the criterion of tonnage, and adopted instead two sets of scantling numbers. To obtain these numbers the length of the vessel, and the breadth, depth, and girth of her half midship frame section, must be determined.

The *Length* is measured from the after part of stem to the fore part of the stern-post, on the range of the upper deck beams, in one, two, and three decked and spar decked vessels, but on the range of main deck beams in awning decked vessels.

In vessels where the stem forms a cut-water, the length is measured from the place where the upper deck beam would intersect the after edge of stem if it were produced in the same direction as the part below the cut-water.

The *Breadth* is in all cases the greatest moulded breadth of the vessel.

The *Depth* in one and two decked vessels is taken from the upper part of the keel to the top of the upper deck beam amidships. In spar decked and awning decked vessels the depth is taken from the upper part of the keel to the top of the main deck beam amidships. For three decked vessels the depth is measured to the top of the upper deck beams in obtaining some of the scantlings, while for others a deduction of seven feet is made.

Using these dimensions, the scantlings and spacing of the frames, reverse frames, and floor plates, the thickness of bulkheads, and the diameters of pillars, are regulated by a "FIRST NUMBER," which is produced as follows :—

For one and two decked vessels.—The *number* is the sum of the measurements in feet arising from the addition of the half moulded breadth of the vessel amidships, the depth from the upper part of keel to the top of the upper deck beams, and the girth of the half midship frame section of the vessel, measured from the centre line at the top of the keel to the upper deck stringer plate.

For three decked steam vessels.—The *number* is produced by the deduction of seven feet from the sum of the measurements taken to the top of the upper deck beams.

For spar decked and awning decked steam vessels.—The *number* is the sum of the measurements in feet taken to the top of the main deck beam, as described for vessels having one or two decks.

The "SECOND NUMBER" regulates the scantlings of the keel, stem, stern posts, keelson and stringer plates, the thickness of the outside plating and deck, the scantlings of the angle irons on beam stringer plates, and keelson and stringer angle irons in hold. It is obtained by multiplying the *First Number* by the length of the vessel.

Having determined these two scantling "numbers", the scantlings for each part of the vessel, if to be built in accordance with Lloyd's requirements, can be determined by reference to the several Tables printed with the Rules of that Society. It should, however, be remarked that the scantlings in some of those Tables are intended only for vessels the length of which does not exceed eleven times their depth from the top of keel. When this proportion is exceeded other regulations come into operation.

5. The Model.—The plans being prepared and the scantlings determined, the next duty of the shipbuilder is to prepare a model, in wood, of the vessel to be built, and

upon that model he arranges the edges and butts of the shell plating, and draws lines showing the positions of the frames. This model is usually made upon a scale of ¼ inch to the foot, but for very small vessels a ½-inch scale is preferred. From this model the lengths of the plates and the frames are generally measured, and these materials are ordered as early as possible from the iron merchant. Sometimes, however, the lengths of the plates are measured from a drawing showing an expansion of the bottom. It is usual to order the shell plates an inch longer than the measurements obtained from the model or expansion drawing, except at the curved parts of the bow and stern, where an excess of from two to four inches is allowed. In most shipyards the breadths of the plates are taken from the "scrive board"—to be described hereafter. The lengths of floors and reverse frames are sometimes obtained from the model or expansion, but generally from the body plan on the sheer draught or from the scrive board. But before giving further explanations upon this subject it is necessary that something should be said about the processes of laying off and fairing the body.

6. Fairing the Body.—The work involved in laying off a wooden vessel of large size was of a very considerable and sometimes difficult character.* But so readily and simply may iron and steel be manipulated, that the laying off of a mercantile vessel built with either of these materials resolves itself into but little more than simply fairing the lines upon the sheer draught. This drawing is usually prepared upon a ¼-inch scale, and although every care may be taken in getting in the lines upon it, yet, when expanded to full size, or even to a ½-inch scale only, discrepancies and points of unfairness are sure to be discovered.

The object in Fairing the Body is twofold; the first being, as the name would indicate, to ensure that the surface of the vessel shall be perfectly fair, and the second to obtain complete agreement between the body, sheer and half-breadth plans.

* See *Practical Naval Architecture;* by S. J. P. Thearle. Published by William Collins, Sons, & Co., Limited.

This process is fully described in the author's work already referred to. It consists simply in drawing new curved lines in the half breadth plan, upon full or enlarged scale, by using measurements obtained from the sheer and body plans, and then in drawing a new body plan to full or enlarged scale by using measurements obtained from the sheer and half-breadth plans. Similarly, lines which appear curved in the sheer plan are drawn to full or enlarged scale by using measurements obtained from the half-breadth and body plans. These processes are repeated until at last the three plans contain perfectly fair lines and are in complete agreement with each other.

In most shipbuilding yards the lines of the vessel are expanded to full size upon a mould loft floor, but at some places they are faired upon paper to a ½-inch or larger scale, and all moulds, etc., prepared by enlarging from the lines so faired. This course of procedure cannot be recommended upon any other grounds than cheapness. It admits the probability of error and consequent unfairness in the form of the vessel, and is not at all conducive to the production of satisfactory work.

It may be remarked that the contracted method of fairing explained in page 32 of the work on *Practical Naval Architecture,* before mentioned, is advantageously adopted in some establishments for the purpose of fairing the extremities of very long vessels.

A further explanation of the work of laying off a vessel built of iron or steel not being within the scope of this treatise, the student is referred to the book already named for detailed particulars of this branch of the shipbuilders' operations.

7. The Scrive Board.—When the vessel has been laid off either upon the mould loft floor, or upon paper, the lines are transferred to the *Scrive Board.* This consists of a number of seasoned deals, secured edge to edge by clamps at the back, the edges being close jointed, and the area of the board large enough to receive a copy of the body plan to full size.

Sometimes two boards are prepared for each vessel—one showing the two sides of the fore body and the other

showing the two sides of the after body. At other shipyards it is customary to draw both sides of each body on the one board, the lower part of each body being at opposite edges of the board, and the lines for the two bodies overlapping each other. This may be done without resulting in indistinctness by making the board rather larger than would otherwise be necessary (See Plate VIII.). Other shipbuilders, again, draw only one side of each body upon the board; making, in fact, a copy of the body plan as ordinarily drawn. For convenience in adjusting the frames, reverse frames, and floors, and setting off the rivets upon them—as will be subsequently described—marks are made at different lengths in each body plan showing the breadths, at those places, of the frames drawn upon the opposite body. This method of preparing the scrive board is not recommended, however, as it affords greater risks of unfairness than the other two methods which have been described.

The scrive board (Plate VIII.) should show—

1. The outer edges of the frame angle irons—marked *a.*

2. The inner edges and upper boundaries of floor plates—*b.*

3. The landing edges of the shell plates—marked *c.*

4. The lines of the upper parts of beams at the outer edges of the frames—*d.*

5. The middle lines of keelsons and side stringers—*e.*

6. The positions of ribbands for holding together the frame in their proper places—*f.*

7. The several water lines by which the vessel was faired. (These are not shown on Plate VIII.)

8. The bow and buttock lines employed for the same purpose (these are omitted from Plate VIII.); and

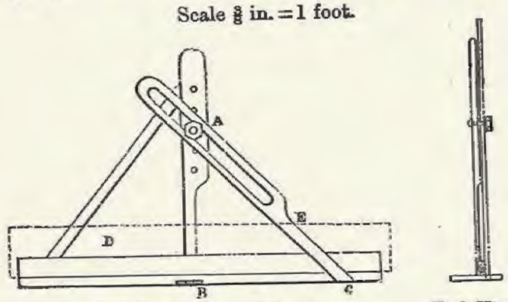
9. When water ballast tanks are fitted, or cellular framing adopted, the girders or longitudinal frames at each transverse section are shown, together with the margin or flange plates and such other lines as may be necessary in such cases.

In addition to the above the base and middle lines of vessel are also drawn.

All these lines are "razed" or scratched into the surface of the board and some of them are distinguished by paint marks of various colours.

8. **Bevellings.**—Bevelling boards are sometimes prepared for the use of the workmen when setting the frames and reverse frames to the curves shown on the scrive boards. But at some shipyards, the workmen take the bevellings direct from the board by the aid of an instrument such as is shown by fig. 1. As will be seen, this apparatus consists of

Scale ⅜ in. = 1 foot.



Front View. Fig. 1. *End View.*

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 scrive board, with the bevelling board D (indicated by dotted lines) resting upon it in the manner shown. The centre line of the tongue of the square is fixed at the point B, where a bevelling spot has been chosen upon a frame curve on the scrive board (usually at a ribband line), and the centre line of the tongue of the bevel is placed at C, where a perpendicular from the frame at the point B on the scrive board cuts the adjacent frame line. The pin A having been fixed at such a height that AB is the frame spacing of the vessel, it consequently follows that the line EC gives the bevelling of the angle iron.

The bevelling of the frames and reverse frames are always *standing* or obtuse, and to obtain this the flanges of the angle iron are placed in opposite directions in the two bodies.

Fitters' Plans.—To further instruct the workmen regarding the details of the ship to be built, plans of the several decks, a sketch of the profile and other details of the construction are drawn upon boards, the whole being protected

by varnish from erasure either by the action of the weather or frequent use. A tracing of the midship section upon cloth is usually provided for the same purpose. The drawings thus supplied show only the iron and steel work of the hull proper, together with the decks; other details for the guidance of the joiners and carpenters being furnished separately at a later stage.

9. **Ordering Materials.**—Some reference has already been made to this department of the shipbuilders' work. It must necessarily be performed at a very early stage in the operations, as nothing can be done towards building the ship until the requisite materials for her construction have been received.

It will be assumed that the midship section, sheer draught, plans, and specification have been approved; also that the lines have been faired, the model made, and scrive board prepared. The keel, stem, and stern post are ordered and put in hand at once. These are usually forged from scrap iron, but, of late, stern posts of steamers have been occasionally made of cast steel. The information given for the supply of keel bars is of a very simple character, consisting simply of the lengths of the several pieces, together with the depth and thickness of the keel. If the keel is to be supplied with the scarphs planed and fitted, and some of the rivet holes drilled, special templates have to be provided, showing the size, spacing, and arrangements of the rivets. The holes in one of each pair of corresponding scarphs should, however, not be drilled until the keel is in place on the blocks; but that precaution is not always observed. A very ordinary length for forged keel bars is forty feet, but, of course, this is largely determined by the length of the vessel.

The stem is ordered in the straight, similar to a length of keel, and is bent to its form in the shipyard; this being done in consequence of the inconvenience of transit with a curved bar, especially when it is required for the stem of a vessel with a cutwater.

The stern post of a sailing ship may be ordered by a sketch to scale, or by a full size pattern made to the lines on the mould loft floor. In every case the sizes and positions of the gudgeons to receive the rudder pintles must be clearly shown, and their position accurately set off by figured dimensions.

The mould or drawings supplied for the stern posts of a screw steamer are necessarily more elaborate than for a sailing ship or paddle steamer. The combination of *rudder post, body post,* and *connecting plate* is termed the *stern frame.* Particulars for forming the propeller boss have to be supplied, and the hole in the body post for the propeller to pass through is roughly drilled before the stern frame is sent to the shipyard. The hole is accurately turned out shortly before the vessel is launched. When the stern frame is cast in steel, a mould must be supplied for the purpose.

These forgings having been put in hand, the materials for the frames, reverse frames, floors, keelsons, stringers, shell plates, deck plates, beams, etc., must be ordered.

It is most important that the dimensions of the iron or steel plates, angles, etc., supplied for a vessel should not be very much in excess of those lengths required for the finished work, as otherwise waste is involved. At the same time, unless the materials are of a sufficient size, the waste is even still greater.

As has already been remarked, the lengths of frame angle irons are usually measured from the model. This is done by means of a flexible scale which is bent to the lines on the model, indicating the positions of the frames. Some shipbuilders, however, prefer to measure frames, reverse frames, and floor plates from the scrive board, and there can be no doubt that this is the more satisfactory method. In the same way, as the scrive board shows the lines of the insides of the floors, the latter and the reverse frames can be most accurately measured therefrom. This is especially the cases with steamers having varying depths of floors; but, even for sailing ships, the measurements may be taken with greater accuracy from the scrive board than from the model, as the latter shows the outside of the vessel only. Some builders, however, order all reverse frames and the floors, except those at the extremities of the vessel, from the model. In ordinary floors which lap or butt at alternate sides of the middle line, careful note must be taken of the long and short arms when preparing the order book for materials.

The lengths of shell plates, as already remarked, are measured from the model, an excess of one inch over the nett length being allowed, except at the curved extremities of the vessel, where the allowance is proportionately greater, even to the extent of three or four inches. The breadths of shell plates are always taken from the scrive board, an excess of one inch over the measured breadth being usually allowed for outer strakes, and of half an inch for inner strakes.

Deck plates, stringer plates, longitudinal and diagonal tie-plates are measured from the deck plans (see Plate VII.), an excess of half an inch to an inch being allowed over the nett lengths and breadths. The dimensions of coaming plates to hatchways, and the lengths of stringer and waterway angle bars are measured from the deck plans; but the lengths of all beams should be obtained from the scrive board, allowance being made for their being turned down to form knees.

The butts of keelson angles, plates, bulbs, bars, etc., are not always set off upon the working plans; although it is very desirable that they should be, in order to secure the best possible arrangement of butts in the vessel. It is, however, too often the practice to measure the total lengths of the keelsons, bilge and side stringers, and subdivide them into convenient lengths of from thirty to forty feet, leaving it to the foremen at the ship to arrange the butts in a satisfactory manner.

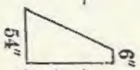
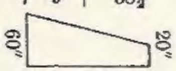
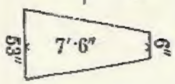
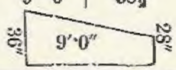
It is necessary before leaving this subject to state and explain the principal symbols employed in designating the various strakes of plating, frames, etc., upon the order book, so that the materials supplied for each part of the vessel may be used precisely where intended.

Frames are usually numbered from aft to forward, and the same numbers are of course employed for the corresponding reverse frames, floors, and beams. The strakes of shell plating are distinguished alphabetically, the garboard, or strake next the keel, being known as *A* strake, and so upwards to the sheer strake (see Plate II.). The plates in each strake are numbered, commencing from aft. The strakes of deck plating are at some yards also marked alphabetically, and the plates distinguished numerically; while at other yards the whole of the plates are numbered, commencing at the after end. When a great many plates in an iron or steel deck happen to be of the same dimensions and thickness, it is advantageous to indicate them all by the same mark when ordering the materials. By so doing, it is possible to order some hundreds of plates without employing many alphabetical or numerical designations. It is, of course, necessary to state how many plates of each size are required in sending out the order.

These several practices are, however, simply matters of detail, the general principle to be observed is that the materials upon reaching the shipyard shall be so marked as to be at once identified and appropriated to the purpose for which each plate, bar, etc., was ordered. Any method or system which gives this result with the least possible labour or risk of error may be considered satisfactory.

On the following pages are given extracts from ordinary order books for frames, etc., for iron and steel ships.

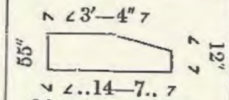
BULKHEAD PLATES.

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

PLATE STEEL.

Mark.	Nos.	Length.	Breadth.	Th.	
		′ ″	″ ″	″	
P.D.P. 1	2	15 3	45¼	$\frac{10}{32}$	
2	2	14 1	50¼		
3	2	17 6	,,	,,	
4	2	14′ 7 × 3″ 4′	55 12	,,	
5	2	12 1	66 58	,,	
6	14	12 1	62	,,	Of taper one side.
7	2	13 6	50¼	,,	
8	2	12 1	27 24	,,	
9	2	,,	27 30	,,	Of taper one end.
10	2	,,	30 33	,,	,, ,,
11	2	,,	33 34	,,	,, ,,
12	2	,,	34 36	,,	,, ,,
13	2	14′ 7 × 12″ 2′	49¾	,,	,, ,,
14	4	16 1	50	,,	,, ,,
15	16	12 1	44	,,	Doublings.
16	2	9 6	42	,,	

ANGLE STEEL.

Mark.	Nos.	Length.	Dimensions.	Th.	
		′ ″	″ ″	″	
E.B.K.	40	36 0	6½ × 4½	$\frac{10}{16}$	Keelson Angles.
E.B.K.	3	,,	6 × 4	,,	
E.S.	13	,,	4½ × 4½	$\frac{12}{16}$	
E.S.	28	,,	4 × 4	$\frac{10}{16}$	
I.	12	,,	3½ × 3½	$\frac{8}{16}$	
M.	22	30 0	3½ × 3	$\frac{7}{16}$	Angles for Fore and Main Masts.

CHAPTER III.

10. Laying the Blocks.—The materials for the vessel having been ordered, we have next to prepare a foundation upon which to build the ship.

The launching weight of mercantile vessels is not usually so great as to render necessary special precautions in regard to piling the ground, etc., such as is often required when ironclads have to be built thereon.

Presuming, then, that the ground is sufficiently solid, and that there is enough breadth and depth of water for launching the vessel when built, we will proceed to lay the blocks upon which the keel is to be placed.

The keel blocks are usually placed at a somewhat less declivity than the ways subsequently laid for launching. A very common declivity for blocks when a vessel is launched end on is about $\frac{5}{8}$ of an inch to the foot, and the launching ways may then be laid at from $\frac{11}{16}$ to $\frac{3}{4}$ inch to the foot.

The blocks are spaced at about four to five feet apart, and should be of stout and substantial baulks of timber—especially those at the bottom of each tier. In laying blocks care must be taken that the vessel is everywhere sufficiently high above the ground for the proper performance of all the operations involved in her construction.

The foremost block is almost invariably the highest, as the excess in declivity of the launching ways over that of the blocks tends to bring the bow of the vessel continually nearer the ground as she slides into the water. The intended height of the ways, nature of the fore shore, and the declivity adopted in launching should all be considered in determining the height of the foremost block, so that care must be taken in fixing it. If the blocks are laid at the same declivity as will be subsequently adopted for the

launching ways, the height of the foremost block will be determined solely by the necessity, already referred to, of affording sufficient head room for working under the flat of the bottom. But if the declivity of the keel blocks is less than that of the launching ways care must then be taken that the forepart of the keel is not brought too near the ground when the stem has reached the bottom of the ways and the after part of the vessel is water borne. It is a great advantage when the ground upon which the vessel is built has the same natural declivity as is given to the launching ways, and in that case it is not unusual to lay the blocks at a uniform height throughout the entire length of the vessel.

11. Arrangements for Stages.—The keel blocks are laid midway between two sets of upright spars which are erected for the purpose of supporting the stages upon which the workmen stand while engaged upon the framework and plating of the vessel. These spars are set deeply and firmly in the ground, and the two sets are spaced sufficiently apart to suit the breadth of the vessel and leave a few feet of clearance. On each side of the vessel these vertical spars are placed in two rows, with about six to eight feet between the rows. The spars are placed opposite each other in the two rows, and each spar is formed of a fir tree sawn up the middle, the two halves being separated by chocks of wood about four inches thick, and the two pieces are then bolted through the chocks. The openings between the two halves of the spars are opposite the vessel, so that horizontal wooden beams may rest upon the chocks between the halves of the two rows of spars on each side of the vessel. These beams are continued to the sides of the vessel and form the supports of the stage planks. A number of holes are bored through the two halves of the vertical spars, between the chocks, to receive bars of iron upon which the horizontal beams may rest at intermediate heights when it is required to place stages in such positions. These holes serve the further purpose of enabling bars of iron to be placed above the horizontal beams to keep the latter from tripping when heavy weights are resting upon the stage. Without further explanation it will be readily seen that this mode of erecting staging around a vessel is very simple and complete.

12. Bar Keels.—There are several varieties of keels in iron and steel ships, but of these the bar keel is the form most commonly adopted. Sketches of this keel in elevation and section are shown by Plate IX. As already stated, it is received in forged lengths of about forty feet, the several lengths being joined by vertical scarphs, as shown in elevation by fig. 2. The sizes of bar keels vary according to the dimensions of the vessels. Lloyd's Rules require a bar keel of 6 in. $\times 1\frac{1}{8}$ in. for a vessel of 100 tons, while for one of 6000 tons it is required to be of no less than 12 in. $\times 3\frac{3}{4}$ in.

The scarphs are required by Lloyd's Rules to be in length nine times the thickness of the keel. When pieces of keel are laid upon the blocks and set straight,

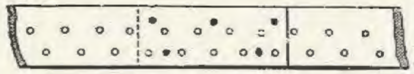


Fig. 2.

the scarphs are connected by several small countersunk rivets—known as "tack" rivets. The tack rivets serve to unite the pieces of keel until the garboard plates are riveted to them, and they are therefore spaced clear of the ordinary keel rivets. They must, however, be spaced sufficiently close to enable the scarph to be caulked before the garboard plates are put on. Their position and usual number are clearly seen by reference to fig. 2.

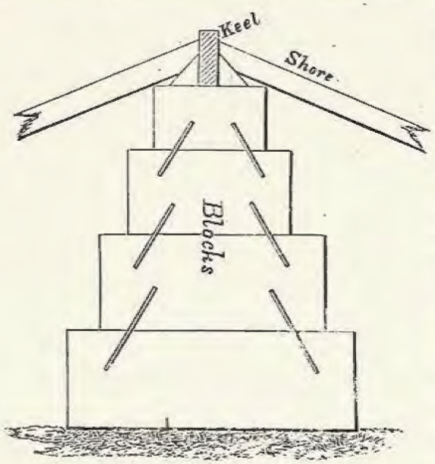


Fig 3.

The rivets in the keel are usually in two rows, arranged in what is termed "zig-zag" fashion, as shown by fig. 2, and they are required by Lloyd's Rules to be $\frac{1}{4}$ inch larger in diameter than would be required for riveting together plates of the same thickness as the garboard, but in no case

need they be more than $1\frac{1}{4}$ inches in diameter. By the same rules these rivets should be spaced five diameters apart from centre to centre in each row.

When the keel bars are laid upon the block, and set straight, they are kept in position by means of shores, and further by pieces of wood nailed to the upper block on each side, as shown by fig. 3.

13. Side Bar Keels.—A specimen of the side bar keel is shown in section by Plate III., and in elevation by fig. 2 of Plate X. Keels formed in this way are not often adopted, chiefly in consequence of the expense of workmanship, but the system is a very strong one, and superior in many respects to that which has just been described. There are several forms of the side bar arrangement, but the distinctive feature of the system is a continuous vertical plate extending from the under side of the keel to the top of the floors, and sometimes continued so as to form a part of the main keelson. A bar is riveted on each side of this plate at its lower part, the collective thickness of the middle line plate and the side bars being at least equal to the thickness of an ordinary bar keel.

The middle line plate and the side bars are obtained in long lengths, and they are so arranged as to give good shift to each other. The side bars are sometimes attached to the middle line plate with small rivets widely spaced, these being arranged so as to be clear of the main riveting of the keel. When the garboard plates have been bent and fitted, the holes for the keel rivets are either marked off upon them when in place, or else the rivet holes are transferred from the *templates*. It should here be explained that a *template* is a pattern, made with thin strips of fir, by means of which plates, etc., are prepared so as to correspond with the adjacent parts of the vessel already in place.

The holes for riveting side bars, garboards, and middle line together, are generally arranged in zig-zag fashion, and spaced about four and a half or five diameters apart, the size of the rivets being governed by the same rule as for bar keels. Great care is necessary in setting off the holes, and in drilling and riveting side bar keels, for when single bars are adopted there are five thicknesses to be riveted together;

and in the unusual case of double side bars the rivets pass through no less than seven thicknesses of plating. It has consequently been found necessary in such cases to reconcile a great many of the holes by riming with a drill when all the parts are screwed together preparatory to riveting. In order to ensure satisfactory riveting in side bar keels it is desirable at first to punch the rivet holes in the middle line plate smaller than the finished size, and then rime them to their exact size, when the side bars are screwed in place. The necessity for carefully closing and screwing up the several parts together after the garboard plates are fitted will be apparent, especially when the work is to be hand riveted. In the case shown by Plates III. and X., however, machine riveting was adopted, and the results were most satisfactory.

14. Flat Plate Keel.—This description of keel, which is shown on Plate V., is of much more common occurrence than that which has just been described. It is most commonly adopted in the cases of vessels when the draft of water is limited, and, in association with an inner bottom and bracket framing, it is almost universal in the Royal Navy.

Flat plate keels are usually made of a single thickness of plate, but sometimes a double thickness is adopted. In the latter case the butts of the two thicknesses are carefully shifted, and the inner thickness extends from edge to edge of the garboard plate on each side of the vessel.

These keels are invariably associated with either *intercostal* or continuous keelson plates to which they are connected by double angle irons, as shown in Plate V. An *intercostal* plate is one that extends between each pair of transverse frames to the shell plating of the vessel.

Lloyd's Rules require that flat plate keels shall be 30 in. × $\frac{8}{20}$ in. for three-fifths the length amidships in vessels of about 100 tons, reduced to $\frac{6}{20}$ in. in thickness at the extremities; and the scantlings are regularly increased for larger vessels, so that when the second or plating number is 70,000 they are to be 36 in. × $\frac{21}{20}$ in. for three-fifths the length amidships, reduced to $\frac{16}{20}$ in. at the extremities. The butt straps of flat plate keels are to be treble riveted, and as much thicker than the plates they connect as is required for bilge strakes. Butt straps are fitted over the butts of both the upper and the lower strakes of double plate keels, and in each case they should be in one length. Care must be taken to arrange the lengths of the plates forming these keels so that the butts shall come exactly at the middle of the frame spaces, as otherwise it is impossible to find room for an efficient treble-riveted butt connection.

Plate keels must be laid upon the blocks at the earliest stage of the work, the same as in the case of bar keels, and straight lines drawn along the middle of each piece of plate must coincide with a line stretched along over the blocks to designate the centre line of the ship. When correctly adjusted the plates must be temporarily secured, while the continuous middle line keelson is being fitted or the transverse frames are crossed.

It should be premised that the holes for the rivets for connecting the keel plate to the frames, keelson-angles, garboard plates and butt straps, should be carefully set off and punched before the plates are laid upon the blocks. By making the length of each plate an exact multiple—say six or seven times—of the frame spacing, very little difficulty will be found in accurately arranging the holes for the rivets so that they may be transferred from a template suited for a great part of the vessel's length.

It is necessary to remark here that when Lloyd's second scantling number is 26,000 and above, the flat keel plate is doubled for one-half of the vessel's length amidships.

15. Stems, Stern Posts, &c.—The stems of all vessels, and the stern posts of sailing vessels and paddle steamers, are of about the same size as their bar keels; but by Lloyd's Rules the stern frames of screw steamers are made from twice to nearly three times the thickness, according to the size of the vessel. For instance, the keel of a 100 ton screw steamer is required to be 6 in. × $1\frac{1}{8}$ in., and the stern frame $5\frac{1}{4}$ in. × $2\frac{1}{4}$ in. But in the case of a steamer of 6000 tons, the keel and stem are each 12 in. × $3\frac{3}{4}$ in., while the stern frame is 13 in. × $9\frac{1}{2}$ in.

Stems and stern posts are almost invariably forged in accordance with moulds or drawings supplied by the shipbuilder. Recently, however, cast-steel stern frames have been at times adopted; but in such cases careful tests should be made upon pieces of steel cut off the ends of such castings in order to ensure that the material is sufficiently ductile. The castings should further be tested by being let fall to the ground after being raised through an angle of 45°. The improvements continually being made in the manufacture of mild steel are such as to suggest that steel castings will be largely employed in the future for parts of a vessel in which wrought iron forgings are now used.

As stated on page 19, stems are supplied in a straight piece, and are bent to the required form in the shipyard. The large forgings required for the stems and rams of ironclads and other war ships must, however, be forged, and subsequently planed to their required form.

The stem of a mercantile vessel is scarphed to the bar keel in the same way that the several parts of the keel itself are connected, and the arrangement of the riveting is the same in both cases. The stern post of a sailing ship or paddle steamer is similarly connected to the after part of bar keel, and the arrangement of rivets in it is after the same fashion. The stern post in these cases extends at least to the top of the transom frame (see fig. 1, Plate XII.), and generally to the top of the poop or raised quarter-deck. The *gudgeons* for receiving the rudder pintles are in most cases forged to the stern post. Sometimes, however, the gudgeons are riveted to the stern post; but this system, which was once common, is now rarely adopted. These gudgeons shonld not be spaced more than from four feet to five and a half feet apart, according to the size of the vessel, and it is usual to allow the weight of the rudder to be borne upon the lowest gudgeon. Care must be taken to allow a sufficient amount of material in the "lugs," forged upon the stern post, for these gudgeons, so as to leave a substantial thickness when the holes for the rudder pintles are drilled ont. The last-named operation is usually performed after the vessel is plated and the rudder is ready to be shipped in place. It need scarcely be said that

the centres of the gudgeons must be in a straight line when finished to receive the rudder pintles.

Plate XI. shows the stern frame of a large screw steamer, and in this case the *body post* extends to a water-tight flat below the lower deck, to which it is strongly attached. In cargo steamers of ordinary size the body post does not extend above the screw aperture, but is forged to a curved form, joining with the rudder post. The advantages gained by the additional security shown in Plate XI. must, however, be obvious, when the vibratory effects due to high engine power are taken into consideration.

In every case care should be taken to effect a good union between the rudder post and the hull of the vessel, especially by means of the transom frame, as shown in fig. 2 of Plate XII.

The hole in the body post of a screw steamer to receive the tail end of the screw shaft is roughly bored before the stern frame is erected, and the finished size of the hole is obtained by being bored out shortly before the vessel is ready for launching, and when the centres of the working parts of the machinery have been set off in the engine-room and shaft tunnel.

The stern post and stem are set accurately in place by their middle lines being plummed on the fore or after sides, and further by the aid of a vertical line transferred from the stem and stern post monlds, the same having been set off upon the latter from the sheer plan on the mould loft floor. Allowance is, of course, made for the declivity of the blocks upon which the vessel is built.

16. Frame Spacing.—The keel being set accurately in place, the positions of the transverse frames are marked upon it, these being generally numbered in rotation, commencing from the aftermost frame, termed the transom frame, which is at the fore side of the rudder post.

Lloyd's Rules require transverse frames to be not more than 20 inches apart when the first scantling number is under 37. This spacing is increased to 21 inches when the number is between 45 and 52; to 22 inches when under 61; to 23 inches when under 71; to 24 inches when under 97; and above that the spacing may be as much as 26 inches.

CHAPTER IV.

17. Framing.—Until within recent years iron vessels for the mercantile marine were, with but few exceptions, framed upon what is termed the *transverse system*. The exceptions referred to are a few sailing vessels and steamers which were built by the late Mr. Scott Russell upon his *longitudinal system*. The *Great Eastern* and the *Annette*, which have been ably described upon several occasions by their talented designer, afford examples of this mode of longitudinal framing. The transverse system of framing is still the prevalent form, but of late it has been variously blended with longitudinal frames in the modes to be hereafter described.

Before considering these compound varieties of framing, we purpose describing the common system of transverse framing, such as is still found in the greater number of iron and steel vessels, both built and building. Plates II. and IV. show midship sections of a sailing vessel and steamer framed in this way.

An ordinary transverse frame consists of the following components, viz.:—

1*st*. A frame angle bar, one flange of which is riveted to the outside or shell plating. This angle bar extends from the keel to the gunwale in all cases (see Plate IX.).

2*nd*. A floor plate, extending across the keel from bilge to bilge, being riveted to the frame angle bar at its lower edge (see Plate IX.).

3*rd*. A reverse angle bar, which is riveted to the upper edge of the floor, upon the side opposite to the frame bar, and, at the termination of the floors, riveted back to back with the frame bars to heights in the vessel varying with her size and type (see Plate IX.).

18. Frame Angle Bars.—The frame angle bars usually butt at the middle line of the vessel, and covering straps, or *heel pieces*, of angle iron of the same size, are riveted to them and the floors upon the opposite side of the latter, as shown by Plate IX. These straps are at least three feet long, and are riveted, like the frames, to the shell plating. When the frames are butted elsewhere than at the middle line (which is not often done), similar straps are fitted on the opposite side.

The sizes of the frame angle bars, according to Lloyd's Rules, are regulated by the first scantling number, described upon page 14.

19. Floor Plates.—The sizes of the floor plates are also regulated by the first scantling number, and a reduction in thickness is allowed at the extremities of the vessel when those at the midship section are $\frac{6}{20}$ inch and above. They are required to be moulded not less than one-half their midship depth at a distance of three-fourths the half breadth of the vessel, and to extend in a fair curve up the bilges to at least a perpendicular height of twice the midship depth of floor above the top of keel.

Floors are made $\frac{1}{20}$ in. thicker in the engine space of steam vessels, and in the boiler space $\frac{2}{20}$ in. thicker.

Except when a continuous vertical centre plate keelson is fitted (fig. 4, Plate IX.), the floors are required to extend from side to side of the vessel. They may, however, be made of two lengths, if efficiently riveted together. In cases wherein the side bar keel system is adopted, or in that of a continuous vertical centre plate without side bars, such as just referred to, the floor plate on each side is connected to the vertical centre plate by double angle irons of not less size than the reverse frames (see fig. 4, Plate IX.).

In all other cases the floor-plates are made in one length for small vessels, and at the extremities of vessels of larger size. Where the breadth of the vessel renders it necessary to fit the floor in two lengths, they are necessarily either butt or lap jointed together. The butt or lap is either at the middle line or a little upon one side of it. The butted joint, shown by fig. 4, is recommended in order to get close-fitted work at this part. But if the parts of the floor are connected by lap joints, it is then desirable that those of alternate floors should be placed at opposite sides of the middle line, as shown by fig. 5.

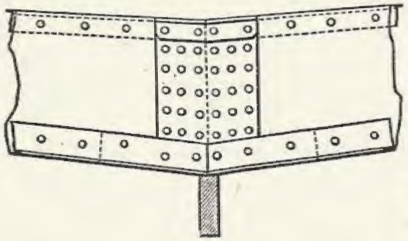


Fig. 4.

In order to clear the frame angle straps, or *heel pieces*, at the middle line, the laps should be situated at about two feet on each side.

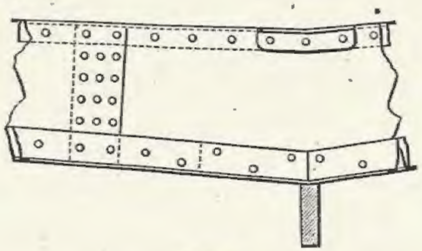


Fig. 5.

When the parts of the floors are butted together, double butt straps should be fitted and they should be treble riveted. If lap joints are adopted, they should be also treble riveted.

It may be remarked that some builders lap joint the parts of the floors at the middle line, but such a system cannot be recommended upon any other grounds than, perhaps, cheapness of workmanship. But considering the labour which is often expended in making good work, owing to the number of surfaces to be closed, it is doubtful whether any saving of cost can be effected by this method. As will presently be seen, there are four thicknesses to be riveted together at both the top and bottom of the floor when lapped at the middle line, besides a number of tapered liners to be fitted.

Floor plates at transverse bulkhead frames are made deeper than elsewhere, in order that the bulkhead plates may be lapped and riveted to them; and in small vessels

the floor is often extended so as to form the lowest plate in the bulkhead, as shown by Plate XIII.

20. Reverse Frames.—The sizes of reverse frames are determined by the same scantling numbers as for the frames.

The reverse frames extend to various heights on the frame, according to the size and type of the vessel. Their purpose is to stiffen the frame, or rather to form, in conjunction with the frame bars and floor plates, a rib of sufficient stiffness.

Reverse frames are sometimes butted at the middle line of the floor, but the better method is to butt them somewhere off the middle line, and on opposite sides upon alternate frames.

Wherever they may be butted, angle iron straps are riveted—these straps being large enough to take at least two rivets upon each side of the butt; but, when butted at the middle line, the straps are fitted on the opposite side of the floor plate, as shown by figs. 4 and 5. Whether the reverse frame be butted at the middle line or not, this piece of double reverse frame must be fitted to assist in fastening the middle line keelson. Indeed, short double reverse frames, or *lug pieces*, are fitted on all frames in way of the keelsons and stringers in hold for the same purpose.

Double reverse frames are riveted to every floor, from bilge to bilge, in the engine and boiler rooms of steam vessels; and in vessels of 17 feet or upwards in depth, from the hold beams, the additional reverse bars are extended to the upper side of the stringers at upper part of bilge and connected to them.

Frames, reverse frames, and floor plates are connected by rivets spaced about seven diameters apart; and the diameters are proportioned to the greatest thickness of plate or angle bar through which they pass.

21. Punching the Frames.—The frame angle bars of a steel ship vary in size, according to Lloyd's Rules, from $2\frac{1}{2}$ in. × $2\frac{1}{2}$ in. × $\frac{5}{20}$ in. in the smallest class of vessels, up to 7 in. × $3\frac{1}{2}$ in. × $\frac{10}{20}$ in. in vessels of the largest size therein provided for. The smaller of the two flanges—when they are of unequal size—is that which is riveted to the shell plating; the floor plate and reverse frame being riveted to the larger flange. By the Clyde system—which is the one most usually adopted—the rivet holes in the flange which is attached to the shell plating are always punched before the angle bar is bent, and in most cases the rivet holes in both flanges are punched in the straight bar. Exceptions are, however, made in the cases of certain rivet holes, these being the holes for the rivets which pass through the laps of the shell plates, those rivets in the same flange which occur at the turn of the bilge and the rivet holes in the transverse flange for fastening the beam knees. All these holes are punched at a subsequent stage of the work, as will be hereafter described.

In order to obtain the proper position of the shell rivets in the straight angle bar for the frame, a batten is bent to the curve of the frame on the scrive board, and the laps of the shell plating are marked upon it. The positions of the rivets which pass through the frame angle bar and the plate laps are then marked upon the batten. These rivets are always in the outer rows on the edges of the outer strakes of plating when the edges of the plates are double riveted, this being done in order that the rivets in question may be effective in closing the lap, fit for caulking, so as to obtain water-tight work. The other rivet, in double riveted laps, is omitted, as to punch a hole for it would unnecessarily weaken the bar. The positions of these rivets being determined, the intervening spaces are subdivided, so as to obtain, as nearly as possible, a spacing of seven diameters of the rivet employed. The positions of the holes which pass through the plate laps are, however, not marked upon the batten, for these must be punched in the frame bars, at a later stage, with great accuracy, in order that they may be in a line with the other rivets in the same row.

When the positions of the frame rivets are marked upon the batten the latter is sprung straight upon the angle bar set apart for the particular frame, and the rivet holes are transferred to the proper flange of the bar, whereupon they are punched, care being taken to punch the holes from the faying surface of the angle iron, in order that the punched holes may be largest on the inside of the vessel.

This precaution, as will be seen hereafter, is alw observed in punching rivet holes, as the latter have tapered or conical form, of which the smallest side is that into which the punching tool first enters. Rivets are made of a conical form under the head, so as to completely fill the rivet holes when hammered up and clenched (see fig. 6).

It has already been remarked that at most of the Clyde shipyards the rivet holes in both flanges of the frame bars are punched before the latter are bent. Some advantage in expediting the work is to be found in this system, which we will now proceed to describe.


Fig. 6.

The scrive board shows, among other things, the inner edges and the extremities of the floor plates. The frame bars and floor plates, in all except small vessels, are connected by a zig-zag arrangement of riveting, in order to effectually close the work. The surface in contact being less when a frame and reverse frame are riveted together, a single line of rivets is sufficient to closely unite them. The height to which the floor plate extends is therefore marked upon the frame angle bar, and a zig-zag arrangement of rivets is set off upon it, of the proper spacing, to that height. Above the floor, to the height at which the reverse frame is extended, the other rivets in the transverse flange are marked with the requisite spacing. Exception is, however, made in the case of the rivets for connecting the beam knee to the frame, these being omitted until a subsequent stage of the work, as great care must be taken to keep the decks and sides in a true and fair line.

By the system we are considering, the rivet holes set off upon both flanges of the frame angle bars are punched before any steps are taken to bend or bevel them.

22. Punching the Reverse Frames.—The holes in the reverse frames, by which they are riveted to the frames, are not punched until the reverse bars are bent; but in some cases the holes in the other flanges of the reverse bars, for receiving the ceiling and sparring bolts, are set off and punched while the reverse angle bars are straight. The rivet holes for connecting the keelson angle irons are not usually punched until the frames are erected, ribbanded, and shored, and the positions of the keelsons have been accurately put in by the aid of battens.

The height of the close ceiling is usually determined by that of the floor plates. Above this height the spacing of sparring bolts will be fixed by the breadth and spacing of the sparring deals. The positions of close ceiling fastenings are similarly determined by the breadths of the ceiling hatches and the positions of the keelsons. No great nicety is required in placing these bolts, so that it is a simple matter to set their positions off upon a batten, and then transfer them to the straight reverse bar. Some builders prefer, however, to punch the close ceiling bolts with a "bear," after the vessel is framed.

23. Bending Frames.—The first operation in frame bending is the preparation of the "set iron." This is a flat bar of soft iron, the section of which varies from about 2 in. × $\frac{5}{8}$ in. to $1\frac{1}{4}$ in. × $\frac{3}{8}$ in., according to the size of the vessel.

The curves of the frame are scratched deeply upon the scrive board, and that of the particular frame to be bent is carefully traced out in chalk. The set iron is then bent accurately to the shape of the curve of the frame, upon the scrive board, and the positions of the bevelling spots—usually the ribbands—are marked upon it. The *set iron* is then taken to the *bending slab* (see Plate XIV.), and the curvature is transferred thereto with a thin slip of chalk.

It should here be explained that the *bending slab* is composed of a number of square blocks of cast iron, with holes in them as shown. These blocks are fitted together, side by side, upon the ground until their united surfaces give a sufficient area for receiving the full length of any frame or other angle bar in the ship when bent. The blocks are usually abont five inches in thickness, and the holes in the blocks are for receiving the various bars and other tools employed in bending the frames, such as will presently be described.

The curve drawn upon the bending slab is that of the outside of the frame, and at a parallel distance from it equal to the breadth of the transverse flange, the curvature of the inside of that flange is drawn by means of a gauge. The next step to be taken is one for which no rule can be laid down, as it is determined by the experience of the workmen.

It is found that, in cooling, a bent angle bar not only shrinks but also loses a portion of its curvature. A point is therefore fixed several inches beyond that given by the set iron for the extremity of the frame, in order to allow for contraction. At the same time a point is fixed within each extremity of the curve, and the set iron is adjusted to a new curve passing through these extreme spots. In this way several inches greater curvature is obtained than is shown by the scrive board, in order to allow for the subsequent straightening of the angle bar when cooling. The amount of additional curvature is of course determined by the experience of the workmen.

Pins are then driven in the holes of the bending slab which are nearest to the set iron, the pins being on its concave side. The intervening spaces, if any, between the pins and the set iron are filled with circular or oval "washers," placed upon the pins, as shown on Plate XIV., or with flat washers and packing pieces where convenient.

All this time the frame angle bar is in a long reverberatory furnace, being heated to a bright redness, almost to whiteness. When ready it is taken from the furnace; an end of the bar is fixed by pins on both sides to the corresponding point on the slab, and then by the aid of a lever, such as is shown on Plate XIV., and by men pulling at a chain attached to the other extremity of the bar, the latter is bent to the required curvature, and secured in this position by bent pins, of the shape shown on the Plate. These bent pins, or "dogs," are straightened somewhat when their shorter arms are driven into the holes of the bending slab and their longer arms are resting upon the flat flange of the frame bar, and consequently they hold the latter very securely.

24. Bevelling the Frames.—Except at the extremities of the vessel, where the bevelling is very considerable, the frames are given such bevelling as they require after being bent. The bevelling is always "standing" or obtuse, and for this purpose the flanges in the fore body look aft, and in the after body forward. The bevels, having been set to the bevellings required at the different ribbands, are applied to the frame angle bar at the corresponding positions, and the necessary bevelling is given to the bar, while it is still hot, by blows from a hammer, and by the aid of a tool such as is shown by fig. 7.

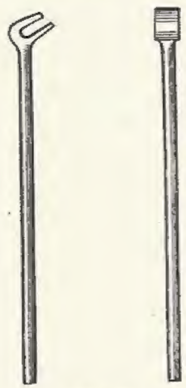


Fig. 7.

When, however, the bevelling of the frame angle bar is very considerable, it is desirable to bevel it before bending, as, being of but thin substance, the angle bar soon loses its heat, and after being bent it is too cold to bevel satisfactorily to any great extent.

When the angle bar is bevelled before being bent, it is first heated in the furnace, and then laid upon a slab, upon which the bevelling spots have been set off on a straight line obtained by means of a batten from the scrive board. Having been first secured by means of the bent pins, or "dogs," already described, the necessary bevelling is given to the bar by the aid of hammers and the tool shown by fig. 7. Care must be taken in bevelling angle bars to open them from the root outwards, as otherwise the surface of the angle bar which fits against the shell plating will be hollow, and so not admit of satisfactory workmanship. To some extent this evil is unavoidable, but with care it may be kept to a minimum. To give a flat surface to the angle bar when bevelled slightly hollow, a small portion of the root of the bar should be chipped off (see fig. 8).

Fig. 8.

When a bar thus bevelled is afterwards bent, it is necessary to check the bevellings after bending, and while it is still hot, so that any changes which may have been made in the process of bending may be then rectified.

The set iron which gives the curvature of the frame for one side of the vessel has only to be inverted to give the curvature for the other side, and this is done, before the

set iron is re-adjusted, by drawing both curves therefrom upon the bending slab. The process of bending and bevelling that side is, of course, the same as has already been described.

25. Bevelling Angle Bars by Machinery.—Among the many useful applications of machinery to the processes in steel and iron shipbuilding, that of the bevelling machine is not the least ingenious or valuable. The machine for this purpose, which is now being largely used, was invented by a Scotch workman named Arthur, and perfected in its present form so recently as the year 1884. The angle bars as they leave the furnace are brought under the influence of a revolving vertical roller and a bevel wheel roller, the latter being so arranged that it can revolve at all the varying angles required for the bevelling of an angle bar. The bevellings are taken at equi-distant spots —say four feet apart—and a dial shows when each spot comes to the roller. At the same time a pointer indicates on a bevel board the bevelling which is being given at any moment to the angle bar. The apparatus is under easy control, and with it an angle bar can be bevelled as required throughout its entire length, the necessary bevellings at each bevelling spot having been previously set off upon the bevel dial of the machine.

The great advantage of this machine is found in the quality of the work which it produces, the bevelled flanges being flat and entirely free from the hollowness and inequalities which are inseparable from the ordinary process of bevelling.

Shipbuilders who use the machine state that they effect a saving of cost therewith; and certain it is that it contributes to a great saving of time, as a frame may be bevelled and set with one heat. It must, however, be borne in mind that the angle bars are somewhat elongated by the pressure between the rolls, and allowance must be made for this in setting off the rivet holes, if the latter are punched before the bars are bevelled.

26. Bending Reverse Frames.—The curve on the bending slab for the inner edge of the frame angle bar is necessarily that of the root of the reverse frame angle bar for that portion of its length which is above the floor plate. If the breadth of the reverse bar be set off on the convex side of this curve, we have the shape to which the edge of that part of the bar is bent. The breadth of the reverse bar set down from the top of the floor plate gives the shape of the remainder of the curve. A set iron is made to this line and the latter is thus transferred to the bending slab, where similar precautions are taken as regards the subsequent contraction and straightening of the reverse frame to those already described for the frames. Rather more additional curvature is, however, given to reverse bars than to frames, because of the inevitable tendency to straighten in the subsequent punching of the rivet holes.

The process of bending and bevelling is the same in both cases—the bevellings above the height to which the floor plates extend being those of the frames at the same bevelling spots. The portion of the reverse frame which is attached to the floor plate is not bevelled. As in the cases of the frame angle bars, the reverse frames at the extremities of the vessel, which have considerable bevelling, are bevelled before being bent, and afterwards corrected.

27. Bending Floor Plates.—Except when required for small vessels, or for the extremities of larger vessels, floor plates are obtained from the steel manufacturers in two lengths. These are either welded, bntted, or lapped together—usually the latter. The plates for the floors are supplied with at least one edge straight, the plates being tapered in breadth to suit the form and dimensions of the floor. The simplest case is, of course, when the two pieces are welded, butted, or lapped at the middle line, as then both are of the same dimensions and form. When the joint is not at the middle line, tbe pieces are necessarily ordered of unequal length and dissimilar form, and in such cases, as has already been explained, the welds or riveted joints are placed upon alternate sides of that line.

To bend the floor plate to its proper form an ordinary set iron is first made to the eurvature of the upper edge of the floor, as given by the scrive board, and a stout set bar—say $2\frac{1}{4}$ in. × $\frac{3}{4}$ in.—is then heated and bent to the required curvature, so that its convex side is of the same form as the upper edge of the floor. While the plate for the floor is being heated to a bright redness, the stout set bar is secured upon the bending slab by bent pins or dogs driven into the holes of the slab, and bearing against its concave edge. The upper edge of the floor plate is laid against the set, and the plate is then bent to the curvature of the latter, the process being effected with the aid of a winch purchase fastened to the wide extremity of the floor. The same process is repeated with the other part of the floor, care being taken to adjust the pieces according to their relative lengths. When the two parts of the floor plate are butted, lapped, or welded at the middle line, then the one is a duplicate of the other. In other cases it is necessary to mark upon the set iron where the joint is to be.

As thus prepared, the inner edges of the floors have the correct curvature of the inside of the vessel; and as a reasonable margin of breadth is always allowed in ordering these plates, it is a very simple matter hereafter to shear the convex or lower edge of the floor to its correct depth and form. It will easily be seen that to shear a concave surface, such as the upper edge, would not be so readily practicable.

The process of bending the floor plates is continued until all are ready, and as each is prepared it is carefully numbered and stacked, until required for further use.

It should be remarked that care is taken to flatten the floors after bending while they are still hot, in order that their surfaces may be smooth enough to properly fit and rivet the frames and reverse angle bars to them.

CHAPTER V.

28. Adjusting Frames, Reverse Frames, and Floors.—Before riveting together the angle irons of the frame and reverse frame, and connecting both with the floor plate, they have all to be adjusted and proved upon the scrive board.

Having traced with chalk the curve of the particular frame upon the scrive board, the frame angle bar is laid in position to discover whether or not it is to its exact shape after cooling. If found to be too convex, it is lifted from the board, and its transverse flange is laid upon anvils close at hand, whereupon, by a few smart blows with a heavy hammer, its curvature is reduced. The places to be struck and the number and extent of the blows are, of course, to be determined only by the experience of the workman in charge.

Should the curvature be too flat, then heavy hammers are held against the outside of the bar, and some smart blows are given to the inner edge of the transverse flange. Here, again, the manipulation is a matter depending upon the experience of the workman.

The frame angle bar having been proved to its correct curvature, chisel marks are made upon it to indicate the positions of the plate laps, ribbands, keelsons, stringers, and deck beams, as shown by the corresponding lines on the scrive board upon which the frame is resting. The marks showing the positions of the angle irons of keelsons and stringers in hold are cut on the inner edge of the angle bar, and the others are cut on the outer edge. Distinctive marks, according to a system agreed upon by the workmen, are employed to indicate whether a ribband or plate lap is meant, and, for better guidance of the workmen who connect the parts of the frame together, paint marks are made upon the transverse flange of the frame

angle bar and upper edge of floor plate, showing the spaces—generally embracing three frame rivets for each—to be occupied by the short lug pieces which assist the reverse frame in connecting the keelson and stringer angle irons to the frame.

When the frame bar for one side of the vessel is set quite true, it is laid on one side, and the corresponding frame bar for the opposite side of the vessel is similarly treated. The accuracy of this angle bar is determined either by trying it upon the one already set, or, when both sides of each body is scrived upon the board, as in Plate VIII., the curvature of the bar may be checked thereon.

The floor plates are next tried in place. Any little unfairness in their upper edge is subsequently neutralised by carefully setting off upon their surface the line of the centres of the rivet holes for the reverse frames, parallel to and at the necessary distance from the line for the top of the floors upon the scrive board.

The two pieces of the floor being proved, they are laid in position upon the scrive board, and the middle line of the body plan is drawn upon them. If the plates are to be butted and strapped at the middle line, then the line just drawn will mark the butt upon each piece of floor plate. If the pieces are to be lapped at the middle, then the middle line of the body plan gives the centre of the lap. In any case the holes for the butt or lap connection are set off from a template provided for the purpose. Fig. 9 shows such a template for a lap

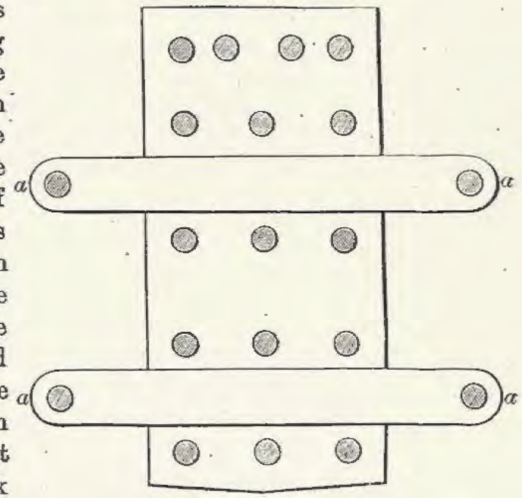


Fig. 9.

joint at the middle line, the four holes (*a*) serving as guides for placing the template in identical positions on each piece of floor plate.

29. Bevelling of Frame Heel.—The next step is to mark off the bevellings of the heels of the frame angle bars which rest upon the keel, and these are subsequently cut and bent to the required form after being heated in an adjacent fire.

30. Rivet Holes for Fastening Beams.—The positions of the rivet holes for securing the beam knees of the several decks are set off on the frame angle bar and punched directly after the angle bar is adjusted. The lines showing the npper edge of each beam are marked upon the frame, and the rivet holes are then transferred from a beam knee template, such as is shown by fig. 10—the outer edge of the template being set to the frame line, and its upper edge to the line of the beam at side on the scrive board.

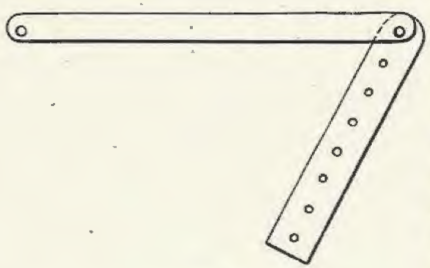


Fig. 10.

31. Rivet Holes in Floor Plates for Frames.—At this stage of the work the two frame angle bars are laid in their proper positions, and resting upon the floors, whereupon the holes in the angle bars are transferred to the floor in the usual way by dipping a small cylinder in whiting, and then putting it into each hole in that portion of the frame bars which rests upon the floor plates.

32. Check Line on Floor Plate.—Before the frame angle bars and floor plates are lifted from the scrive board, a straight line is struck upon the two lengths of floor plate in a direction about parallel to the base line, and marks are made in the line with a centre punch or cold chisel, for the purpose of a check when the pieces of floor and the frame bars are subsequently screwed together and ready to be riveted.

33. Shearing and Punching Floor Plates.—When these

things have been done, the curvature of the frame angle bars is drawn upon the lower edges of the floor plates, and the floor plates are removed in order to be sheared at the lower edge and punched for the frame and reverse frame rivets. The spacing of the latter is now easily determined, as the positions of all the keelsons are accurately marked upon the floor. The average spacing of the rivets is about seven diameters, as for the frame.

When shearing the floors at their lower part, fully half an inch of the plate within the line is cut off, so that the frame bars always project from half an inch to an inch below the floors.

Before the floor plates are ready to be riveted together, and to the frames and reverse frames, the "limber" or drainage holes have to be punched in them. These are usually from two to three inches in diameter, and are placed in the positions shown by Plate II.

34. Fitting together Frames, Reverse Frames, and Floors.—The frame angle bars and floor plates are riveted together upon a light staging at the fore end of the keel, so that when ready the entire frame may be pulled down to its proper position on the keel, and then erected.

On each side of the keel, at a distance less than the half breadth of the vessel, a "skid" is laid upon blocks at about the height of top of keel, this skid being capped by an angle iron laid with the angle upwards, as shown by Fig. 11. At the fore part of the keel, these skids are inclined down to the level of the staging upon which the frames are riveted, so that with the aid of a winch and tackle the frames may be readily slid into their proper places.

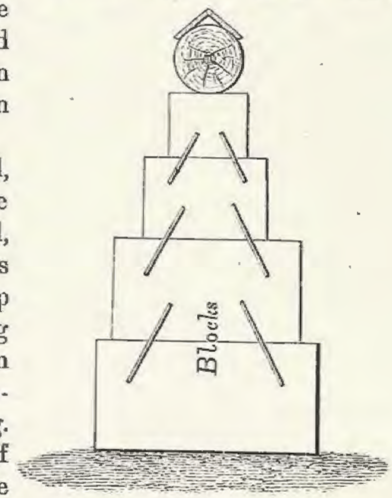


Fig. 11.

The two pieces of frame bar and the floor plates for each frame are then screwed together upon this low staging, and adjusted at the lap or butt by the aid of the straight line drawn upon the floor plates.

When this has been done, the rivet holes are marked upon the unpunched flange of the reverse angle bars. These are copied from the floor plates and frames by bending a flexible batten around the inside curve of the frames and floors, the batten being held in place by clamps. The positions of the holes already punched in frames and floors are copied upon the batten, and therewith transferred to the reverse bar, which is at once punched.

Meanwhile the lug pieces for securing the keelson angle irons have been prepared. These are in short lengths, so as to embrace at least three frame rivets. They are held in position by the workman, and when the inner flange is fair with the reverse frame (as found by holding a straight batten over both), the rivet holes in the reverse frame and floor are copied upon the lug pieces.

At the extremities of the vessel these lug pieces are not generally riveted in place until the frame is erected and fair. In these cases the lug pieces are bevelled, and the bevelling is carefully taken at the vessel. At amidships, and for a considerable length of the vessel, the lug pieces do not require to be bevelled. The lug pieces are screwed together with the other parts of the frame, including the frame butt straps or heel pieces at the middle line, and the butt straps to the reverse frames. The whole is then carefully fitted and riveted together. It is now usual to do this riveting with a machine, and not only is this cheaper than hand riveting, but it results in superior workmanship, especially as regards the closing of the several parts.

35. Beams.—Before the frames are erected, it is usual in most yards on the Clyde to temporarily attach the beams of one or more decks to them, and then to lift the frame and beams together. The beams are generally attached to alternate frames, so that one-half of the frames will not be connected in this way. On the Mersey the beams are not usually lifted until the frames are in place.

A description of the construction and mode of preparing the several kinds of beams generally in use is necessary before we proceed further.

When wood decks are fitted, the beams are generally of the bulb plate and double angle iron type, as shown by A, fig. 12; but sometimes a rolled beam, known as a "tee bulb," or Butterly Section, is adopted, as shown at B. In special cases, when heavy weights have to be borne, as in those of the gun decks of war ships, rolled beams, such as is shown at D, or riveted beams, as shown at C, are adopted.

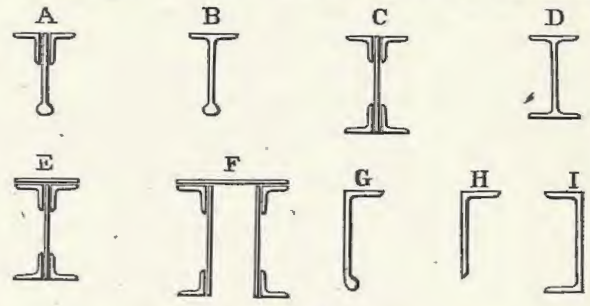


Fig. 12.

Beams of the description indicated by C and E are also fitted in the holds of steamers when placed at more than the ordinary distance of two frame spaces apart; and at times such beams as shown by F are fitted when more than ordinary strength is required. Beams of angle bar as at H, of angle bulb as at G, or of channel section as at I, are also used, more especially under iron or steel decks when no wood flat is laid thereon, in which cases they are spaced at every frame.

36. Round of Beam.—Deck beams have usually a rounded or arched form, both for the sake of the strength thereby obtained, as well as to assist in freeing the deck of water.

The transverse curvature is termed the "round up," and is part of the arc of a circle. The normal round up of the midship beam from which the vessel's depth is measured by Lloyd's Rules is $\frac{1}{4}$ in. per foot of its length.

A mould to the beam is prepared upon the mould loft floor, and upon it are drawn the middle line of the deck and the positions of all the beam frames. The distance between the middle line and each frame mark on the mould is, of course, the half length of the beam at that frame. The beam is usually made about a half to three-quarters of an inch shorter than this at each end, so as to clear the outer flange of the frame angle bar.

37. Bending Beams.—The plate bulb of a beam, such as is shown by A, fig. 12, the plate webs of those shown by C, E, and F, and the entire beam, when of the rolled sections indicated by B, D, G, H, and I, must be set to the curvature given by the beam mould before preparing their knees and cutting them to the required lengths. Angle irons at the upper and lower edges of beams have also to be similarly bent. Beams and their angle irons are usually bent cold by a screw press or beam-bending machine, but sometimes they are bent hot upon a bending slab.

When very long and deep beams are made, in the manner shown by C, E, and F, their webs are usually composed of several pieces, each of which partakes of the required curvature. These pieces, both in the cases of the web plates and upper or "rider" plates, as in E and F, are connected by butt straps, and after the portions of the web are riveted together, the whole is adjusted to the required curvature. The same adjusting process has to be repeated when the beam is completed, in consequence of the slight alteration in form which results from riveting the angle irons. Indeed, in every case of an angle iron being riveted to a bulb or flat plate of a beam, the curvature of the latter is slightly altered, so that the beam requires to be adjusted to the mould before being lifted in place.

38. Beam Knees.—The knees of iron and steel beams are formed either by heating and bending their extremities, or by welding a piece on each end to form the knee. In the former case the material for the beam must be ordered of sufficient length to span the breadth of the vessel where the beam has to go, with the addition required for the lengths of the two knees. In the latter case the portions for the knees are supplied separately, and are welded in place upon the shipbuilder's premises.

Bent knees are formed in two different ways. Either the whole breadth of the beam extremity is bent, or else it

is split into two portions, the lower of which only is turned down to form the knee. The former of these two methods is almost invariably applied to bulb plate beams, as A, fig. 12, having bent knees, and the latter to beams of the Butterly pattern, as at B and D. When the whole breadth of the beam is bent, it is necessary to weld a

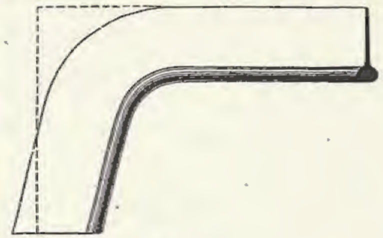


Fig. 13.

piece of plate in the upper corner of each knee, as shown by fig. 13; and when the beam is split and bent, a triangular piece of plate is welded to the upper and lower portions to form the knee, as shown in fig. 14.

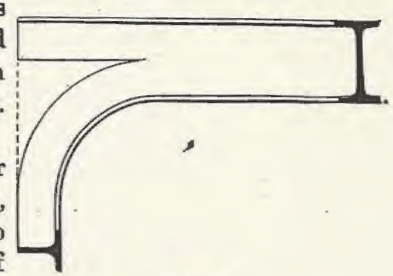


Fig. 14.

In making a welded or "slabbed" knee (fig. 15), the portion of the bulb between the extremity of the beam and the turn of the knee (C) is chipped off, and a short piece of plate bulb (D, E) is welded to form the knee, its upper end being curved, as at C. A small piece of plate is welded at G, whereupon the knee is ready to be cut to its length. Some tests which were made, under the directions of the Committee of Lloyd's Register, on

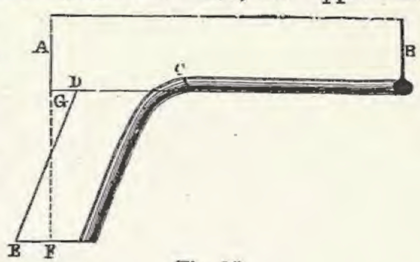


Fig. 15.

the Clyde in the year 1885, in order to determine the relative efficiencies of bent and welded beam knees, gave results which proved the superiority of the former.

When sections such as are shown by C, E, and F, fig. 12, are adopted, the endmost plates of the web are sometimes cut to the form of the knee, and the lower angle irons of the beam are continued to the bottom of such knees. It is not at all unusual, however, to attach these beams to the frames and stringers of the vessel with bracket and gusset plates, as will be shown hereafter.

The beams under iron or steel decks, when placed at every frame space to efficiently stiffen the plating, are, as already stated, made of the sections shown by G, H, and I, fig. 12. In such cases the connection with the frames of the vessel is often made by the aid of bracket plates.

Lloyd's Rules require that beam knees should be in length at least twice and a half the depth of the beams, and when the midship beams of sailing ships are more than 36 feet in length, their knees are required to be three times the depth of the beam.

In forming beam knees, it is desirable to give them a boldly rounded form, and not to suddenly bend them at the upper part of the knee.

39. Punching and Riveting Beams and Beam Angle Irons.—The holes in the upper flanges of beam angle irons for receiving the nut and screw bolts for wood decks, and the rivets for iron and steel decks, are punched before the angle irons are riveted to the remainder of the beam.

To set off the holes for the bolt fastenings of a wood deck is a very simple matter, as the edges of the planks are usually parallel to the middle line of the deck. By arranging a starting point at the middle line of the beam, the distance apart of the nut and screw bolts, in either of the two angle irons, will be double the breadth of the deck planks, and an intermediate hole is placed in the opposite angle iron of the beam. There is thus a fastening in every strake of deck plank [redacted] at each beam, the fastenings in adjacent planks being on opposite sides of the beam.

In the case of an iron deck being laid, more care must be exercised. The landing edges of the deck plating are set off on the beam mould, but the holes in the angle iron at the landing edges are not punched. The intermediate holes are, however, set off between the landing edges to the required spacing, and these are punched before the angle irons are riveted to the remainder of the beam. The holes

for riveting the beam and its angle irons together are marked off upon each from a template, keeping a common starting-point, say at the middle line.

40. Completion of Beam Knee.—When the beam is correctly set to its round and the knees are formed, the centre of the beam is marked, and the exact length and bevel of the knee are obtained from the mould and scrive board. The beam is then cut to its exact length, and the holes for the rivets in the knee are copied upon it from the same template as was used in marking the corresponding rivets on the frame angle bar (see fig. 10). Only two of these rivet holes are now punched, these being for the purpose of holding the beam in place with screw bolts until the line of the upper edge of beams is correctly sheared in. When that operation has been performed, the remainder of the holes are drilled in the knees, and then they are riveted to the frames.

The rivet holes in the beam knees are spaced more closely than those joining the frames and reverse frames, about five diameters being a very usual pitch. This is done in order to make the connection between the beam and frame as efficient as possible.

41. Lifting and Horning the Frames.—The parts of an ordinary transverse frame, such as is usually to be found in steel sailing ships and steamers, are now supposed to be riveted together on the low staging laid at the fore end of the keel. It should be remarked that when the parts are riveted together, the heel of the frame is nearest to the position at which it is to be erected. By the aid of tackles, worked from a winch, the frame is pulled down over the top of the keel to its proper position, the sides of the frame being supported by the Λ shaped skids shown by fig. 11. These skids diminish the friction, and therefore the tendency to rack the frame; but it is nevertheless necessary that the latter should be moved with care, in order that its curvature may not be altered.

When the frame has reached its proper station, as numbered on the keel, it is lifted into the upright position by the aid of a pair of derricks, one on each side of the keel. The nearest frame on the fore side of the stern post, usually known as No. 1 frame, is the first which is lifted, and about a dozen others are also raised and connected to it by ribbands, upon which the spacing of the frames is accurately set off. When this is done, the whole are "plumbed" and "horned."

In "plumbing" the frames, a "plumb bob" is hung from the middle of the beams at each end of the group of frames which has been lifted, and the frames are then shored so as to bring both "plumb bobs" over the middle of the keel.

Next, the foremost and aftermost of the frames are set to the proper "rake"—that is to say, their heads are set as much abaft the perpendicular as is equivalent to the inclination of the blocks upon which the keel is laid. For instance, if the upper deck beam is 24 feet above the keel, and the blocks are laid to an inclination of $\frac{3}{4}$ of an inch to the foot; then the plumb from such a beam should be at eighteen inches abaft the position marked on the keel for the heel of the frame. In this way the frame is set perpendicular to the keel.

The next thing to be done is to "horn" the frames, or set the beam to each frame in a line square to the keel. There are several modes of attaining this, but one of the best and simplest is to drop a plumb from each extremity of a beam, and join the points so plumbed with a line. The frame must then be set so that this line is square to the keel, as may readily be determined by using a long square prepared for the purpose.

A less exact but very common mode of horning the frames, is to join each extremity of a beam with a point on the keel at some distance from the frame, using tape lines for the purpose. The beam is then moved until both tape lines show the same length, whereupon the frame is set and shored in that position.

By joining about a dozen frames with accurately spaced ribbands, and setting them in the way we have described at the extreme frames, the accuracy of the position of the intermediate ones is assured. The process of plumbing and horning is repeated with similar groups of frames until the whole are raised, ribbanded, and shored in place.

When this has been done, the breadths of the vessel at the several ribbands are carefully checked by breadth staffs.

The stern post and stem are not usually lifted in place until the framing between them is completed, or nearly so. In both cases they are plumbed, and their rake, etc., checked by means of straight lines copied upon them from their moulds, and corresponding with lines drawn upon the mould loft floor.

It is very important that the frames of a steel ship should be carefully ribbanded and thoroughly supported by shores, in order to ensure a fair surface, without having to resort to the improper use of packing pieces. When a frame does not fairly conform to the curve of the ribbands, it is sometimes possible to adjust it by cutting out the rivets in the butt or lap of the floor plates. When this is done, the holes must be reconciled by rimeing before the joint is re-riveted.

It is very necessary that all the frames and heel pieces should rest upon the keel, in order that the garboard plates, when an inside strake, may be properly fitted to them without the use of packing, and that the packing may not be unduly thick when the strake is an outside one. Each frame is temporarily secured to the keel by a "clip," or "keel strap," until the shell plating is fitted and riveted, and the middle line keelson is in place.

42. Framing of the Stern.—The stern framing of an iron or steel vessel is very frequently put together, and even temporarily plated, upon the ground near the building slip. When completed it is taken to pieces and permanently erected in place.

The manner of framing the stern is shown by Plate XII., regarding which it should be remarked that fig. 1 does not represent the same vessel as figs. 2 and 3.

It will be seen from this Plate that the stern frames, marked *s*, *s*, *s*, etc., in fig. 1, are attached to the transom frame by means of brackets, and radiate from the transom. The transom floor should be one and a half times the depth of the midship floor of the vessel, in order that the stern frames may be properly connected to it at their heels, and that an efficient attachment may be made between the transom and the stern post. The number of stern frames is governed by the half girth of the stern, it being necessary that the spacing of these frames at the knuckle should be the same as at the other parts of the vessel.

The upper deck stringer plate is carried round the stern, being connected to the transom floor by an angle iron, and riveted to the top of the beam on the fore side of the transom.

An angle iron is riveted to the transom floor on each side of the stern post, and is through riveted to the latter, as shown by fig. 1 of Plate XII.

The stern frames are usually laid off upon the mould loft floor, and made to the moulds so determined; but very often only the knuckle and rail lines, together with the form of the transom frame, are furnished to the workmen, who "mock up" the remainder in place, and so obtain the moulds for the radiating frames.

43. Middle Line Keelsons.—The principal varieties of middle line keelsons are shown by Plate IX.

Fig 1A of that plate shows a middle line single plate keelson standing on the floors, with angle bars riveted to its upper and lower edges. This is the form of middle line keelson most frequently adopted. As will be observed, a "rider plate" is riveted on the top of the two upper keelson angle bars, and this should extend for three-fourths the length of the vessel amidships. When the second scantling number of Lloyd's Rules is 33,000 and above, a foundation plate of not less than 18 inches broad and $\frac{10}{20}$ inch thick is fitted on the top of the floors under the middle line keelson plate, in just such a way as shown in fig. 2A. The butts of the vertical plate, rider plate, and angle bars should be carefully shifted, so as to maintain a uniformity of strength in the keelson. The butts of the vertical plate should be connected with double straps, each $\frac{3}{20}$ inch thicker than half the thickness of the plates they connect, and be treble riveted. These butt straps should extend, as nearly as possible, the full depth of the keelson, and be either joggled over the flanges of the angle bars at the top and bottom,

or else the spaces between the angle bars on both sides should be fitted with plates of the same thickness as the angle bars, and of the breadth of the butt strap; after which the straps should be fitted over all, and the whole carefully riveted together. As this latter method involves riveting together five thicknesses of material in the whole depth of the straps, the former is preferable, especially when the butt straps are carefully fitted. The butt straps of the rider plate are fitted on the upper side and treble riveted; also the butts of the angle bars are covered with angle iron straps sufficiently long to receive at least three rivets on each side of the butt.

As will be observed from the several figures in Plate IX., the middle line keelson is riveted to the reverse frames and to pieces of angle iron, known as "lug pieces," of the same size as the reverse frame, riveted back to back with the latter.

When the reverse frame angle bars are butted at the middle line, these short back angles serve as butt straps for them. It is preferable, however, as already remarked, to butt the reverse bars away from the middle line, say on the side opposite to that on which the floor plates are butted, as it is difficult to obtain a thoroughly satisfactory connection to the middle line keelson, when of the type now being considered, if the reverse frames are butted beneath it. Under any circumstances, the employment of a foundation plate under such a keelson serves to effect a far more efficient connection than is possible without it.

This type of middle line keelson is usually stopped at the collision bulkhead, and attached thereto by a bracket; also at the after part of the vessel, it is continued as far as the shape of the stern will permit. Before and abaft the extremities of the keelson the depth of the floor plate is considerably increased.

44. Middle Line "Box" Keelsons, such as shown by fig. 2A, have at times been fitted, but as it is impossible to get access to the interior of such keelsons in order to clean and paint them, their use has been almost entirely abandoned.

45. Intercostal Keelsons, with Bar Keels.—Keelsons of this type are shown by fig. 3A of Plate IX. When the second scantling number of Lloyd's Rules is under 13,000, the keelson is made with a plate bulb on the upper edge; but when the number is above 13,000 the portion of the keelson above the floors is as shown by fig. 3A.

The bulb plate for a middle line keelson is two to three inches deeper than required for the main deck beams of the same vessel, and it is riveted to the intercostal plate either by being scored down over the floor, or by the intercostal plates being continued sufficiently above the floors.

When the keelson is as shown by fig. 3A, the middle line plate is continued down and riveted between the floors to the intercostal plate.

In every case the intercostal plates are attached to the floors by single angle irons, as shown.

46. Intercostal Keelsons with Flat Plate Keels.—As already stated (see page 28), whenever flat plate keels are adopted, they are associated with either intercostal keelsons or centre through plate keelsons.

When the ordinary transverse system of framing is employed, the middle line keelson is fitted intercostally, and so are the angle irons at the lower edge of the intercostal plate. These latter should be turned up at one end, as shown by Plate V., in order to effect a good connection.

In vessels whose second number is under 13,000, Lloyd's Rules require a bulb plate to be riveted upon the top of this keelson; but when the number is above 13,000, or when the length of the vessel exceeds ten times the depth, a centre vertical plate keelson with double angle irons is required, as before described.

Other forms of middle line keelsons are at times fitted, especially in connection with side bar keels. But the preceding include all the varieties which are usually met in association with ordinary transverse framing.

The method shown by figs. 4 and 4A of Plate IX., although unusual, is worthy of passing notice. In this case, the middle line keelson plate is continuous throughout its entire depth, and the floor plates are consequently in two lengths, butting against it. The floors are connected to the keelson plate by double reverse bars turned down against it in the form of a knee, as shown. The heel pieces

at the back of the frames pass through slots cut in the bottom of the keelson plate, and assist in making good the transverse connection. The connection is further aided by the lower angle irons of the keelson, on the floors, which are riveted to two foundation plates, one on each side.

47. Side Keelsons are the keelsons fitted on each side of the midle line keelson, at about midway between the latter and the commencement of the bilge curvature (see *A′*, Plate II.).

48. Bilge Keelsons are fitted at the lower turn of the bilge on each side (see *B′*, Plate II.).

49. Stringers in Hold are the keelson-like longitudinal arrangements fitted on the insides of the frames between the lowest tier of beams and the bilge keelson. One such stringer is fitted in small vessels, and two in larger ones (see *C′* and *D′*, Plate II., also see Plate V.).

50. Functions of Keelsons and Stringers in Hold.—Before considering these parts of the framing of a vessel when built upon the ordinary transverse system, it is desirable that something should be said regarding the purposes they are intended to serve.

The object of the transverse framing is primarily to stiffen the shell plating, and so enable it to develop the full extent of its efficiency.

Similarly, a chief purpose of side and bilge keelsons and stringers in hold is to stiffen the transverse frames, and hold them in their correct relative positions. They also contribute longitudinal strength to the vessel, and that to a considerable degree, as may be inferred from the increased scantlings given to them when the vessel has great length in proportion to her depth.

To better connect the keelsons, etc., with the frames, lug pieces are riveted back to back with the reverse frames, and the lower angle bars of the keelsons, etc., are riveted to both the reverse frames and the lug pieces.

Intercostal plates, as shown by A Plate II., further assist to keep the frames in their correct relative positions, and to prevent the floor plates from tripping; also when the intercostal plates are attached by angle irons to the shell plating, the keelson serves not only to stiffen the frames, but to assist in locally stiffening the shell plating also.

51. Details of Side Keelsons.—The arrangement and construction of side and bilge keelsons and stringers in hold in classed vessels is determined by the dimensions and proportions of the latter. A complete description of these requirements for all classes and type of ships would occupy a very considerable space in these pages, so that for such specific details reference should be made to Lloyd's printed Rules and Regulations.

We will, therefore, content ourselves with examining the construction and connections of the principal varieties of these keelsons and stringers, without considering fully the conditions and limitations of their employment.

The most elementary form of bilge keelson, and that most frequently employed, is formed of two angle bars, fitted and riveted back to back, and riveted to the reverse frames and lug pieces. Such a keelson is shown by figs. 1 and 1A of Plate XV.

Bilge keelsons and bilge and side stringers are sometimes formed in the same way.

Lloyd's Rules require that when the second number of the vessel is 15,000 and upwards, intercostal plates are to be fitted between the angle bars of the side keelsons as far forward and aft between the floors as practicable, and to be attached to the outside plating by an angle iron (see figs. 3 and 3A, Plate XV.).

Vessels whose second number is under 15,000 may have "wash plates" fitted in lieu of intercostal plates: that is to say, the intercostal plates may be thinner, and need not be attached to the shell plating.

The object of these "wash plates" is to stop the wash of any water that may lie in the spaces between the frames when the vessel is rolling; and of course the same purpose is served by the intercostal plates, which have, in addition, structural uses. When the middle line keelson is worked intercostally between the floors, or when it takes the form of a continuous plate, attached to a flat plate or side bar keel, the necessity for such a precaution is not so great.

Circular "limber holes" are cut in both intercostal and

wash plates to allow water between the floors to drain to the pumps. See Fig. 3, Plate XV.

When "double bottoms" or "water ballast tanks" are built into the vessel, as will be considered hereafter, neither the intercostal plates nor the side keelsons are required, but when the double bottom is fitted only throughout a portion of the vessel's length, the side keelsons are extended into the double bottom for not less than three frame spaces, in order to preserve a continuity of longitudinal strength.

In all cases the angle bars for side keelsons are fitted in long lengths, and their butts are carefully shifted and strapped. The butt straps are of angle iron not less than two feet long, fitted into the throat of the angle bars, and riveted to each flange. It is necessary to plane off a portion of the angle iron butt strap to a rounded form in order to properly fit it against the angle bars which it connects.

In vessels of large size and extreme proportions of length to depth, Lloyd's Rules require very considerable strength in the side keelsons, and this is effected by continuing the intercostal plates above the floors, and riveting to them a continuous plate keelson with double angle bars on its upper and lower edges, as shown on Plate IV. The depth of this keelson is increased with the ratio of the vessel's length to her depth. For instance: when the second scantling number is 35,000 and under 40,000, and when the length of the vessel is above fifteen and not exceeding sixteen depths, the continuous plate keelson is three-fourths the depth of the middle line keelson of that type required for the same vessel, and extends throughout one half the vessel's length amidships.

52. Details of Bilge Keelsons.—Bilge keelsons assume similar forms to the side keelsons, only that the employment of intercostal plates is not insisted upon by Lloyd's Rules, except in the case of large vessels and those of extreme proportion.

53. Details of Stringers in Hold.—These stringers are sometimes of the double angle iron type as already described, but in larger vessels bulb plates are fitted between the angle iron bars, and in still larger vessels plate stringers, with double angle irons at their upper and lower edges, are wrought. Plates II. andIV., also figs. 2 and 2A, and 4 and 4A of Plate XV., show instances of each of these arrangements. At times, too, intercostal plates are fitted to stringers in hold, attached to the shell plating in the same way as already described for side keelsons. An instance of this kind is shown by Plate IV.

When bulb plates are fitted it is usual to chip the extremities of each length of plate to a scarph form, and then to overlap and rivet them together. A very efficient connection is, however, made by chipping off a small portion of the bulb at the butt, and fitting two treble riveted butt straps, each rather more than half the thickness of the plate.

When plate and angle iron hold stringers are fitted, the butts of the plate and angle irons should be carefully shifted and strapped, as in the case of the middle line keelsons of the same type.

It has already been remarked that keelsons are extended for some distance into water ballast spaces, where other longitudinal connections are provided, in order that there may be no break in the continuity of the vessel's strength. For the same reason these keelsons and stringers are extended, whenever practicable, through transverse watertight bulkheads, and the places where they pass through are afterwards made watertight by such arrangements of short plates and collar pieces as is shown by Plates XIII. and XVI., which show, respectively, an ordinary transverse bulkhead of a steamer, and the collision bulkbead of an iron sailing ship.

As the number and arrangement of hold stringers is determined partly by the depth in hold, it sometimes happens that when vessels have raised quarter-decks, bridge houses, etc., it is necessary to fit such stringers in one part of the vessel to stiffen the framing, and not in another. In these cases, too, the stringers in hold, as well as those to the several deck beams, overlap each other for several frame spaces each way. Further particulars regarding these means for preserving uniformity of strength at what is termed "breaks" will be given hereafter.

54. Mode of Fitting and Riveting Keelsons. — The transverse framing having been erected, ribbanded, and faired, it is usual to proceed at once with the middle line, side and bilge keelsons, and with the hold stringers.

The materials for these will have been ordered in accordance with a sketch showing the shift of butts of plates, angle irons, bulb plates, etc., composing the keelsons. Not only is it necessary that the parts of each keelson shall have a proper arrangement of butts, but it is equally desirable that the butts of the parts composing adjacent keelsons and stringers shall be properly shifted in regard to each other. This is easily effected, as the angle irons and bulb plates are usually ordered in lengths of about forty feet, and the plates for vertical plate keelsons are from sixteen to twenty feet in length. A sketch showing the shift of bntts for the angle bars, bulb plates, etc., of the keelsons and stringers in hold shonld be snpplied to the foremen in charge of the work at the ship.

In describing the method of fitting a middle line keelson, we will suppose one of the vertical plate type standing upon the floors.

The rivet holes in the reverse frame and opposite lug pieces at the middle line having been punched or drilled, a long batten of about the same width as the lower flange of the keelson angle bar is laid in a fore and aft direction upon the line of holes intended for one of the keelson angle bars, and with its edge almost touching the middle line of the vessel. The positions of the rivet holes are then copied upon the batten, and transferred to an angle iron bar appropriated for the purpose, the horizontal or smaller flange of the angle bar being the one so marked. The positions of the rivet holes in the upper or vertical flange are next set off to the proper spacing required for the size of rivet being used. About six to seven diameters is the usual distance between these rivets, and when the vessel is large, and consequently the vertical flange of the angle bar is wide, these rivets are arranged in a zig-zag fashion, as shown on Plate XV. In spacing the rivet holes for keelsons it is necessary to note the positions of butts to plates and angle bars, on the sketch already referred to, in order that the rivet holes in the angle bars on the one side of the keelson may suit the butt straps on the other side.

In fitting keelsons it is customary to commence at the after end of the vessel, so that we will assume that the length of bar already prepared for punching is the aftermost piece on one side. The angle bar having been punched it is fitted and screwed in place, and the next length of angle bar is similarly prepared. This process is repeated throughout the length of the hold.

After two lengths of lower keelson angle bar have been fitted upon one side, the bars at the other side are commenced, again starting from right aft. Similar battens are laid along the tops of the reverse frames, and at a distance from the bars already fitted, equal to the thickness of the vertical plate of the keelson. The rivet holes in the reverse frames and lug pieces are then copied upon the battens, and transferred to the angle bars intended for that part of the keelson. At the same time the holes in the vertical flange of the keelson bar already in place are copied from it by means of a batten template, and, having chosen a common starting-point for this and the template already made, the rivet holes in the vertical flange of the new length of bar are then set off.

This process is repeated throughout the length of the keelson on that side, and the bars are screwed in place, leaving a space between them equal to the thickness of the vertical keelson plate. The rivet holes in the lower edge of that plate are set off upon it by means of a template copied from the holes in the bars.

Before putting the plates into their places, however, the holes in their upper edges for the upper angle irons of the keelson have to be set off, these being spaced similarly to those in the lower edge. Also, the rivet holes for the butt straps have to be arranged and marked in accordance with the size of rivet being employed; and these holes having been punched, the plates are fitted in place and screwed to the angle irons, the work starting from aft as before.

The rivet holes in the angle bars fitted to the upper edge of the keelson are marked by the aid of batten templates, the position of the holes being of course copied from those already punched at the upper edge of the vertical plate. These bars are punched and fitted, after which templates

are made for the rivet holes in the rider plates which are to be riveted to the upper face of the angle bars.

In this way a middle line keelson of the type under consideration is fitted together, and the butt straps of the several plates and angle bars are fitted and their rivet holes marked when the whole is in place. Before proceeding with the side and bilge keelsons and the stringers in hold it is usual to line them in fairly on the inside of the vessel with shearing battens. The lug pieces and the notches cut upon the frames fix the line of each with a great degree of accuracy, but by using battens in the way we have stated all slight irregularities are corrected.

When the line of the keelson is thus got in, the rivet holes in the reverse frames are set off on each side of it, and the holes are either punched with a "bear," or drilled. It sometimes happens that lug pieces have to be taken off and others fitted, in order to agree with the newly sheared lines.

A batten of about the breadth of the lower flange of the keelson angle bar is then laid upon the reverse frames and lug pieces; the rivet holes for one of the two keelson bars are copied thereon, and thence transferred to the angle bar set apart for the purpose. The rivet holes in the vertical flange are set off to their proper spacing, and the two sets of holes in the angle bar are then punched. After this is done the holes in the reverse frames and lug pieces for the opposite angle bar are copied upon a batten as before, and thence transferred to the angle bar. The holes in the other flange of this keelson bar are copied from the opposite bar, already punched by means of a template; and when applied to the angle bar care is taken to fix the template at a determined starting-point, common to both bars of the keelson, in order that all the rivet holes may agree when the angle bars are in place.

Or, if thought proper, the rivet holes in both vertical bars may be set off from a prepared template; still taking care to fix upon a certain starting-point, in order that the rivet holes in both flanges may be in agreement.

These modes of procedure are followed throughout the entire length of each side or bilge keelson, or stringer in hold, in punching the rivet holes in their angle bars.

When a bulb, intercostal, or vertical plate is to be fitted between the keelson angle bars, a space is left between them equal to the thickness of that plate, when templating the hole in the reverse frames and lug pieces.

At the forward and after extremities of the vessel some of these angle bars have considerable curvature in them. Moulds are made to the curvature in such cases, and the angle bars are bent to the required form in the machine used for bending the beams.

When intercostal plates are fitted to the keelsons, batten moulds or templates are made for the intercostals, and upon these the rivet holes in the vertical flanges of the angle bars are copied, and thus transferred to the intercostals. The holes in the lower edges of the latter, for riveting the short pieces of angle iron attaching them to the shell plating, are then set off, and the intercostal plates are punched. The corners of these plates in the way of the frame and reverse frame angle bars are sheared or punched off, and the angle bar on side of the keelson has also to be moved out of place in order to get in the intercostal plates, which must necessarily be put in sideways.

Bulb plates for keelsons are templated off the angle bars already in place, and when they have been punched, the whole is screwed tightly together ready for riveting. At the fore and after parts of the vessel some of these bulb plates have to be bent to the curvature of the side, and this is done in the beam bending machine.

Side intercostal plates are not attached to the floors, but * intercostal plates at the middle line are, as previously stated, connected by a single angle iron to each floor. In such cases the rivet holes for them in the floor plates are punched before the frames and floors are riveted together, and those in the intercostal plates at the same time as the other rivet holes in them. The corresponding holes in the short pieces of connecting angle iron are marked upon the latter when held in place.

Side intercostal plates should be fitted with great nicety, so as to bear tightly against the floor plates at each end of them.

All cases in which a lug piece stands too high, a floor

plate projects, or a reverse frame is unfair, should be carefully noticed, and the unfairness or unevenness rectified before proceeding to rivet the keelson to the reverse frames and lug pieces. Here and there a packing piece may be permitted, but as a rule this should be avoided. Work cannot be termed satisfactory in which the several parts are not closely fitted together, and if care be taken a vessel may be built without requiring any packing between the keelson angle irons and reverse frames. Under no circumstances should packing be put between keelson bars and * lug pieces, but rather the lug piece should be cut off, and another one be properly fitted and riveted in its place.

The surfaces between the keelson angle bars, reverse frames, and lug pieces, should be carefully closed in riveting, so that in no case the rivet may be felt by putting a very thin testing knife between the surfaces.

The riveting of keelsons is done by hand even in cases when the frames are machine riveted, as it has been found that the great weight of the hydraulic machine riveter renders its use for this part of the vessel very costly. As, however, the quality of the riveting by the machine is so superior to ordinary hand riveting, it is to be hoped that ere long some means will be devised whereby the employment of a riveting machine for this and other parts of the vessel may be rendered economically practicable.

CHAPTER VI.

55. Water Ballast Tanks and Double Bottoms—their Purpose.—Until about the year 1852 the practice of carrying stone or rubble ballast in steamers when proceeding in a light condition to their loading ports was universal, no departure having been made from the system which was adopted in sailing ships, and still continues, with few exceptions, at the present day. The time occupied and the cost involved in loading and discharging ballast in this way is of course considerable, especially in the case of steamers making short runs, such as the colliers engaged in our coasting trade. In the year above named the use of water ballast was first tried with very satisfactory results, and the practice of fitting water ballast tanks very soon became very general in small coasting steamers. The development of steam navigation in over-sea trade was accompanied by an extension of the water ballast system to almost all classes of steamers, until at the present day we find very few such vessels which do not have, in one or more of the holds, double bottoms for containing water when they are proceeding from port to port in a light condition. The advantage of water as ballast in an enclosed tank is, as need scarcely be said, to be found in the fact that it may be made to flow into the vessel without the expenditure of labour or money, and can be pumped out when required by steam machinery in the vessel fitted for that and other purposes. So that whenever a vessel is possessed of steam power, water is the cheapest kind of ballast which can be employed.

56. Earliest Ballast Tanks.—The earliest water ballast tanks were independent of the hull, being ordinary flat tanks placed upon the floors, and united to each other by

pipes. The water was admitted into the tanks by means of a sea-cock, and pumped out in the ordinary way by a donkey engine.

An improvement upon this arrangement was soon devised by making the bottom of the vessel serve as the bottom of the tank, and by building an inner bottom for a portion of her length to serve as the top of the tank. This inner bottom was supported by longitudinal girders resting upon the floors, and the sides of the tank were formed by similar girders connected with the shell plating.

57. Watertight Connection with Side of Vessel.—The difficulties experienced in making a watertight connection between these boundary girders and the bottom plating led to the adoption of various methods of construction at this part of the vessel. Experience has shown that some of these methods are superior to others, and so we find that only two or three modes of forming the margins of double bottoms are now in vogue. These will now be considered, together with the other details of water ballast tanks and double bottoms, before giving attention to those parts of an iron or steel vessel which are common to all systems of construction.

58. Water Ballast Tank Arrangements. — Consider, then, a vessel framed in the ordinary way, such as has been already described, and suppose it is decided to fit a double bottom for the whole or a portion of her length, for the purpose of carrying water ballast.

It may here be remarked that ordinary double bottoms are not usually fitted throughout the entire length of the hold, and that when provision is made for so carrying water ballast it is in the form of a *cellular bottom*, such as will be hereafter described.

The length of a water ballast tank is, of course, determined by the quantity of water ballast to be carried; for the depth of such tanks is not varied very considerably. The position of the tank is regulated by the requirements for putting the vessel into the proper trim when light. If the machinery is placed at the after end of the vessel, the water ballast tank will be in the fore part of her; and if the machinery is amidships there may be tanks in both the fore and after holds. These are questions which affect the design and not the construction of the vessel. Plate VI. shows a small cargo steamer with a water ballast tank in the after hold, and in order that the vessel may not be trimmed too deeply at the stern thereby, a fore peak tank is also fitted, the top of which is a little below the load water line.

59. Ballast Tank Girders.—As already stated, the top of the water ballast tank, as ordinarily fitted, is supported by longitudinal girders, resting upon, and attached to, the floor plates. These should be spaced not more than three feet apart, and should not be terminated abruptly at the extremities of the tank. At the fore end of such a tank in the after hold, and at the after end of such a tank in the fore hold, the girders should be continued, if possible, through the transverse bulkhead for a short distance, and attached to such longitudinal portions of the structure as may be in the vicinity of their termination. Similarly, at the after and fore extremities, respectively, of such tanks, the girders should not all be stopped at the same frame space, but terminated in such a way as not to give rise to discontinuity in the strength of the structure.

The longitudinal girders should be connected to double angle lugs on girders and floors. Side intercostal plates and side keelsons are not usually fitted in the range of double bottoms, owing to the presence of the girders; but when the double bottoms do not extend throughout the whole of the hold, these side keelsons are extended into them a distance of three spaces of frames, in order to preserve a continuity of longitudinal strength. Lloyd's Rules require the plating of the tops of ballast tanks to be not less than $\frac{6}{20}$ inch thick, and in the largest vessels it is $\frac{8}{20}$ inch; while under engines and boilers it is from $\frac{1}{20}$ to $\frac{2}{20}$ inch thicker. The butts and edges of the inner bottom plating to these tanks may be lap-jointed and single riveted, and the butts of the girder plates are usually double riveted.

60. Various Types of Ballast Tanks.—It is not necessary to state further details relating to the plating and

girders of ordinary ballast tanks, such as are being considered, so that we will now proceed to examine the several modes of forming the side boundaries of these tanks, and making a watertight connection with the sides of the vessel.

Plate XVII.* shows some of the principal of these methods. Fig. 1 on that plate illustrates a system named after Mr. M'Intyre, who devised and introduced it. By this system the frame and reverse angle irons are cut at the side boundary of the tank, but the transverse strength of the vessel is efficiently maintained by means of the brackets *a*, *a*, one of which is thoroughly riveted to the floor frame and reverse frame inside the double bottom, and the other is as well connected to the portion of the frame and reverse frame outside the double bottom. Both brackets are connected by means of angle irons to the boundary plate of the ballast tank, which in fig. 1 is a flat plate standing perpendicular to the surface of the bottom plating.

Fig. 4 shows an improved modification of the system which is attributed to Mr. Withy, a shipbuilder of West Hartlepool.

The essential features of the M'Intyre tank are, however, to be seen not only in the systems illustrated by figs. 1 and 4 of Plate XVII., but also at the side boundaries of the cellular bottoms and ballast tanks shown by Plates III. and V. The primary principle in them all is the attachment of the margin or "flange" plate of the ballast tank to the shell plating by means of a continuous longitudinal angle iron, both edges of which may be chipped, caulked, and so made watertight. To do this, both the frame and reverse angle irons have to be cut in two, and the floor plate in most cases stopped short. The bracket connection, when properly done, restores the transverse strength of the frame; and, as will be seen by referring to all the figures illustrating this subject, it is necessary for this

* The particulars shown on this and Plate XVIII. are taken from an instructive paper on *Water Ballast*, read by Mr. B. Martell, the Chief Surveyor of Lloyd's Register, before the Institution of Naval Architects at Glasgow in the year 1877.

purpose to make the margin or flange plate as wide as possible, for upon the breadth of this plate depends the size of the brackets and the number of rivets in their angle iron connection.

It is desirable to remark here that the name of flange plate is sometimes given to the boundary of double bottoms formed in this way, in consequence of the flanged or bent form given to the npper part of the plate, as shown by figs. 3 and 4 on Plate XVII.

[The margin plate should be $\frac{1}{16}$ of an inch thicker than the inner bottom plating, and the butts double riveted.]

Fig. 2 of Plate XVII. shows a method which has been adopted by Mr. James Laing, shipbuilder, of Sunderland. Only the reverse frames are cut, and for this compensation is afforded by doubling the frames in the way of the margin plate for a length of about three feet. The margin plate is flanged and fitted against the shell plating, and a watertight connection is obtained by means of wrought-steel collars riveted to the frames, outside plating, and inner bottom, as shown.

The method illustrated by fig. 3 of Plate XVII. was employed by Messrs. C. Mitchell & Co., of Newcastle. The reverse frame is cut as in the preceding system, and the frames are doubled as compensation for the same. But the margin plate is flanged and fitted perpendicular to the shell plating, as in the M'Intyre system. This flange plate is connected to the shell plating by an angle iron which is wrought as a collar piece around the frames.

Figs. 3 and 4 on Plate XVIII. show a method which was employed on the N.E. coast of England for making the boundary of a water ballast tank watertight, without severing either the frame or reverse angle irons. The margin plate is scored around the frames and reverse frames, above the floors, and is attached to the vessel's side by forged pieces of angle iron closely fitted to the shell plating and reverse frame, and joggled against the frame. The spaces behind the reverse frames are filled with forged plugs, which are tightly fitted. The whole is then carefully caulked.

61. **Comparative Merits of Systems.**—The preceding

are the only methods of making an efficient watertight connection between the margin plate of a water ballast tank and the shell plating of a vessel which merit much attention, and, of them, the modification of the M'Intyre system, shown by fig. 4. of Plate XVII., is the one which is most commonly met with. The ballast tank of the small cargo steamer shown by Plate V. has a tank fitted in this way, and the boundary of the cellular bottom of the large steamer whose midship section is shown by Plate III. is connected to the shell plating in a similar manner.

The great advantage of this method is to be found in the facilities it affords for getting perfect watertightness. For, provided the lap joint, whereby the flange plate is attached to the remainder of the inuer bottom, is watertight, and the butt straps of the flange plate are the same, then the only places where leakage can occur are at the surfaces of the outer angle iron joining it to the shell plating, and at the rivets in the short angle irons whereby the brackets are attached to the flange plate.

Both edges of the outer angle irou may be chipped and caulked, the only difficulties in this work being experienced in the way of the frame angle irons, and at these places a small piece of hemp or tow steeped in red lead paint is usually placed between the shell plating and the outer angle bar of the flange plate in the way of the frames.

The edges of the short bracket angle irons are chipped and caulked, and tow or hempen stop-waters, dipped in red lead paint, are fitted under both ends of each outer bracket angle iron, to serve as stop-waters in the event of a rivet not properly filling its hole thereat.

Similar steps may be taken to secure watertightness in the system shown by fig. 1, Plate XVII.; but the lower angle bar of the flange plate is not so easily caulked, being * on the inside and not the outside of the tank.

When the margin of the water ballast tank is made, as shown by figs. 2 and 3 of Plate XVII., hempen stop-waters must be fitted between each frame angle iron and the shell plating, both above and below the margin plate. Even with this precaution, it is not so easy to obtain watertight work as by the system previously considered.

The use of wrought-iron plugs associated with the forged angle irons, as shown by figs. 3 and 4, Plate XVIII., is expensive, and the work must be very carefully done to stand the pressure due to a head of water.

62. Procedure in Framing a M'Intyre Tank.—It has been before remarked that water ballast tanks, as distinguished from cellular bottoms, generally occupy only a portion of the length of a steamer which is otherwise framed in the ordinary way. Moreover, in most particulars, water ballast tanks constitute additions to, rather than modifications in, the transverse framing where they are fitted. It is true that in the M'Intyre system the frames and reverse frames are severed at the margin of the tank, and in Mr. Laing's system double frame angles are fitted in short lengths as compensation for cutting the reverse frames. But these items do not constitute or lead to any marked changes in the framing of a vessel by the ordinary transverse system.

Some builders, indeed, proceed to frame their vessels in the same way at a ballast tank as elsewhere, and subsequently cut the frames and reverse frames, in order to fit the margin plates. But this method is not to be recommended, as it leads to unnecessary labour. Usually the frame and reverse angle irons are ordered in two lengths for each side of the vessel, in way of a ballast tank on the M'Intyre system. The frames, reverse frames, and floor plates are bent, adjusted, and punched, as before described; but, in addition, the brackets are prepared from the scrive board, and riveted to the frames, floors, and reverse frames, before being erected.

A temporary connection is at the same time made between the portion of the frame above and that below the margin plate, by bending stout strips of iron, of the breadth of the frame angles, to the curvature of the outside of the frames in the way of the margin plate, and attaching the same by nut and screw holts to the outside of the two portions of the frame on each side of the keel. The form of these stout strips of iron is obtained from the scrive board, and holes are punched in them to correspond with those already punched in the frame angle irons, so as to enable a good

temporary connection to be made. In this way the frames of small vessels are sometimes lifted entire, the same as if they were not severed, and the outer strips or clamps are kept on until the vessel is shored, ribbanded, the margin plate in place, and the whole ready to receive the outer plating. In the case of larger vessels, however, it is usual to first get the lower part of the frame into place, after which the remainder is lifted and connected to it by means of the before-mentioned curved strips of iron.

It is scarcely necessary to describe the method of taking account of and preparing the longitudinal girders to a water ballast tank, as the process is obviously very similar to that already described when referring to side and bilge keelsons.

Particulars of the plating to double bottoms or ballast tanks will be given further on.

CHAPTER VII.

63. Cellular Double Bottoms.—The *Great Eastern*, built by Mr. Scott Russell in 1858, was the first steamer framed upon the longitudinal system, and an important feature in that vessel's construction was what is now known as a cellular double bottom. The *Great Eastern* has both longitudinal and transverse frames, but the latter are subordinate to the former. Longitudinal strength was important in a long and large vessel, and so the longitudinal frames were numerous and continuous. The mutual intersection of the two sets of frames forms cellular spaces, and these are covered for a considerable portion of the vessel's length with an inner bottom. From this it will be seen that the *Great Eastern* was not only the first vessel with longitudinal framing, but that this system of framing and cellular bottoms are closely identified. The *Annette*, an iron sailing vessel, built by Mr. Scott Russell in 1861, was similarly framed, but no inner bottom was fitted.

64. Cellular Double Bottoms of War-Ships.—For rather more than twenty years the armour-clad ships of the Royal Navy have been constructed with inner bottoms extending to the height at which the armour plating commences. From thence upwards these vessels are invariably framed upon the ordinary transverse system. But in the double bottom space the framing is of a composite character—that is to say, both transverse and longitudinal frames are fitted. These two sets of frames are made of the entire depth between the two bottoms, and by their intersection with each other the double bottom space is divided into a number of cells. The vertical keel or keelson plate at the middle line of the vessel in these cases is so fitted and connected as to constitute a watertight division in the double bottom space, and the upper boundaries of the double

bottom, which serve at the same time to form the armour shelf on each side, are also made watertight. In this way the double bottom becomes available for holding water ballast, whereby the freeboard of the vessel may be decreased at will. The primary object of the inner bottom, apart from structural considerations, is however to keep the vessel afloat in the event of the outer bottom being damaged by ramming, shot, or any other cause.

The transverse framing in these cases is of three kinds. In order to make the transverse sub-division of the double bottom watertight, especially at transverse watertight bulkheads, solid watertight frames are employed. These consist of unpunctured floor plates, extending from frame to reverse frame, and from armour shelf to middle line vertical keel plate. The greater part of the transverse framing in the double bottom is, however, constructed upon the "bracket system," such as will be presently described (see Plate XIX.). Besides these, lightened solid frames are placed under the machinery, and at such other parts as require extra stiffness and rigidity. These lightened solid frames, as their name would suggest, are formed with floor plates, extending from inner to outer bottom, and lightened by cutting holes, some of which are large enough to allow a man to crawl through them.

The longitudinal frames in these vessels consist of continuous plates, extending from outer to inner bottom, connected to each with angle irons, one of which is continuous and the other fitted in short lengths between the transverse frames. The plates of these longitudinal frames are connected by vertical angle irons to each of the bracket and solid floor plates of the transverse frames, which the longitudinal intersects.

If the lower angle irons of the longitudinal are wrought continuously, then the frame angle irons in the double bottom will necessarily be fitted in short lengths between them; and this is the course which is usually adopted.

In that case the reverse angle irons of the transverse frames are continuous from armour shelf to armour shelf, and the upper angle irons of the longitudinal frames are fitted in short lengths between them.

Such is the bracket system of transverse framing, associated with longitudinal frames, which has for so many years been adopted in all British armour-clads and most others. Considered in conjunction with the inner and outer bottoms of the vessel, the whole constitutes the cellular system. It admits of various modifications as regards the details of combination, some of which will presently be considered. Even in the Royal Navy a uniform practice has not prevailed, but the general features of the system as therein found are such as have been just described.

65. Names of Parts of Cellular Bottom.—The nomenclature adopted in the Admiralty Office and Royal Dockyards is not precisely the same as we shall presently have occasion to employ when describing corresponding practices in the mercantile marine. Ships of war almost invariably have flat plate keels, as shown by Plate XIX., and the vertical plate standing upon it is termed the "vertical keel plate," and not "keelson plate," as is usual in the mercantile marine. Moreover, the longitudinal frames are known in mercantile ships as "girders," this being due to the fact that the same term was previously employed to designate the longitudinal vertical plates supporting the inner bottoms of ordinary water ballast tanks. Then, again, the "flange" or margin plate in the mercantile steamer takes the place of the "armour shelf" in the war ship. With these trifling exceptions, there is no difference between the designations adopted in the two services; but, as we shall presently see, there are some marked distinctions between the general systems of combination.

66. Cellular Construction in Modern Mercantile Ships.—The adoption of the cellular system of framing double bottoms in the mercantile marine grew out of the ordinary water ballast tank arrangement. So far back as the year 1874 a steamer was built in Italy for an English firm with a centre plate keelson and side bar keel, deep floors lightened with manholes, a longitudinal girder on each side of the middle line, extending the full depth of the floor, and vertical margin plates. The inner bottom plating was riveted to the tops of the vertical keelson plate, longitudinal girders, and margin plates—thereby forming a cellular double bottom, with lightened solid transverse framing throughout. The attachment of the transverse framing above the ballast tank to the margin plates was the same as in the M'Intyre system.

In this case we see the essential features of the cellular double bottom system, but without the bracket framing which now sometimes accompanies it.

Messrs. Austin & Hunter, shipbuilders, of Sunderland, have, however, the credit of first applying the bracket system in the mercantile marine. Figs. 1 and 2 of Plate XVIII. show in plan and section (on a much reduced scale) the framing of the double bottom of a vessel built by them in the year 1876.

Referring to the plan of this vessel's framing, it will be seen that at intervals of about eight frame spaces continuous deep floor plates are fitted, extending from inner to outer bottoms, having a frame angle iron at the lower edge, and a reverse frame angle iron at the upper edge.

Midway between these, bracket frames, as shown by *B*, fig. 2 of the plate, are placed; the construction of these being shown by the sketch. Midway again between these bracket and solid frames, vertical angle iron stiffeners are riveted to the longitudinal girders, extending from frames to reverse frames.

The spaces left between the frames already described are then sub-divided by fitting ordinary frame angle irons from side to side of the ballast tank.

The outer shell plating is therefore stiffened by four sets of frames. The arrangement of longitudinal girders in this case is shown by the plan.

This is a remarkable and efficient mode of framing; and such a decided departure from pre-existing systems of double bottom construction is creditable to the skill and enterprise of the builders.

Some little time elapsed after the building of this vessel before the cellular systems—whether with brackets or without—became very common in the mercantile navy.

A considerable impetus was, however, given to the cellular system when it was taken up by the Messrs. Denny of

Dumbarton, who succeeded in so presenting the claims of such vessels to the Board of Trade, as to obtain a valuable concession for them in measuring their tonnage capacity.

Prior to Messrs. Denny's interference in the matter the tonnage depth of hold in vessels fitted with cellular bottoms was taken from the top of an imaginary floor below the level of the inner bottom, the depth of that floor being assumed to be such as would be required for the vessel if framed in the ordinary way. The Board of Trade regulations for measuring tonnage now permit the depth of hold of a vessel with a cellular bottom to be measured from the top of such inner bottom. This concession has led to the very extensive adoption of the cellular system in vessels having a water ballast tank throughout the greater part of their length, as a sensible reduction is made in their tonnage, and therefore in their working expenses.

67. Details of Cellular Bottoms in Mercantile Marine.—The Rules of Lloyd's Register of Shipping for the construction and scantlings of cellular bottoms provide for all existing types, and the Committee state that other plans of fitting such bottoms may be adopted if previously submitted to and approved by them.

There are two principal types of cellular bottom construction in vessels of the mercantile marine, viz.:—those with solid floors at every frame and those with intercostal solid floors at alternate frames. Longitudinal connection and stiffening are furnished in the former case by means of a continuous centre girder and side intercostal plates, and in the latter by continuous girders on each side of the continuous centre girder, both the girders and the intercostal plates being of the same depth as the floors. When the breadth of the cellular double bottom from margin plate to margin plate is less than 34 feet, and solid floors are fitted at every frame, then side intercostals are not usually associated with the centre girder; but when the breadth is from 34 feet to 44 feet two lines of intercostal plates are fitted on each side of that girder. In vessels whose plating number is under 13,000, which have floors at alternate frames, two continuous girders, exclusive of the margin plates, are fitted on each side of the centre girder. Between 13,000 and 33,000 three such side girders are fitted; and there are four of them when the plating number is between 33,000 and 38,000.

Each principal case will now be considered more in detail, commencing with that in which solid floors are fitted to every frame. These solid floors are lightened with manholes of no larger size nor more numerous than is necessary to render all parts of the double bottom properly accessible. A transverse section of a double bottom framed in this way is shown by Plate XX[illegible]. The solid floors vary in thickness from $\frac{6}{20}$ in. to $\frac{8}{20}$ in., according to the size of the vessel, and they are attached to the centre girder by angles varying from $3\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{7}{20}$ in. to 4 in. × 4 in. × $\frac{9}{20}$ in.; these being double for half the length of the vessel amidships when the plating number is 24,000, and in the machinery space of all vessels. Elsewhere the connection is made with single angles. The reverse angles throughout the cargo holds are of the same size as the reverse frames elsewhere, but in the machinery space it is desirable that the double reverse angles should be increased in size in order to receive the larger rivets which attach them to the thicker inner bottom plating under the engines and boilers. The angles connecting the floor plates and the frame brackets to the margin plate vary from 3 in. × 3 in. × $\frac{7}{20}$ in. to 4 in. × 4 in. × $\frac{9}{20}$ in. The intercostal plates are attached to the floors by single angles, which are rather smaller than those connecting the floors to the centre girder. Recently, however, some builders, both in England and Scotland, have flanged the side intercostals when of steel, so as to connect them to the floors without the aid of angles, the flanging being performed upon the steel in a cold condition by means of a plate-bending machine; and in other cases the upper edges of the floor plates have been similarly flanged in order to avoid the use of reverse frames thereat. Sometimes, too, the upper edges of the intercostals have been flanged in order to connect them to the inner bottom without the aid of the short lengths of angle bar which are otherwise required for the purpose. In each case the object seems to be that of saving weight of material and reducing the cost of riveting; but in view of the extra labour and extreme care required in the flanging and fitting, it is doubtful whether much has been gained by the practice. It will be quite clear that the cold flanging system is best available when right angled bevelling is required or when the angle is the same throughout, and consequently it is rarely applied to the lower edges of either floor plates or intercostals. The work has, however, to be performed with great nicety in order to get closely fitting surfaces, such as are essential to an efficient riveted joint. Moreover, the flanging system never yields the same rigidity as is afforded by the solid "root" of a rolled angle bar. In view of this fact, it is now required that flanged floors and intercostals shall be $\frac{1}{20}$ inch thicker than would be used if angle bar connections were adopted.

In this system of cellular bottom construction the outside plating, except garboard and flat keel plates, which are entirely within the boundary of the double bottom, may be reduced $\frac{1}{20}$ inch in thickness when $\frac{11}{20}$ inch thick and above.

In all other respects the details of the foregoing mode of cellular framing are identical with those of the system now to be considered, viz., that in which solid floor plates are fitted intercostally between continuous longitudinal girders and at alternate frames only. Triangular bracket plates may, however, be fitted in lieu of solid floors at alternate frames throughout the cargo holds in vessels whose plating number is 11,000 and under; but in all vessels framed by this system, intercostal solid floors are fitted at every frame under the engines.

The solid floors are, of course, lightened by manholes, as in the method already described, these being obviously necessary in order that the cellular bottom may be accessible throughout its length. When a vessel has a flat plate keel, bracket plates are fitted to connect the centre girder to the intermediate frames which are without floors, and the same arrangement is adopted in vessels having hanging keels when the plating number is 18,000 and above. See Plate III.

The intermediate frame angle bars are of the size required for the frames outside the double bottom, but the vertical flanges of the remainder of the frame angles in the cellular bottom are usually of the same breadth as in the previous system.

With the number of longitudinal girders already mentioned as being required for cellular bottoms constructed in this way, it is necessary that the inner bottom should be additionally stiffened with transverse reverse angles placed at each intermediate frame space, but by increasing the number of longitudinal girders, this additional stiffening to the inner bottom may be dispensed with. It will be evident that for the inner bottom plating to successfully withstand the water pressure brought upon it, without buckling or leaking, and in order to carry the weight of cargo which will rest upon it, efficient stiffening must be provided, and hence the above requirement.

Not only must brackets be fitted outside the cellular bottom at every frame space to connect the side framing with the margin plate, as in the other system of cellular bottom construction, but brackets must also be fitted at the intermediate frame spaces within the cellular bottom. In each case the angles connecting the brackets to the margin plate vary from 3 in. × 3 in. × $\frac{7}{20}$ in. to 4 in. × 4 in. × $\frac{9}{20}$ in., as already mentioned.

The usual arrangement at the centre line of cellular bottom vessels, which are not limited to draught of water, is to have a vertical centre through plate extended down from top of floors and riveted between two side bars, the three thicknesses being collectively equal to the thickness required for a bar keel in such a vessel. When solid floors are fitted only to alternate frames, the frame angles generally pass through slots cut in the centre through plate and side girders, and extend from margin plate to margin plate; but in the other system of framing the floors are connected to the centre girder by single vertical angles when the plating number is less than 24,000, while in large vessels double vertical angles are fitted for one half the length amidships. Double angles are, however, used throughout the engine and boiler spaces in all vessels. When a flat plate keel is adopted, the angle bars connecting it to the centre through plate are of the size required for a middle line keelson in a vessel of the same dimensions not having a double bottom; that is to say, they vary from 3 in. × 3 in. × $\frac{6}{20}$ in. to $6\frac{1}{2}$ in. × $4\frac{1}{2}$ in. × $\frac{10}{20}$ in.

This method of constructing a cellular double bottom in a small vessel having a centre through plate keel is illustrated by Plate XX., but in this case the intermediate frame angles are connected with brackets to the margin plate, and not to the middle line girder. Fig. 2 of the Plate shows the centre girder, and fig. 1 a side girder; the latter being, in this instance, lightened with manholes spaced eighteen feet apart, and with smaller holes in the intermediate spaces. These intermediate holes are, however, objectionable sources of weakness in a continuous girder, and should not be cut; every necessary facility for examining the cellular bottom being afforded by the manholes in the floors.

The single frame angle and reverse bars for stiffening the outer and inner bottom plating between the solid floors will be seen in both figs. 1 and 2 of this Plate. The frame angle bars in each case pass through both centre and side girder plates, slots being cut in the latter for the purpose.

This is better shown by fig. 2 of Plate X., which is a longitudinal elevation of the centre line girder of the vessel whose midship section is given on Plate III. Fig. 1, Plate XXII., shows an elevation of a portion of one of these continuous longitudinal girders, and fig. 2 is a plan of the margin plate which is shown in section by fig. 1 of Plate X.

In this vessel, also, the longitudinal or girder plates are all continuous, and the floors are fitted intercostally. The frames F. F. extend from the margin or flange plate on one side of the keel to the corresponding plate on the other side—that is to say, throughout the entire breadth of the cellular bottom. The lower angle irons of the girders are therefore fitted in short lengths between the frames. The upper angle irons of the girders are continuous, and consequently all the reverse angle irons are in short lengths between the girders.

This is a very strong and satisfactory arrangement. Longitudinal strength is amply provided by the continuous girder plates and the angle irons on their upper edge, while the transverse strength—which is greater than by the Admiralty system of framing—is found to be all that is required. The process of erecting and fairing the framing of the cellular bottom is much simplified by making the

frame angle bars continuous, and not fitting them in short lengths as by the Admiralty arrangements. For, as the curvature of these frame angle bars is accurately obtained from the scrive board, they form, when carefully ribbanded and shored, an excellent and correctly-shaped foundation upon which to rest the girders, floors, and the other components of the cellular bottom framing.

When the longitudinal girder plates are fitted continuously, it is necessary to take care to shift the manholes clear of each other, transversely, and of the manholes in the inner bottom plating; also to keep them clear of all butts, in order to preserve continuity of strength. For the same purpose the manholes are not made larger or more numerous than is necessary for rendering all parts of the cellular bottom readily accessible for examining the cement, and for cleaning, painting, or repair. Manholes are not cut in the centre girder or vertical keelson plate; and sometimes this is made so as to be a watertight division between the portions of the double bottom on each side of it. Such an arraugement is not, however, desirable, as it might cause the vessel to incline dangerously, if one side were penetrated and flooded while the other was empty. On this account it is customary to leave air spaces at the upper part of the middle line girder, in order that the two sides of the cellular bottom may be in communication with each other. For a somewhat similar reason—that is to say, in order that all the cells in each watertight space may be in free communication, when being flooded with water, after the latter has reached above the level of the manholes—air spaces are left at the upper corners of the solid floor plates, as shown by Plate III.

Another mode of cellular double bottom construction is shown by Plate XXXV., fig. 2. In this system an arrangement of rectangular and triangular bracket plates takes the place of the usual solid floor plates pierced with manholes.

Lloyd's Rules require the butts of the side girders and margin or flange plate to be double-riveted; and in vessels whose second number is under 21,000, the butts of the centre girder are to be connected by double butt straps, double riveted, as shown by fig. 2, Plate XX. When the second number exceeds 21,000, the butts are to be treble riveted, with the alternate rivets in the back row omitted, as shown by fig. 2, Plate X.

The double butt straps in all cases are required to be not less than $\frac{3}{20}$ of an inch thicker than half the thickness of the plates they connect.

68. Margin Plates.—The depth and thickness of the margin plates (exclusive of flange) to cellular bottoms is fixed by Lloyd's Rules, and these vary from 18 inches $\times \frac{6}{20}$ inch, in vessels whose second number is 11,000 and under, to 30 inches $\times \frac{9}{20}$ inch, when that number is from 33,000 to 38,000. In the same case the centre girders are respectively 32 inches $\times \frac{8}{20}$ inch, and 44 inches $\times \frac{10}{20}$ inch.

It will thus be seen that the breadth of the margin plate limits either the "rise of floor" or the breadth of the cellular bottom; as a very great rise cannot be given to a vessel whose middle line girder is 32 inches deep, and margin plate at bilge is 18 inches deep. It is, however, imperatively necessary that the margin plate should not be narrower than this scale permits, for its breadth limits the number of rivets connecting it with the frame brackets, and therefore the efficiency of the connection of the framing above to that below.

To make that connection as strong as possible, double angles are sometimes fitted to the bracket plates, this being always done at web frames, except when half diamond plates connect the double reverse frames to the inner bottom.

The means adopted for caulking and otherwise making the margin or flange plate watertight were described at page 73, when referring to the M'Intyre System of forming the boundaries of double bottoms.

69. Inner Bottom Plating.—The plating of inner bottom, by Lloyd's Rules, varies from $\frac{6}{20}$ inch to $\frac{8}{20}$ inch in thickness throughout the cargo holds; but in the engine and boiler space its thickness ranges from $\frac{7}{20}$ inch in small vessels to $\frac{10}{20}$ inch in steamers of the largest size; while in many cases the inner bottom under the engines is made even still thicker. The middle line strake throughout a half the length of the double bottom is also increased from $\frac{1}{20}$ to $\frac{2}{20}$ inch in thickness beyond the ordinary inner bottom plating of the cargo holds.

When double bottoms are fitted with longitudinal girders, extending on the top of ordinary floors, the inner bottom plating may be single riveted, both at the edges and butts, and either a transverse or longitudinal arrangement of plating may be adopted. Double bottoms, when constructed in this way, usually occupy only a portion of the length of a vessel, and as both the plating and girders are additions to the ordinary structure, the disposition of the inner plating is not a matter of much importance.

But the case of cellular bottoms is very different, as the transverse and longitudinal frames are considered, in conjunction with the inner plating, as integral parts of the structure of the vessel; and the inner bottom plating in such vessels should therefore be fitted longitudinally, with a view to obtain the maximum structural value of the materials.

It will be readily seen that the transverse strength obtained from the inner bottom is the same by both systems of arranging the plating, whereas the longitudinal efficiency of the plating is greatest when it is disposed in the same way as the outer bottom. For in either arrangement, transverse or longitudinal, the middle line strake of inner bottom must be laid longitudinally, and consequently with a transverse arrangement of the plating, there will be a double row of laps or butts near the middle line of the vessel. The longitudinal lines of laps, which occur with the longitudinal arrangement, will in no case diminish the transverse strength more than has already been effected at this double row of butts or laps, which, by the way, occur where transverse strength is of the greatest importance. This aspect of the case is clearly argued in an able paper read by the late Mr. W. John before the Institution of Naval Architects in 1880. That gentleman further called attention, at the same time, to the necessity for arranging these longitudinal laps of plating, so that they may occur about midway between the longitudinal girders, where they are supported by the reverse bars fitted in short lengths between the girders. For, when the longitudinal girders are continuous, the transverse connection of the solid floors or brackets with the girders is effected by rivets only; and consequently the advantage to the connection of the two sides by means of the flat plate of inner bottom on the top of the girder is very considerable.

The butts of the inner plating of cellular bottoms should be carefully shifted, as is done with the butts of the outer bottom. Moreover, these butts should be shifted clear of the butts in the longitudinal girders, and, if possible, clear also of the manholes in these girders.

Lloyd's Rules require the butts and edges of the middle line strake (right fore and aft), also the butts of the inner bottom in the engine and boiler space, to be double riveted. When the second number is 20,000 and under 30,000, the butts of the inner bottom are to be double riveted for half the length amidships. In vessels whose second number is between 30,000 and 38,000, the butts of the inner bottom and the edges of an additional strake on each side of the middle line are to be double riveted throughout. In all other cases single riveting is permitted, except at the margin plate, the riveting of which has been already described.

The spacing of rivets in all watertight joints at this part of the vessel is to be not more than four diameters of the rivet.

70. Systems of Work in Framing Cellular Bottoms.—The modes of procedure adopted in framing a vessel built upon the longitudinal or cellular systems will, to a considerable extent, be governed by the particular character of the system adopted.

As already mentioned, the ironclad ships of the Royal Navy have usually continuous longitudinal plates and continuous angle irons at their lower edge. The frame angle irons are consequently fitted in short lengths. The reverse frames are continuous, and so the upper longitudinal angle irons are in short lengths.

In some foreign war vessels both the frames and reverse frames have been continuous, and the angle irons of the longitudinal have therefore been fitted in short pieces. This arrangement has served to more closely balance the

longitudinal and transverse strengths of the framing, by increasing the latter and diminishing the former. As the vessels in question were short and broad, a reason was furnished for the departure from what had hitherto been the invariable practice in framing ironclads.

In the mercantile marine various systems of framing cellular bottoms prevail, as the preceding pages will have shown. Bnt the continuous longitudinal girder and continuous [redacted] frame arrangement is the most usual and, upon many grounds, the most desirable mode of construction. This system will now be considered. In every case the centre girder or keelson is continuous, and when the vessel has a flat plate keel, the lower angle bars of that girder are continuous also. Under such circumstances, it is impossible to reeve the frame angle bars through the middle line girder, so as to extend it from side to side of the cellular bottom; and as continuous transverse frame bars are generally preferred in the mercantile marine to the arrangement of short lengths of frame, which is usual in the Royal Navy, the frame bars are butted against the middle line girder, and knee pieces of frame angle iron are riveted to them, back to back, and to the side of the girder.

When, however, a centre plate or side bar keel is adopted, the frame angle bars pass through slots cut in the middle line girder, and in most cases these angle bars extend from flange plate to flange plate, as already described.

In proceeding to frame a mercantile vessel with a cellular double bottom, when solid floors are fitted at alternate frames, the frame angle bars are passed through the slots cut for them in the centre girder; or, if the vessel has a flat plate keel, the frames are butted against the lower angle irons of the centre girder, and attached to the girder plate by the knee pieces, fitted back to back with the frames. In either case the frames, when in place, are carefully ribbanded and shored.

The portions of floor plate between the centre and the adjacent side girders are next got into place, whereupon the first pair of side girders are dropped down over the frame bars, and attached by means of short angle irons to the pieces of floor plate already wrought.

The next set of floor plates on each side are put into place, and then the next pair of longitudinal girders, and so on until the margin plates are reached. As the longitudinal girders are got into place the angle irons on their upper edges are wrought, after which ribbands are fitted on the inside of the vessel, to fair the inner surface of the longitudinal girders, and consequently that of the whole of the cellular framing. The pieces of reverse angle iron, and the lengths of angle iron at the lower edges of the girders are fitted, whereupon the whole is screwed up, and made ready for riveting.

The framing of the cellular bottom should be riveted before the framing above is commenced.

If bracket plates are fitted in lieu of solid floors, a similar order of procedure may be adopted by fitting the lower brackets before the longitudinals are got into place, and subsequently fitting the upper brackets when the reverse frames are in.

The method of framing a cellular bottom, just described, is only applicable to the case when the frame angle bars are in one length, either from margin plate to middle line, or to the margin plate on the opposite side of the vessel. When the frame angle irons are in short lengths between the longitudinal girders, as in the case of most British armour-clads, a different order of procedure is required.

In such instances the short lengths of frame which extend from the centre girder, or "vertical keel plate," to the adjacent longitudinals on each side, are first fitted in place, these being turned up against the vertical plate, and riveted to it. The first set of solid floors or bracket plates are then put in and attached to the frame angle irons, a ribband is then fitted under these frames on each side, and carefully shored. Next, the first pair of longitudinals are fitted and attached to the bracket plates already in place, after which the reverse frames—which are continuous—are got in across the vessel, attached to the longitudinals and bracket plates, and both supported and faired by well shored ribbands at each extremity.

When this is done the next lengths of frame angle iron on each side are got in, then the corresponding bracket or solid floor plates, and after that the next pair of longitudinals. Another set of ribbands is fitted, and this process is repeated until the armour shelf is reached. As the work of framing proceeds, the short angle irons joining the brackets to the longitudinals are fitted, so as to effect a proper connection. When the whole has been well ribbanded, faired, and shored, it is riveted together. If thought proper the frames, floor plates, bracket plates, reverse frames, short angle irons, and girder plates, may be riveted as the several parts are got into place and screwed together, but great care has to be taken in such a case to check the accuracy of the work as it proceeds. Under machinery compartments, where solid floors are spaced as closely as ordinary framing, it is always desirable, if possible, to rivet the work as it proceeds, in consequence of the limited room for doing the work when all the parts of the framing are in place. But, elsewhere, the distance between the solid floors is sufficient to enable the riveting of the framing to be done at any time before putting the shell plating on the vessel. When solid floors are fitted at every frame, and the longitudinal girders are therefore worked intercostally, the process of framing a cellular bottom is much simplified. The solid floors, frames, and reverse frames on each side of the centre girder are riveted together on the ground—usually with a hydraulic riveter—and then lifted bodily into their place and connected to the centre girder by their vertical angle bars. The whole is ribbanded, faired, and shored, after which the intercostals are wrought, and the margin plates fitted and connected. Very frequently all the sets of floors, frames, and reverses are riveted before any of them are lifted into place; and in some shipyards the manholes and drainage holes in the solid floors are punched with full-sized oval or circular dies in a hydraulic press.

Having thus described the rotation of the work in erecting the framing of a cellular bottom, it remains only to point out the modifications in bending and templating which these styles of framing render necessary.

The frame angle bars, when continuous from margin plate to middle line or opposite margin plate, are punched, bent, and set in the same way as already described. Solid floor and bracket plates are cut to the forms given by the scrive board, which shows the girders and margin plate at every frame. The girders being vertical, the ends of the floor plates (except those which are next the margin plate) are parallel. The continuous girder plates are obtained in lengths as long as is procurable, and being butted midway between the transverse frames, their lengths are multiples of the frame spacing. The curvatures of their upper and lower edges, when parallel to middle line, are given by bow and buttock lines drawn through their moulding edges, but for the greater part of the vessel's length these edges will be straight and parallel. The slots cut in their lower edges, to allow the frame angle bars to pass through, are easily set off to the regular frame spacing, and all the rivet holes in them may he marked from one set of templates. Indeed, every part of the framing of a cellular bottom may be prepared, including the punching of the rivet holes, before a commencement is made in putting it together and riveting it. Even the holes in the reverse frames for the inner bottom plating, omitting those at the landing edges, may be punched the same as is done with the frame angle bar for the riveting of the outer bottom plating.

The margin plates, and in some instances the girder plates, at the extremities of the bottom are made to moulds obtained at the vessel by means of the transverse frames already ribbanded and faired.

In the Royal Navy the longitudinals stand everywhere perpendicular to the surface of the bottom, and in that case their form is laid off upon the mould loft floor. This involves a geometrical problem of a somewhat difficult character, as compared with most mould loft work, and several solutions of it will be found in the Anthor's treatise upon laying off iron and steel ships.*

* See Thearle's *Practical Naval Architecture*, pp. 162 to 169. William Collins, Sons, & Co., Limited.

CHAPTER VIII.

71. Web Frames.—It has been before remarked that one of the principal functions of the framing of a ship is to stiffen the shell plating, and thereby enable it to endure the stresses to which it is subjected without bending. For, directly the shell plating begins to alter its form under a stress, it ceases to develop its full efficiency as a component of the structure. To further stiffen and support the frames is an important duty of the side and bilge keelsons, and the side and bilge stringers. The beams serve to keep the two sides of the vessel in their relative position, and, by their connection to the frames, stiffen and support the latter, and aid in keeping them to their proper curvature. Transverse bulkheads, too, fulfil a similar purpose. Each and all these portions of the vessel satisfy other requirements than those just named; but it is necessary, nevertheless, to bear in mind that the shell plating is the most important element of structural strength in a ship, and that the framing, keelsons, stringers, beams, bulkheads, etc., are, among other things, essential stiffeners of the shell plating.

It happens sometimes, in preparing the design of a steamer, that the boilers and machinery will not admit of beams being put where they are very much needed. Stowage requirements will interfere similarly with the arrangement of hold beams in the cargo spaces, and large hatchways have often a similar effect.

Besides the expedient of fitting wide plate stringers, supported by brackets, and considerably stiffened by angle irons, in cases wherein a complete tier of beams on alternate frames is impossible, another device has been largely adopted during recent years for effecting the same or similar objects. Wide transverse frames, or, rather, narrow partial bulkheads, have been fitted at proper intervals to supply that stiffness and rigidity to the shell plating which cannot in most cases be contributed by means of beams. These are termed "web frames," and a sketch of such a frame is given on Plate XXXVI. The vessel, of which the midship section is shown on Plate III., has web frames in her boiler and engine compartments, and one of these is indicated by dotted lines.

An ordinary web frame consists simply of a wide plate attached to the shell plating by a frame angle bar, and stiffened on the inner edge by double reverse angle bars (see also Plates XXXV. to XL).

When the vessel has a cellular bottom the web frame is efficiently connected to the margin plate of the same, and in other cases it is lapped against the floor plate, or connected to it by a butt strap.

As shown by Plates XXXV to XL., also by Plates IV and XXI.,* the web frames and side stringers are united at their intersections by "diamond plates," which serve to preserve both the transverse and longitudinal continuity of this network of rigid framing. The web plates are scored over narrow keelsons and side stringers, and widened in the way of deeper ones. In all cases a continuity of transverse strength is, so far as practicable, maintained. The primary object of the web frame is, however, as previously explained, to stiffen the shell plating, and keep it to its correct shape.

Provision is made by Lloyd's Rules for such frames in machinery compartments of classed vessels; but, as before mentioned, their application is not limited to such spaces, as they are now very often fitted in all parts of the cargo space where transverse stiffening is especially required. In Plate VI. such frames are shown as substitutes for hold beams in a cargo space, abreast a large hatchway, and this is a very usual arrangement in such cases.

Lloyd's Rules require, when the 2nd number is 16,000 and under 18,000, that not less than three web frames shall be fitted on each side in the engine and boiler space; these to be formed of plates of not less thickness than the frames,

* Plate XXI. does not refer to the same vessel as Plate IV.

and varying in breadth from 14 inches to 18 inches, according to the depth of the vessel. Further particulars of these web frames and their connections will be given presently, when considering the web-frame system of construction. When the number is 18,000, and under 30,000, these frames are to be not more than from 8 to 10 feet apart; and when the number is 30,000 and above, they are not to exceed 8 feet apart. The web frames are to be fitted in way of the deck beams where practicable, and if fitted between the beams they are to be connected to the stringer plate by bracket knees above and below the same (see fig. 2, Plate IV.).

72. The Web-Frame System of Construction.—In the large unarmoured vessels of the royal navy the use of web frames was general before their introduction into the mercantile marine. It was not unusual to associate them with a much lighter description of frame—there being three or four of the latter to each one of the former. The lighter frames have been considered sufficient for the purpose of providing the needed local stiffness to the plating, while the web frames have contributed the principal structural stiffness.

During recent years considerable developments have been made in the application of web frames, associated with wide intercostal stringers, to the framing of mercantile ships, in order to obtain the desired transverse strength without the interposition of iron or steel deck flats and tiers of beams in the cargo holds. After acquiring much experience with the system as adopted in classed vessels, the Committee of Lloyd's Register have formulated Rules to govern the future application of the web frame and side stringer arrangement in vessels built under the supervision of their Surveyors for classification.

The depth of the vessel is necessarily the criterion upon which the breadth and spacing of web frames and their associated side stringers are based in any particular case, and the depth is measured from the top of keel to the top of the first complete tier of ordinarily spaced beams, the round of such beam being always taken at one quarter of an inch to the foot of midship breadth of the vessel.

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The web frame and side stringer plates are of the thickness required for the frame angle bars in the same vessel, and they vary in breadth from 14 inches when the vessel is under 16 feet in depth to 18 inches in vessels of the largest size. The web frame is usually formed as shown by figs. 2 and 3, Plate XXXVI., with double reverse angles on the inner edge, but sometimes a single angle is fitted of equivalent strength. Similarly, the inner edge of the side stringer has double angles of the same size as on the web frame or an equivalent single angle bar (see figs. 1 and 3, Plate XXXVI.). The web frame is attached to the shell plating in all cases with single frame angles, and the side stringers are worked intercostally, being attached to the ordinary reverse frames and to the shell plating with single angles of the same size as the reverse frames.

Sometimes the web frame is made in one continuous length, and in that case the side stringers are, of course, worked in short lengths extending from web frame to web frame; while in other cases the plates and angles of the side stringer (except the angles connecting it to the shell) are continuous, and the plates and inner angles of the web frames are fitted in short lengths between them. The former is, however, the more usual practice, and the one best adapted for yielding the maximum transverse strength for which the web frames are primarily intended. At the same time much can be said, especially in the case of long vessels, for the continuous side stringers in view of the superior longitudinal strength thereby afforded.

There are several modes of combining the angles with the side stringer plates, the principal of which are shown by Plates XXXVI. and XXXIX., and will be described more in detail presently.

When a side stringer is 18 inches in width, and the web frames are more than 8 feet apart, the former is supported by a bracket knee of the thickness of the frames, situated midway between the web frames. See Plate XXXVI.

To effect a satisfactory connection between web frames and side stringers at their junction, a diamond-shaped plate, of the thickness of the web frame, is fitted; the size of the "diamond plate" being 24 inches by 18 inches for 14-inch web frames, 30 inches by 21 inches for 15-inch web frames, and 30 inches by 24 inches when the web frame exceeds 15 inches in breadth (see Plates XXXVI., XXXVIII., and XXXIX.). If the web frame is continuous and the side stringer is intercostal, the long diameter of the diamond is placed horizontal, and *vice versa*. When the web frame or side stringer has a large single angle bar on the inner edge, instead of a double angle bar of smaller size, a short length of double angle is fitted in way of the diamond plate to enable the latter, by means of the additional rivets, to afford the desired connection at the place of junction.

The web frame is strapped to the floor plate, of which it is a prolongation, in vessels not having a double bottom (see fig. 2, Plate IV.); but when a double bottom is fitted, the web frame is connected to the margin plate with double angles, and in most cases the connection is further aided by "gusset," or half-diamond, plates riveted to the double reverse frames and the inner bottom, as shown by Plates XXXV. and XXXVI.

In order to obtain the full transverse stiffness which the web frame is capable of communicating to the vessel, the through beams attached to their heads should be of increased size (such as are nsed for strong beams in the hold), except when an iron or steel deck is fitted upon the beams, in which case the latter should, at the web frames, be of the size ordinarily fitted to alternate frames in a similar vessel, with a knee three times the depth of the beam. Various other measures are adopted, such as the use of brackets and gussets, under different circumstances, in order that the transverse ties at these web frames may be equal to the strength which tbe latter are capable of affording. See fig. 2, Plate IV.

As already remarked, tbe spacing of the web frames and the number of side stringers associated with them are regulated by the depth of the vessel. When the latter is under 17 feet, measuring from the top of keel, the web frames are placed at eight frame-spaces apart, with one side stringer above the bilge stringer. Vessels of 17 feet and under 18 feet in depth have 15-inch web frames, eight frame-spaces apart, and two side stringers; but in this case the double angle bilge stringer is omitted. An exception is, however, made in vessels otherwise requiring three tiers of beams and under 18 feet in depth to the middle or lower deck, the web frames in such cases being not more than six frame-spaces apart.

It is neither necessary nor desirable to state Lloyd's requirements in detail for all the successive gradations of depth; but it may be remarked that when the vessel is between 21½ feet and 22½ feet deep the web frames are 15 inches wide, and not more than six frame-spaces apart, with three side stringers; or, alternatively, the web frames may be 18 inches wide, and two side stringers of the same width may be substituted, in vessels fitted with a double bottom, provided the brackets outside the margin plates be extended up the bilges to a height of three times the middle line depth of ordinary floors required for a vessel of that size. The extra length of these brackets is properly considered to afford stiffness to the framing and shell plating as high as they extend, and therefore to diminish the depth of side requiring support from the side stringers, which, with the web frames, are of greater width than in the other arrangement. Further it may be remarked that when the vessel's depth is between 23½ and 24 feet, 18-inch web frames, six frame-spaces apart, are associated with three side stringers.

From the examples just given it will be seen that increased width of web frame and side stringer may, within certain reasonable limits, be accompanied by increased spacing between the side stringers; and that, generally, increase in the vessel's depth, or of the depth requiring web frames, is accompanied by a closer spacing both of the web frames and the side stringers, as well as by increased width in the web frames and stringers.

The web-frame system of ship construction has, however, received a wider application than has hitherto been considered. It is in the raised quarter-deck type of steamers that we find the most interesting and complete examples of the substitution of web frames and side stringers for lower

deck beams, and for beams of extra strength widely spaced in the lower hold.

Plates XXXVI., XXXVII., and XXXVIII. show in elevation and transverse section the web framing of a steamer of that type. The depth of some of these vessels, measured at the raised quarter-deck, is very great. Lloyd's Rules provide for depths up to the higher limit of 28 feet, and in that case the web frames are only four frame-spaces apart, with four side stringers. But, in addition to these, four beams of extra strength, formed of plates and four angles, are fitted and efficiently connected to one of the side stringers and to the web frames by large gusset plates and vertical brackets of the thickness of the side stringers; also an additional transverse watertight bulkhead is fitted midway between the after-engine room bulkhead and the after-end of these vessels. This statement of the requirements for the higher limit of depth will, perhaps, serve to indicate the general principles which underlie the rules regulating the application of the web-frame system in raised quarterdeck and other deep vessels. Elsewhere than in the range of the quarterdeck the arrangement of web frames, &c., is, of course, based upon the height of main deck at the middle of the vessel's length.

Moreover, in all cases wherein web frames are fitted in lieu of lower deck and hold beams, the transverse watertight bulkheads are additionally stiffened by a vertical web and by a "box beam," so as to compensate for the loss of support due to the absence of decks.

We will now briefly consider the details of the principal systems of web-frame construction at present in vogue, commencing with that shown on Plate XXXVI.

In this arrangement the web-frame plates are continuous, and the side stringers are fitted between them; both the web frames and the side stringers being of the same breadth. The angle bar, on the upper side, connecting the stringer to the reverse frames, is kneed at one extremity against a web frame, and the face angle to the side stringer on the under side is kneed against the other web frame. Short connecting angles are fitted where there are no kneed ends, so that the stringer plate and web frames are joined by double angles above and below the former. The upper face angle extends from web frame to web frame, and the diamond plate completes the connection of all the parts at their intersections.

In another arrangement the double angles of the web frames are in short lengths and the double face angles of the side stringers are continuous, passing through slots cut in the inside of the web plate. The angles attaching the side stringer to the reverse frames extend from web frame to web frame, while the web frames and side stringers are joined at their intersection with four angles, and the whole is further connected by means of the diamond plates.

Other efficient combinations are possible, and are sometimes adopted, one of the most interesting and satisfactory being that practised by Messrs. W. Denny & Brothers, of Dumbarton, and shown by Plates XXXIX. and XL.

In this arrangement the side stringers are made about $3\frac{1}{2}$ inches to 4 inches wider than the web plate, so as to allow continuous face angles upon the former to be fitted in a reverse way and to pass over the diamond plates, which latter are necessarily in two pieces. The angle connecting the side stringer to the reverse frames is kneed at each extremity against the web frame. The Plates sufficiently illustrate all the other details of the arrangement, including the connection which is made where the side stringer comes against a transverse watertight bulkhead. See Plate XL.

It frequently happens that double angle bars, or double angle and bulb stringers, pass through a web frame, thereby wounding it at the place of intersection. In such cases it is usual to effect an efficient connection at the intersection by means of an intercostal plate, extending to the depth of the web frame for a frame space on each side of it, which is riveted to the stringer, and has double face angles on the inner edge. A diamond plate is riveted to the web frame and these face angles in the usual manner. This arrangement not only enables the web frame and intersecting stringer to act in unison, but it also serves to restore the stiffening that was lost by cutting the web frame to allow the stringer to pass continuously through it.

Before concluding our description of the web-frame system, it may be of interest to refer to an arrangement which has recently been adopted in some small steamers employed in the coasting trade, to serve the twofold purpose of affording transverse stiffness abreast long hatchways and of supporting the deck thereat without the assistance of side pillars in hold; the latter being notoriously much in the way of stowing, loading, and discharging certain cargoes, and liable, too, to be knocked away. This arrangement is shown by fig. 1, Plate XXXV., and, as will be seen, consists of a web frame arched at the top so as to form a rigid support for the deck. One or two of these web frames are placed at each side of the hatchway, the number being determined by the length of the latter.

An alternative to the use of the web frame with associated side stringer arrangement is sometimes provided in the form of extra strong transverse frames of the ordinary spacing, and composed of frame and reverse angles of large size—often of equal section—lapped against each other just sufficiently for the purpose of riveting, as shown by fig. 3 of Plate XLI.

For instance, in a steel steamer of about 4900 tons gross, requiring frames $5\frac{1}{2}$ in. × $3\frac{1}{2}$ in. × $\frac{9}{20}$ in., spaced 24 inches apart, with reverse frames 4 in. × $3\frac{1}{2}$ in. × $\frac{9}{20}$ in., it became necessary to provide additional transverse strength as compensation for an excessive depth to the lower deck beams, and in lieu of a tier of hold beams or equivalent web frames, the vessel was built with deep frames, as shown in the above-named figure. In this case the frames and reverse frames are each 6 in. × $3\frac{1}{2}$ in. × $\frac{9}{20}$ in., so that with an overlap of $3\frac{1}{2}$ inches, the depth of girder so obtained was $8\frac{1}{2}$ inches at every frame. This arrangement of deep frames is, in this case, associated with two intercostal side stringers formed with double angles each $6\frac{1}{2}$ in. × $4\frac{1}{2}$ in. × $\frac{11}{20}$, and an intercostal plate 15 in. × $\frac{9}{20}$ in.

73. Z and [Frames.—Since the general use of steel as a material for shipbuilding various schemes have been proposed for further lightening the scantlings, without at the same time diminishing the strength of the vessel. The economical advantages to the mercantile shipowner arising from a reduced weight of hull are obvious, as the margin of displacement remaining for cargo-carrying purposes is correspondingly increased. Similar considerations are operative in preparing the specifications of war ships; for by decreasing the weight of the hull proper it is possible to clothe an ironclad with thicker armour, enable her to carry a greater coal supply, or in some other way add to her efficiency.

The excellent qualities displayed by the mild steel, which has almost entirely superseded wrought iron as a material for shipbuilding, have contributed very materially towards the acceptance by shipbuilders of new forms of rolled sections for frames and other purposes. So uniform is the quality of mild steel that "lamination" and "reediness," which are such frequent faults in wrought iron, are now rarely found in steel angles, channel or girder bars. The Admiralty have for some years past been in the habit of using steel bars of Z shaped section for the frames above the cellular bottoms in war ships. By so doing the necessity for riveting frame and reverse bars together has been overcome, for the Z bars alluded to are really a frame and reverse bar rolled in one. It is true that the area of steel in the section, as employed by the Admiralty, is less than the combined area of the frame and reverse frame sections; but, on the other hand, the bar is not weakened with rivet holes, such as are necessary in the latter case, for connecting the frame and reverse frame together. If it were required a Z bar could, of course, be rolled equal in sectional area to that of the combined frame and reverse frame; but it is doubtful whether any advantage would be obtained thereby, for the frame and reverse frame combination, as usually employed, is not a theoretically economical arrangement of the materials, but the nearest approach to such as was possible at a time when no other means for obtaining anything like a Z shaped section were available. Now that Z or [sections can be obtained in sound, trustworthy materials, there no longer seems to be any reason, except that of additional cost, for adhering to the old combination of frame and reverse bar in steel ships. It is upon this account that a device which has for some time been advantageously adopted in war ships is now finding its way into the mercantile marine.

As already stated, Z or [frames are only employed above the cellular bottom. Even were the vessel framed from keel to gunwale upon the ordinary transverse system the Z frames could not be advantageously extended below the top of the floor plates. In H.M. ships the webs of the frames are split and the two flanges opened apart at their lower extremity, to the breadth of the armour shelf or margin plate of the cellular bottom. A bracket plate is fitted into the angular space thus formed, and riveted to the separated portions of the frame, thereby affording a means for connecting the Z frame to the margin plate or armour shelf, which connection is effected in the usual way, by a short length of angle iron on each side. In the case shown by Plate XIX., the vessel, which is unarmoured, has bracket framing with an inner bottom; and the Z frames are split as already described, one-half of each being attached to the frame and the other half to the reverse frame above the uppermost longitudinal frame, which is watertight, and forms the margin plate or boundary of the double bottom.

If the Z shaped frames were employed in a vessel having ordinary transverse framing throughout, a connection between the Z frames and the floor could be obtained in a similar manner by riveting one portion to the lower and the other to the upper edge of the floor plate. Only a comparatively short length of the Z bar need be opened thus, the remainder of the floor being connected to the usual frames and reverse bars—which latter would be butted and strapped to the parts of the Z bar or overlap them for a short distance.

74. Bevelling and Bending Z Frames.—It is obvious from the shape of the sections that the methods of bending and bevelling angle iron frames, as previously described, cannot be applied to Z bars.

The positions of the rivet holes having been set off upon these bars in the usual way, and the same having been punched, the frames are bevelled before being bent. To bevel the frames the blocks forming the bending slab are arranged so as to leave a straight narrow trench—about four inches wide—extending the entire length or breadth of the slab, at a line of joints in it.

A batten is then bent to the curve of the frame on the scrive board, and the bevelling spots are marked upon it. This batten is next sprung straight along the line of the before-mentioned trench, and the positions of the bevelling spots are copied upon the edge of the same. The heated

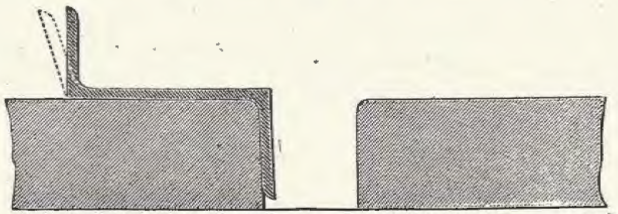


Fig. 16.

bar is removed from the furnace and laid upon the slab with a flange in the trench (see fig. 16). When the bar is correctly placed in regard to the bevelling spots, the flange above the slab is bevelled in the usual way. The bar is reheated and inverted, the bevelled flange being now in the trench, whereupon the other flange is bevelled—the same bevellings being applied as before. Before the bevelled Z frame can be bent to its curvature it must be reheated, and while this is being done preparations are made upon the bending slab, such as will now be described.

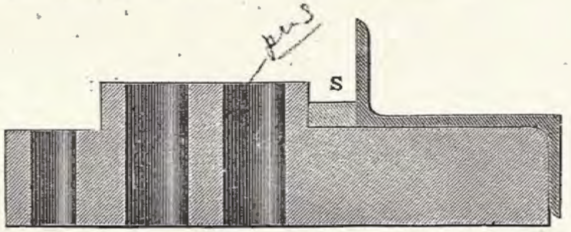


Fig. 17.

Cast-iron blocks are prepared of the form shown in section and plan by figs. 17 and 18 respectively. As many of these are required as will suffice for bending the longest frame in the vessel, the blocks being placed closely together.

The curvature of the frame is obtained from the scrive board by means of the usual set iron, and the above mentioned cast-iron blocks are arranged upon the bending slab to the form of the curve in such a way that the set iron may rest upon each of them in the manner shown by S, fig. 17. The blocks are then firmly secured to the bending slab by means of bolts placed through the holes in them and the holes in the bending slab. We have thus a surface prepared for bending the frames, which is sufficiently raised above the level of the slab to protect the one flange of the Z bar from injury, while the heel of the other is being pressed and bent against the set iron. The frame is

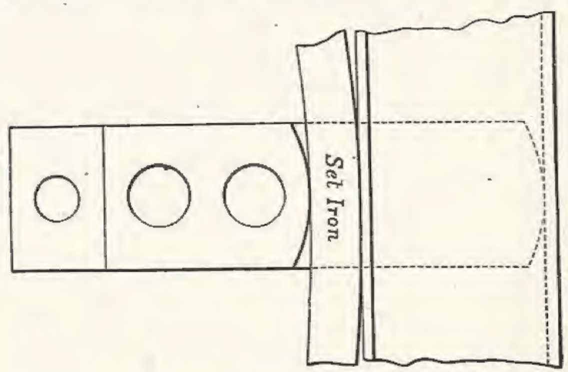


Fig. 18.

carefully bent to the curvature of the set iron by fixing one end of it and attaching a winch purchase to the other. After the bending process is completed the bevellings are checked and corrected.

As will be readily seen, the [(channel) section may be bent and bevelled in the same manner as angle bars, and upon that account it has of late been used by shipbuilders in preference to the Z section for the frames, and in some cases for the beams, of vessels, although certain experiments made upon bars of both forms of section show that the Z bars more successfully resist deflection under bending stresses by not buckling out of the plane of direction in which the stress is applied so readily as the [section.

For further details of framing, as at present practised, see Appendix.

CHAPTER IX.

75. Sheering the Deck Lines.—The frame work of a vessel having been erected, plumbed, horned, ribbanded, and shored, the surfaces of the beams to the several decks are next correctly sheered and faired. On the Clyde, generally, and at most of the shipbuilding districts in the east of Scotland and the north-east of England the beams, as already explained, are temporarily attached to the frames before the latter are erected. Elsewhere the beams are lifted into place after the vessel is framed and ribbanded. Whichever system is adopted the beams are not permanently riveted until the correct positions of the upper surfaces of their extremities are marked upon the frames with the aid of sheering battens. This is done at the same time that the correct lines for the side and bilge keelsons and the side stringers in hold are set off. Reference has already been made to the cases of these keelsons and stringers for vessels framed upon the ordinary transverse system. Bnt, whatever be the system of framing, the arrangement and connection of the deck beams are not influenced thereby.

The positions of all keelsons and stringers are notched upon the frames when the latter are finally proved upon the scrive board; and if ordinary care be taken in putting the portions of the frame together and in adjusting the latter when erected, it will be found that sheering battens bent around the sides and bottom of the vessel will pass fairly, or nearly so, through the notch marks copied from the scrive board. To provide, however, for the possibility of error the holes in the reverse frames for receiving the keelson and stringer angle bar rivets are not punched until the exact positions of the keelsons and stringers have been sheered in. For the same reason the beams are only tem-

porarily connected to the frames when lifted with the latter into place.

That the surface of a deck should be fair is more important than the fairness of a side stringer or keelson. The latter is to a large extent a question of appearance, but the former is also a matter of utility, and even efficiency.

Battens are therefore bent around the sides of the vessel so as to pass as nearly as possible, consistent with fairness, through the notches on the frames, indicating the position of the beams at side. Care is taken to keep the upper surfaces of the battens, on both sides of the vessel, level at each frame. When these lines are put in, the beams are adjusted so that their upper surfaces at the sides of the vessel shall coincide with the sheer lines. The upper surfaces of the beams to each deck are then faired by stout longitudinal ribbands already in place, shores being placed under the middle of beams where necessary to keep them to their proper positions. The holes for the beam knee rivets are then drilled, and the beams are riveted in place.

As already mentioned, by the Clyde system two holes are punched in the beam knees from a template before the parts of the frame are riveted together; this being done in order that the beams may be temporarily attached to the frames before being faired. If, when the beams are correctly sheered, these holes do not exactly coincide with those already punched in the frames from the same template, they are reconciled by rimeing, and larger rivets are put in them.

76. Deck and Hold Stringers.—The construction and functions of the stringers which are fitted below the lowest tier of beams have already been described. We have now to consider the stringers which are placed upon the extremities of each tier of beams, or at that part of the vessel where beams would be placed if their absence were not compensated by the additional stiffening capabilities afforded by the stringers.

The principal functions of a deck stringer are as follows:—

1*st*. To assist in connecting the deck beams to the side of the vessel.

2nd. To stiffen the shell plating in the vicinity of the stringer.

3rd. To contribute longitudinal strength to the vessel.

The last named is probably the least important of the services rendered by the stringer plating, considered independently of the remainder of the structure; for its longitudinal strength is evidently limited to the tensile strength of the plate and angle irons connected therewith. But it is in association with the beams and adjacent shell plating, especially that of the sheer strakes, that the chief structural value of the stringer plating and angle irons is developed. For, situated as the stringer plating is in a plane about normal to the surface of the side plating, it forms, in connection with the latter, a girder at each tier of beams, which is eminently adapted to resist the various strains set up in a sea-way.

The upper deck stringer serves the further purpose of forming a water-tight boundary to the deck, and provides the means for efficiently fastening the deck ends and margin planks.

77. Upper Deck Stringer when Wood Deck is Laid.—This is the most common form of upper deck stringer in iron or steel sailing ships and steamers, and it is usually so associated with angle irons as to form a gutter water course, as in the case of the sailing ships shown on Plates II. and XXIII.

As will be at once observed by an examination of these sketches, the stringer plate constitutes a most important part of the connection of the beams to the side of the vessel. There are rarely more than six or seven rivets in an ordinary beam knee, and the shearing resistance of the rivets is, clearly, not equal to the sectional strength of the beam. But by means of the stringer plate the connection is considerably augmented; for the latter is riveted to the angle irons or upper flange of the beam throughout its entire breadth, and to the sheer strake of shell plating by a stout continuous gunwale angle bar. The plan of stringer in fig. 3 of Plate XXIII. shows that in this case there are ten rivets joining each beam to the stringer plate, and about twelve rivets per beam in each flange of the

gunwale angle bar which joins the stringer plate to the sheer strake.

The inner angle bar of the stringer plate serves to stiffen, and therefore strengthen it, but its chief purpose is to form a side of the gutter water course, and to resist the caulking of the deck planking.

78. Upper Deck Stringer when Iron Deck is Laid.—In the small cargo steamer, illustrated by Plate V., an iron deck is laid, and as the scuppers are in such a case flush with the surface of the deck plating, no water course is reqnired. We have, therefore, only one angle bar on the top of the stringer—viz., that which connects it to the sheer strake.

79. Main and Lower Deck Stringers.—The steamer whose midship section is shown on Plate III. has a gutter water-course between the deck erections, such as is fitted in the sailing vessel, but as the frames extend to the bridge deck, the outer angle iron is therefore fitted in short lengths. It is necessary in that case to resort to the same course as is adopted in the lower deck of a vessel when a wood flat is laid on the beams. This is shown in greater detail on Plate XXIV., which exhibits in plan and section the lower deck stringer of an iron or steel sailing ship. The stringer plate is attached to the shell plating by means of short angle irons, termed chock pieces, and a continuous angle bar is fitted whereby the stringer is connected to the reverse frames. As at the upper deck, a gutter water-course is formed between the angle bar just referred to and another which resists the caulking of the deck flat.

Whenever an iron lower deck is laid, or in cases when there is no deck flat at all, this inner angle bar, and therefore the water-course arrangement, is omitted, as shown by Plate III.

80. Poop, Bridge and Forecastle Stringers.—The simple case of a bridge, forecastle, or poop deck stringer is illustrated by the Plate just referred to, the stringer plate being connected to the upper strake of plating by an angle bar, against which the deck planks are fitted. No water-course is here required in consequence of the absence of bulwarks; the surface of the margin plank or covering board strake being but a little above the level of the deck flat.

81. Hold Beam Stringers.—For convenience of stowage the hold beams of vessels are sometimes widely spaced, and made of extra strength. In that case the hold beam stringer is additionally stiffened by angle irons and other means. In Plate V., which shows the midship section of a small cargo steamer, the hold beams, which are of extra strength, are situated at every tenth instead of every second frame; and in this case the hold beam stringer is shown to be additionally stiffened by an angle bar on its inner edge fitted between the beams; the attachment of the latter to the stringer being aided by means of gusset plates. In vessels of greater depth of hold still greater stiffening is provided, as will be seen by referring to the orlop deck stringer on Plate IV., fig. 2. As will be observed, in this case, and in Plate V., the stringer is stiffened and supported between the widely spaced beam by bracket plates riveted to the frames. Further particulars upon this subject will be found in the next Article.

82. Spacing of Beams and Stringers in Hold.—From the preceding remarks it will be seen that there is a close association between beams and stringers, not only as regards the mutual support which these parts of the structure yield to each other, but because of the fact that stringers to some extent take the place of beams as an element in contributing transverse stiffness to the vessel.

By Lloyd's Rules the spacing of beams, or the arrangement of stringers substituted for beams, is regulated by the depth of the vessel amidships, measured from the upper part of the keel to the top of the upper, spar, or awning deck beams. An exception is made in awning deck vessels of less than 16½ feet depth of hold, which it is not now necessary to consider.

By the same rules "all upper deck beams, and the middle deck beams of three-decked ships, and the main deck beams of spar and awning decked ships, are to be fastened to alternate frames." This is the fundamental beam arrangement in iron and steel vessels.

Lloyd's Rules then proceed to describe the arrangement of side stringer, fitted midway between the bilge keelson and deck beams required in classed vessels having depths to keel varying from 13 feet to 15½ feet. When the latter depth is reached an additional stringer is required, all fore and aft, at the upper turn of bilge on each side. Further than that, when the vessel's depth of hold is 15½ feet, hold beams of extra strength are required at every tenth frame, and instead of the side stringer being formed of double angle irons, with either bulb or intercostal plate, as the case may be, a hold beam stringer has now to be provided, which is attached to the shell plating, supported by brackets at alternate frames, and secured to the beams by gusset plates, as previously described (see fig. 19).

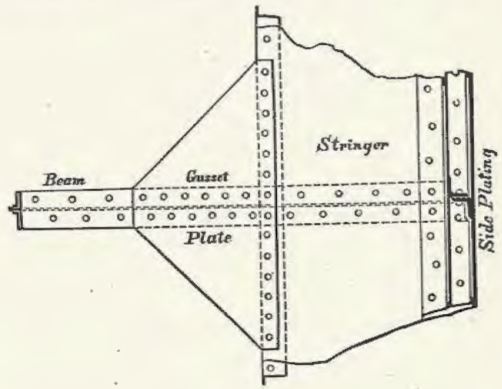


Fig. 19.

When between 15½ and 19½ feet in depth to keel, the arrangement of hold beams of extra strength fastened to every tenth frame is still permitted, but the hold stringer, having received accessions of strength at 16½, 17½, and 18½ feet depth, is now provided with a double angle iron 3½ × 3½ × $\frac{7}{20}$ fitted on its inner edge, and a face plate, upon the angle irons, $\frac{7}{20}$ in thickness (see fig. 2, Plate IV.).

At 19½ feet depth of hold, *sailing* vessels are required to have hold or lower deck beams fitted to every alternate frame.

Sailing vessels of 23 and under 24 feet in depth are required to be fitted with two double angle iron stringers, extending fore and aft between the bilge keelsons and hold lower deck beams.

When between 24 and 26 feet in depth, bulb plates are to be riveted to the side stringers, extending all fore and aft on both sides of the vessel, the bulb plates being of the size of the hold beams.

In sailing vessels of 26 and under 27 feet, intercostal plates are associated with the bulb stringers; and when 27 feet of depth is reached, an orlop stringer is required, attached to the shell plating and supported by bracket plates.

When the depth to keel of a sailing vessel reaches $28\frac{1}{2}$ feet, orlop beams of extra strength, fitted to every tenth frame, are required in addition to the stringer plate.

The rules then recur to the requirements for steamers, and provide for the hold beams and stringers in such vessels when from $19\frac{1}{2}$ feet to 39 feet in depth to keel.

In the above-named regulations, the depth from the lowest completely laid tier of beams is a factor in fixing the hold beam and stringer requirements, in addition to the entire depth from keel to upper deck. The height provided for between the upper and lower or middle decks varies from seven to eight feet in accordance with the total depth of the vessel.

It is not necessary to state Lloyd's Rules upon this subject in greater detail, but it was desirable to cite some portion, at least, of the before-mentioned particulars in order to illustrate the principle upon which the spacing of beams and stringers in hold is based. That principle evidently consists in increasing this element of stiffening to the side of the vessel with every increase in her depth. For depths under $15\frac{1}{2}$ feet, one tier of beams is considered sufficient, and the space between those beams and the bilge is stiffened by a double angle iron stringer on each side, aided, in the deepest vessels, by a bulb plate.

At $15\frac{1}{2}$ feet depth of hold an extra row of beams is found necessary, but for convenience of stowage these are widely spaced. In addition to the beams a side stringer is now fitted at the upper turn of bilge.

With the increase of depth beyond $15\frac{1}{2}$ feet further additions to the hold stringer are made, and when $19\frac{1}{2}$ feet of depth is reached, sailing ships are given two complete tiers of beams.

And so the increases in stringers and beams are continued until the depth of 39 feet is attained; beyond which no specific provision is made, but the case is required to be specially considered by the Committee.

As a further illustration of the value assigned to stringers, it may be remarked that when the height between the decks of a vessel exceeds eight feet, additional transverse stiffening is required by Lloyd's Rules, which stiffening usually assumes the form of a double angle iron stringer as shown upon the midship section in Plate III.

Whenever a deck is laid upon a tier of beams, these rules require the beams to be placed at not more than two frame spaces apart.

Where steel decks $\frac{7}{20}$ inch and under, or iron decks $\frac{6}{16}$ inch and under, are fitted, and no wood deck is laid on the same, beams of angle bar or angle bulb are fitted to every frame except at the ends of hatchways.

83. Further Details of Stringers.—The breadths and thicknesses of stringer plates for upper and lower decks or hold beams are set forth in tables accompanying Lloyd's Rules, and are regulated by the three-fold conditions—of proportion of depth and breadth to length, and the value of the second scantling number. The same tables show under what circumstances it is necessary to supplement the stringer plate with an iron deck. Vessels are considered of ordinary proportions when just under ten depths and eight breadths in length.

The same table which supplies the particulars of the required breadth and thickness of the upper and hold beam stringer plates amidships shows also the extent to which both these measurements may be tapered at the extremities.

When one iron or steel deck is laid, the stringer plate is reduced to one inch in breadth for each seven feet of the vessel's length, but no reduction is made when more than one such deck is required.

The greatest breadth of the stringer plate is maintained for half the vessel's length amidships, and gradually tapered from thence to the ends.

Wood roughtree stanchions are not permitted to pass through upper deck stringers. When frames are extended through to form bulwark stanchions, or the frames of poops, forecastles, and bridge houses, a continuous angle iron is wrought on the upper deck stringer inside the frames. The arrangement in such a case is as shown on the midship section, Plate III.

In passing it is desirable to remark that frames are very rarely carried through stringer plates to form bulwark stanchions, but the method of supporting and stiffening the bulwark shown by Plates II., V., and XXIII. is generally preferred. Further particulars regarding the construction of bulwarks will be stated hereafter.

84. Mode of Preparing and Fitting Stringer Plates.—The arrangement of butts of the stringer plates is made upon the deck plans provided for the use of the workmen at the ship, as shown by figs. 1 and 2 of Plate VII., which represent the stringers and other deck ties for an iron sailing ship. The butts are carefully shifted with regard to those of the adjacent sheer strake, or other strake of shell plating.

Stringer plates are punched from templates made with battens in the usual manner (see fig. 22), there being a batten at each beam. The holes already punched in the upper surfaces of the beams are copied upon the template, and when this is done the positions of the holes are transferred upon the plate set aside for the purpose, being marked upon its under side, from which side the holes are punched. The holes for the butt strap rivets at each extremity of the plate are also set off on the same side. The plate is turned over, the spaces between the holes *A. A* and *B. B*, fig. 3, Plate XXIII., are then subdivided, and the intermediate rivet holes set off, upon lines struck for the purpose, to the required pitch, whereupon these holes are punched from the upper side of the plate. At the same time holes to receive the fastenings of the wood deck are marked upon the stringer plate and punched.

As will be seen from Plate XXIII., it is desirable to arrange the rivet holes in the top of the beam so that the holes marked *A* and *B* shall serve also for the two stringer angle bars.

Some builders, however, do not extend either of the beam angle bars beyond the reverse frames, in order to avoid three-ply riveting at *A. A*. Although a rivet is lost in the beam connection by this arrangement, a compensating advantage is gained in the soundness of the rivets at *A. A*, which, of course, must be perfectly watertight.

The reason for punching the rivet holes from different sides of the stringer plate will be apparent when we consider that its under side is the faying side in regard to the beams, while its upper surface fays against the stringer angle irons.

The holes for the butt straps are set off on the lower side of the plates from templates which are prepared so as to include the rivet holes in the stringer angle bars. The butt straps are fitted to the under side of the plate, so that the upper surface may be flush at the water-course. These holes are consequently punched from the under side of the plate.

The butts of upper deck stringer plates should be planed in order that they may closely fit, and consequently great care is taken in templating each stringer plate against its adjacent plate already prepared.

Stringer plate butt straps for iron ships are required by Lloyd's Rules to be one-sixteenth of an inch thicker than the plates they connect for one half the vessel's length amidships, and when the number regulating the plating is under 8000, those to the upper deck may be double riveted. In larger vessels the butt straps to upper deck stringer are treble riveted, and when the 2nd scantling number is 33,000, and under 40,000, the butts of middle deck stringers are also treble riveted, and both they and the upper deck stringer butt straps are required to be one-eighth inch thicker than the plates they connect; the treble riveting being extended for two-thirds the vessel's amidships. The upper deck stringers of steel vessels, whose second number is 20,000 and above, have double butt straps fitted to them for half the length amidships, or the butts are lapped.

85. Stringer Angle Bars and Chock Pieces.—The continuous angle bars to stringers are fitted in as long lengths as are procurable, and their butts are shifted clear of those of the stringer plates and adjacent shell plates. In the way of upper deck scuppers the outer stringer angle bars to the upper deck are sometimes cut right through, and compensation is in that case afforded by riveting an angle iron of the same size upon the inside surface of the sheer strake plating, immediately below, and extending it from frame to frame. Some builders, however, prefer to weld a piece of plate to the upper flange of the bar in the way of the scupper, so as to widen it sufficiently to allow the scupper hole to be cut through it, and leave a breadth equal to that of the bar above the hole. In that case care has to be taken to properly caulk, and otherwise make the joint of the bar and sheer strake below the scupper hole thoroughly watertight. The ends of gutter water-courses are always formed by welding corners to the angle bars, and when the outer and inner angle bars are riveted, the edges of the bars are chipped and made watertight by caulking.

In all cases where the frames and reverse frames pass through a stringer plate, the latter is attached to the shell plating between the frames by short pieces of angle iron, known as chock pieces, as already described. These chock pieces are frequently fitted upon the upper side of the stringer right fore and aft, but as the angle iron on the inside of the reverse frames is somewhat in the way of riveting the chock pieces when so situated, it is not unusual to place them upon the under side of the stringer throughout a great part of the vessel's length amidships. The form of the vessel at the extremities renders it, however, necessary that the chock pieces at these places should always be put on the upper side, especially aft.

In the case of spar and awning deck stringer plates, and those to the upper deck in the way of poop, bridge-house, and forecastle, the spaces between the frames are filled in solid and made watertight. Sometimes wooden chocks are fitted in these spaces, which are caulked and then covered with Portland cement; but a better way is to fit cast-iron blocks, and make them watertight by means of corrosive cement.

At the after part of a vessel it is often found impossible to bevel angle irons sufficiently to serve as chock pieces, and in that case the stringer plates should be flanged and riveted to the shell plating.

Considerable care is necessary in fitting the continuous angle bars on the inside of the reverse frames, which are required when the frames pass through the stringer plates, so that these angle bars may fit closely against the reverse frames and be efficiently riveted to them. If the frame of the vessel is carefully ribbanded and faired in the neighbourhood of each tier of beams, the insides of the reverse frame will, of course, be reasonably fair.

It is, however, found desirable in practice to fit and rivet these continuous stringer angle irons before the side plating is fitted, as by so doing the frames receive very considerable support, and their fairness is checked at an early stage of the work. If any frames are then found to be unfair, the beam fastenings can be cut adrift and fairness established; whereas, if the work of riveting these stringer bars be deferred it may be found necessary not only to fit packing pieces between them and some of the reverse frames, but also to fit packing to an objectionable extent between the frames and shell plating, in order to obtain a fair surface to the side of the vessel. These remarks apply chiefly to the lower and middle decks, as the fairing of the gunwale is generally more closely attended to than that of the parts of the framing between the gunwale and the bilges.

In addition to the reasons already given, it will further be seen that the riveting of the angle bar to the reverse frames can be better done before than after the shell plating is on.

The continuous angle bar, to the lower or middle deck, is not usually carried right aft, when it would require a very considerable amount of bevelling in order to fit against the reverse frames. It should, however, be extended as far aft as is practicable.

86. Overlap of Stringers at Breaks.—When there are breaks in the continuity of a deck or tier of beams, as in the case of a raised quarter deck—with or without a bridge house, or a sunk forecastle—the stringer plating is extended beyond the break on both sides of it.

The upper deck beam stringer plate should maintain its breadth to the break of the quarter deck, and then be gradually reduced in breadth until it terminates at the fourth frame abaft the break, being fitted and riveted to the outside plating.

When the raised deck exceeds one-quarter of the vessel's length the number and arrangement of the hold beams, beam stringers and stringers in hold, should be in accordance with the requirements for the increased depth of the vessel at that part. The main deck stringer plate in that case extends about seven frame spaces abaft the break, and the raised deck stringer is continued to about four frame spaces before the break. Further than this the stringer plates below the main deck should have a shift of about sixteen feet overlap, or the necessary continuity of strength be obtained by other satisfactory means.

Arrangements are also made for maintaining continuity of strength when an iron deck is severed at the break. Some of these will be considered hereafter when discussing the arrangements in vessels having these breaks in their longitudinal connections.

87. Breasthooks.—At the fore and after extremities of deck and hold stringers, and bilge and side keelsons, the two sides of the vessel are connected by means of what are termed "breasthooks" when in the bow, and "crutches" when at the stern. The generic term "breasthook," is, however, usually applied to these portions of the hull. In Plate XXV. the part marked B is a breasthook, which, in this case is fitted at the extremity of a side stringer in the hold of an iron sailing ship. The purpose of the remainder of the connections shown in this Plate will be explained presently.

In the case of ordinary deck stringers the junction of the extremities of the plates on each side forms a breasthook, and when the decks are eight feet apart and above, or when the plating number is 24,000 or above, additional hooks should be fitted between them.

The ordinary "breasthook" is, however, fitted at the extremities of bilge keelsons, side stringers, etc., and consists of a plate having the same thickness as the midship floor plate, riveted to the stringer or keelson on each side, and thereby joining the two sides of the vessel together. Such a breasthook is in fact a horizontal floor, and should be made sufficiently wide to serve the purpose of such.

Below the lowest tier of beams the breasthooks should be not more than four feet apart, and a satisfactory arrangement of keelsons and stringers would be so spaced at the extremities of the vessel. If, however, the spacing of stringers and keelsons below the hold beams is more than four feet, additional breasthooks should be fitted and attached to double angle irons provided for the purpose and riveted to the reverse frames.

88. Arrangements to Prevent Panting.—The curvature of a vessel's transverse vertical section constitutes, in itself, a valuable element of stiffening to the structure. But as that curvature diminishes towards her extremities, it is often found necessary to supply at these parts additional internal stiffening to prevent the sides of the vessel from developing a tendency to flexibility, which is known as "panting." This tendency is found to be more general at the bow than at the stern, but instances of panting have been observed at both extremities of a vessel. It is, as may be supposed, more likely to occur in sharp than in full-ended vessels, unless due precaution for preventing it be observed. When a vessel with comparatively fine extremities is propelled through a series of waves, the bow and stern are, alternately, deeply buried in the sea and left almost entirely unsupported by it. This, of course, occurs more or less throughout every part of her length, but the comparative absence of curvature in her frames at the bow and stern renders them less capable of resisting the forces which are acting upon them. These forces are usually the greatest at the bow, which is particularly liable to receive blows from the sea. The excessive fineness of the after body renders it necessary, too, that the sternmost floors shall be extended to a greater height than the floors of the forebody. Panting, however, as has been said, occurs sometimes at the stern as well as at the bow, and provision has to be made for preventing it; the nature and extent of that provision being determined by the form of the vessel, and the details of her construction at the extremities.

The measures for preventing panting must necessarily be of such a character as shall stiffen the framing against lateral strains; and whenever an iron deck flat, or beams for a wood flat, are situated midway between the hold beams and the floors, the value of these, as provisions against panting, will of course be taken into account. Such iron flats are not unusual at the extremities of steamers, but in sailing vessels, and indeed in all cases wherein no existing structural arrangement will sufficiently stiffen the comparatively straight frames, special precautions should be taken to prevent panting.

Several means are adopted for this purpose, the extent of the stiffening being determined by the form of the vessel at the part in question.

Plates XXV. and XXVI. show two so-called "panting arrangements" for iron or steel sailing vessels. In Plate XXVI. the bilge stringer is widened to the extent of 24 inches from the stem to four frame spaces abaft the collision bulkhead; being fitted intercostally between the frames, and attached by angle irons to the shell plating. This stringer is half inch thick, and to give it further stiffness within the fore peak, a bulb plate $8 \times \frac{1}{2}$ inch is riveted to its inner edge. Abaft the collision bulkhead the stringer is stiffened by brackets B. B. riveted to alternate frames. The fore extremities of the "panting stringers" are joined by a $\frac{5}{8}$ inch breasthook.

It will be remarked that in this case an iron chain locker bulkhead, on the foreside of the collision bulkhead, ties the two sides of the vessel together, and very materially aids the panting stringer in providing the required transverse stiffness.

Plate XXV. shows another method which was fitted in a vessel with somewhat finer extremities than the preceding. This "panting arrangement" is very efficient, consisting as it does of a panting stringer, wrought intercostally, and three panting beams, one of which is on the foreside of the collision bulkhead, and two abaft it. These beams are connected to the stringer by means of gusset plates, besides being riveted to the frames. In this instance, too, an iron chain locker bulkhead co-operates with the special panting arrangement, the transverse support of the bulkhead being rendered more serviceable by means of the bracket plates on each side shown on the Plate.

This is an excellent arrangement, and it is to be recommended in the case of sharp bowed sailing ships of about say, 1400 tons.

The arrangement shown by Plate XXVI. is aided by an intercostal stringer, 16 inches wide, situated immediately above it, as shown in the profile view. The panting arrangements in the bows of smaller vessels will be proportionably reduced in extent and scantling.

At the after part of large sailing vessels panting beams, and sometimes panting stringers, are fitted when the form of the stern renders them desirable.

89. Deck Tie Plates.—These are of two kinds—viz., longitudinal and diagonal. The former are fitted in all vessels except when an iron deck is laid, the latter are placed only upon the beams of sailing vessels.

90. Longitudinal Tie Plates are laid all fore and aft on each side of the hatchways on each tier of beams (see Plate VII.). They are lapped or butted together, and at least double riveted. The breadths of tie plates are regulated by the same scantling number as determines the thicknesses of the shell plating.

Upon hold beams where no deck is to be laid, or where tie plates would interfere with the stowage of the cargo, double angle irons of the size required for lower deck stringers may be substituted, and these should be placed at the middle line or at the sides of the hatchways.

It may be remarked in passing that when placed at the middle line it is not unusual to leave a space between them to receive the shifting boards, which are used when a grain cargo is carried.

The purpose of longitudinal tie plates is to keep the beams to which they are riveted in the same relative position with regard to each other, and so resist the tendency to buckling which occurs in a sea way, or through the squeezing of the cargo when stowing. They also contribute some longitudinal strength, which is, however, appreciable only when under tensile stresses, and then but to a small extent. Their chief function, as already remarked, is to keep the beams to their work.

91. Diagonal Tie Plates are chiefly of value in resisting the strains communicated to the deck by the masts. They are, therefore, required by Lloyd's Rules to be fitted on the beams of all sailing vessels in the way of the masts, at the deck on which the latter are wedged; and, in addition, when the plating number is 15,000 and above, diagonal tie plates are to be fitted all fore and aft on the upper deck.

Plate VII. shows the arrangement of longitudinal and diagonal tie plates to both the upper and lower deck of an iron sailing ship, the masts in this case being wedged at both decks. This is a case in which the plating number exceeds 15,000.

Where diagonal plates cross each other at the fore and aft tie plates, between the beams, and a deck is to be laid thereon, one set of tie plates should be set down in way of the crossing, so as to leave one thickness only projecting at the beam. The object of this precaution is, as may be supposed, to avoid unduly wounding the deck planks.

Care should be taken in preparing and fitting the butt straps, which connect the diagonal tie plates with the fore and aft ties, stringer plates, etc., so as to secure an efficient rivet connection on both sides of the joint. Better work is generally obtained by joggling and lapping the diagonal ties at these parts than by butting and strapping them.

Holes are punched or drilled in tie plates to receive deck fastenings, as by this means the deck plank is made to stiffen the tie plate, and keep it in the plane of its work.

92. Deck Plating—Purpose of.—Iron or steel decks, either partial or entire, are now a very common feature in iron or steel vessels, even when not required by the classification rules relating to their size and proportions. The structural purposes of deck plating are so closely allied to those of deck stringers and tie plates, that the stage at

which we have now advanced in this volume appears convenient for their consideration. The amount of longitudinal strength contributed hy a wood deck to an iron vessel cannot be very considerable. Not only the absence of butt connections in the form of straps, but also the comparatively yielding character of the material prevent a wood deck flat from rendering much assistance to the iron parts of the structure in resisting the stresses of an extensive and compressive character to which the upper works of a vessel are continually being subjected. The two materials, both in their elastic qualities and modes of combination, fail to operate together. The wood deck of a wood ship is a valuable portion of her structure in regard to stress resisting functions, because in that case the elastic qualities are more nearly uniform, and all the parts act together, the side and bottom planking being very little, if at all, more rigid than the deck planking.

When, therefore, a wood deck is laid upon the beams of an iron or steel ship, its primary purpose is as a flat to walk upon and to keep the cargo dry. It makes the vessel watertight, and so far seaworthy, but its value, considered structurally, is small. Upon that account iron or steel decks should be fitted in all vessels above a certain size, and in smaller vessels when of more than ordinary proportions of length to depth or breadth. Looking at the many positions assumed by a vessel, considered as a girder, when rolling and pitching among waves, the importance of making the upper deck approximate in streugth to that of the side upper works will be manifest. For at times the deck and sides are equally inclined to the vertical, so that what is at one moment the top of the girder is at another the side, and *vice versa.* Indeed, the plating of an iron or steel deck may be properly considered as a continuation of that of the side of the vessel, which latter, in this case, becomes, approximately, an iron or steel cylinder with closed ends. In every iron vessel an iron deck is structurally superior to one of wood, but in large vessels, and especially when of considerable length in proportion to their depth and breadth, such decks are essential to their safety.

93. Steel Decks by Lloyd's Rules.—Vessels under ten depths or eight breadths in length are not required by these Rules to have steel decks until their plating number reaches 23,000, and then the deck is to be $\frac{6}{20}$ inch thick, and to extend over one half her length amidships. When the number reaches 25,000, the steel deck of that thickness extends throughout her entire length. The number 29,000 requires a steel deck $\frac{7}{20}$ inch thick, and when the number becomes 35,000 one half of the middle deck is of steel the same thickness as the upper deck. The scale progresses until the number 48,000 is reached, when two entire decks are of steel $\frac{8}{20}$ inch thick; and ultimately, when the number is 64,000, both decks are to be $\frac{9}{20}$ inch in thickness.

With each increase in the vessel's proportions the numbers diminish at which a steel deck or two steel decks are required, so that all vessels over fifteen depths, or ten and a half breadths in length, are to have a $\frac{7}{20}$ inch steel deck. A vessel of these proportions, whose plating number is 42,000, must have three complete steel decks, the upper being $\frac{10}{20}$ inch, the middle $\frac{9}{20}$ inch, and the lower $\frac{7}{20}$ inch in thickness.

It is not necessary to give the intermediate or other requirements of Lloyd's Rules in regard to steel decks (which may be substituted by iron, in iron vessels, of corresponding sixteenths instead of twentieths in thickness). Sufficient has been said to indicate the conditions which regulate these requirements, and therefore the purposes which the steel decks are expected to serve as components of the structure.

94. Steel Decks Associated with Wood.—Sometimes wood deck flats are laid upon the steel decks, but in this case Lloyd's Rules do not allow any reduction in the thickness of the latter for any part of the length; although a reduction of half an inch in the thickness of the wood deck is allowed from that required for a case in which no steel deck is laid.

In iron and steel cargo steamers it is not unusual to have an iron or steel deck not covered with wood; but in passenger vessels a wood deck flat is laid upon the upper deck, at least, and sometimes npon the others. When a wood deck

is laid upon one of iron or steel, the former should be efficiently fastened to the latter between the beams, as the wood deck is able in that case to render valuable stiffening assistance to the iron or steel deck, and so resist any tendencies to buckling. A firm and close connection is further necessary to prevent any leakage in the wood deck from lodging between the surfaces, and thereby causing corrosion. Hence the wood flat shonld be carefully fitted in the first instance, and the upper surface of the iron should be covered with a thick coating of paint.

95. Systems of Deck Plating.—There are two systems of fitting iron and steel deck flats—viz., "clencher" and "flush." The former is generally adopted in the mercantile marine, and the latter is usual in the Royal Navy. Specimens of clencher fitted deck plating are to be seen in Plates III. and V. In flush deck plating the edges of the plates are joined by strips fitted either on the upper or the under side; being, in fact, joined similarly to the butts in the clencher system. (See Plate IV.)

Plate XXVII. shows a plan of a portion of the iron deck in the vessel whose profile is seen on Plate VI. The deck plating by the clencher system is generally arranged similarly to the bottom plating—viz., in alternate upper and lower strakes. The lower strakes rest upon the beams, and the upper strakes are lapped upon the edges of the lower strakes, with packing pieces between their under surfaces and the upper surfaces of the beams.

There is a variation of the clencher system of fitting deck plating—not so common—in which one edge of each strake rests upon the beam, and the other laps upon the edge of tbe adjacent strake. By this system tapered liners are of course required, the close fitting of which is not so certain as in the case of the parallel liners cut from plates of the same thickness as the lower strakes. This method of fitting deck plates is identical with the common clencher system of planking boats.

96. Connections at Edges and Butts.—The edges of iron and steel decks are usually single riveted, and the butts should be double riveted for at least half the vessel's length amidships.

Both edges and butts should be planed—the former for the sake of appearance, and to facilitate the caulking, and the latter for close fitting, and therefore watertightness and general efficiency.

The spacing of rivets is the same as for watertight work elsewhere. 4 diameters.

97. Spacing of Beams under Steel Decks.—It has been stated elsewhere that a close spacing of beams is under certain circumstances necessary when a steel deck is laid upon it.

Lloyd's Rules require that when a steel deck is $\frac{7}{20}$ of an inch and under, and no wood deck is laid upon it, beams of angle iron or angle bulb are to be fitted at *every* frame (see Plate XXVII.), except at the ends of the hatchways, where beams of the ordinary size are required.

Where steel decks exceed the above thickness, the use of angle bulb or angle bar beams, placed at every frame, is also considered preferable to the ordinary arrangement of stouter beams at alternate frames.

98. Partial Steel Decks.—In cases wherein the steel deck does not extend right fore and aft, it is most important that the extremities of the partial steel deck should taper gradually from the middle line towards the sides of the vessel until it merges into the breadth of the stringer plate. This precaution, it need scarcely be said, is necessary in order to avoid sudden discontinuity in the longitudinal strength.

In all iron and steel vessels some portions of the deck beams are covered with plating, in addition to the ties and stringers; as for instance at the mast partners, around hatchways, and more especially under the galley, donkey boiler or distilling apparatus, when such is fitted. Plate VII. shows the deck plating under the galley and donkey boiler in an iron sailing ship, the windlass of which is worked hy steam. In such cases of partial plating the same precautions should be observed in regard to fitting and riveting as have already been described.

The methods of templating deck plating, being the same as that of shell plating, will be considered hereafter.

CHAPTER X.

99. Bulkheads are the vertical partitions which subdivide the interior of a vessel, either transversely or longitudinally, for purposes of convenience and safety. The bulkheads with which we are chiefly concerned are required to be watertight, both in themselves and in their connections with the remainder of the hull. They should, moreover, be made sufficiently strong to withstand the pressure which they would be called upon to endure in the event of either of the adjacent spaces of the vessel being filled with water.

In the mercantile marine the bulkhead subdivisions are almost wholly disposed transversely, the only important exceptions being in the cases of wing bunker bulkheads, which, however, are usually of slight construction, and not expected to be perfectly watertight.

In the Royal Navy longitudinal watertight bulkheads are frequently employed, especially in the large ironclads which are propelled with twin screws, and supplied with separate sets of boilers and engines for each propeller. Their chief value in these cases is, of course, that of providing safety against the risks of injury from projectiles, rams, or torpedoes. Subdivision into nnmerous compartments is an important feature in modern naval design for war purposes, and this principle is adopted both in the double bottom space and throughout the whole of the remainder of the vessel to the height of the iron decks above the water line. Longitudinal middle line bulkheads separate the vessel into two portions, each of which contains independent means of propulsion and sources of buoyancy.

In the mercantile marine the demands for stowage facilities do not admit of so extensive a subdivision, nor indeed is there such a necessity for longitudinal watertight partitions as in the case of war ships.

Sailing vessels have, usually, only one bulkhead, fitted transversely at a short distance from the bow, being known as the collision bulkhead in consequence of the service which it is intended to render, viz., that of keeping the vessel afloat when the bow is damaged by collision. Such a bulkhead is shown by Plate XVI.

Steamers necessarily require several transverse watertight bulkheads; for, in addition to the provision against risks of collision, the machinery and boilers must be separated from the cargo spaces, and precautions must be taken in screw steamers against the possibilities of fracture in the propeller shafting. Consequently screw propelled vessels usually require at least four transverse watertight bulkheads, one of these being situated at a short distance from each extremity of the vessel, and one at each extremity of the machinery space. These four bulkheads will be seen in the profile view of the small cargo steamer shown by Plate VI.

100. Number of Bulkheads by Lloyd's Rules.—These Rules require a collision bulkhead in all sailing vessels at a "reasonable distance" from the bow, also the four bulkheads, already alluded to, in screw steamers; those at the bow and stern being "at a reasonable distance" from each end of the vessel.

In steamers 280 feet long and above, an additional bulkhead is to be fitted in the main hold, about midway between the collision and engine room bulkheads; also in steamers of 330 feet long and above, an additional bulkhead is to be fitted in the after hold. All these bulkheads are to extend to the upper deck in vessels with one, two, or three decks, to the spar deck in spar decked vessels, and to the main deck in awning decked vessels, except the collision bulkhead, which is extended to the awning deck. The object in fitting these bulkheads is evidently that of endeavouring to keep the vessel afloat in the event of either compartment being filled with water.

Still further subdivision is encouraged by Lloyd's Committee, inasmuch as the number of the complete watertight transverse bulkheads is recorded in the Register Book. Stowage requirements operate very much against an increase of transverse subdivision in ordinary mercantile vessels, as it is found impossible to employ them profitably as general traders when a greater number of transverse bulkheads are fitted than these Rules insist upon. Some of the largest passenger steamers have, however, been further subdivided with great advantage, having regard to their safety against dangers of collision or other means whereby their sides may be penetrated. This course has of late years received some encouragement from the Admiralty, who have entered approved vessels upon a selected list for employment under government charter as transports or armed cruisers in time of war.

101. Details of Transverse Bulkheads (see Plates XIII. and XVI.). Watertight bulkheads are always extended to the shell of the vessel, and connected thereto with double frame angle bars, except in the way of cellular inner bottoms, in which cases the bulkheads are attached to the latter, and a watertight frame is usually fitted immediately below each bulkhead.

The thickness of bulkhead plating is regulated according to Lloyd's Rules by the 1st or frame number, and varies between $\frac{5}{20}$ and $\frac{8}{20}$ of an inch in thickness. When the rules require $\frac{6}{20}$ inch, or thicker, bulkhead plates, the upper half of the bulkhead is allowed to be $\frac{1}{20}$ inch thinner than the lower half.

Bulkhead plates are usually arranged transversely, but sometimes a vertical arrangement is adopted. The two arrangements in one bulkhead are shown by Plate XIII. Both edges and butts may be single riveted and lapped as in the Plate, and the spacing of rivets must, of course, be such as to permit the joints to be properly caulked and made watertight. Bulkheads are stiffened with vertical stiffeners on one side, and with horizontal stiffeners upon the opposite side; these are, respectively, indicated by the letters *V S* and *H S* on Plates XIII. and XVI. The stiffeners are usually angle bars reinforced at times with bulb plates. Tee-bars, angle bulbs, web plates, and semi-box stiffeners are also sometimes employed.

Lloyd's Rules require the vertical and longitudinal stiffeners to be of angle bars of the same size as those of the frames; the vertical stiffeners are to be spaced not more than 30 inches apart, and the horizontal stiffeners are to be not more than four feet apart below where the bulkheads are stiffened by a laid deck. Bulkheads of 40 feet in breadth and above have horizontal stiffeners of bulb angles, and engine-room bulkheads are additionally stiffened with one or more vertical webs. (See Appendix.)

Where stringers and keelsons pass through the transverse bulkhead, the joints are made watertight with wrought-iron collars (see Plates XIII. and XVI.) properly fitted and caulked.

The rivets in the double frame angle bars, which connect bulkhead plates to the shell of the vessel, are necessarily spaced sufficiently close in one flange to allow the edges of the angle bars to be properly caulked and made watertight. There is also a closely spaced single row of rivets in the shell plating at each watertight bulkhead, thereby reducing the effective area of a transverse section of the shell plating at these places. This weakening of the shell is the more to be regretted as the bulkheads render the structure at these localities more than ordinarily rigid, thereby still further creating discontinuity of strength. Various measures have been proposed and tried for restoring the efficiency of the shell plating, but that which has found the most favour is the one required by Lloyd's Rules. It consists in extending the liners between the frames and the outer strakes of plating, each in one piece, from the fore side of the frame afore, to the aft side of the frame abaft the bulkhead frames. By this means almost one half of the section of the shell plating at the bulkhead is doubled for a length of more than two frame spaces.

The consideration of this question properly pertains to a later stage of this work, but it was thought desirable to refer to it now, inasmuch as it is so intimately associated with the efficiency of transverse watertight bulkheads.

From what has been said in regard to stringers and keelsons it is now scarcely necessary to remark that these,

together with deck plating, and all other longitudinal iron or steel ties, are continuous through the transverse bulkheads.

It sometimes happens that a transverse bulkhead cannot be extended continuously in one plane from floors to upper deck, in consequence of some interfering arrangement in the vessel's design. In such cases it is recessed, stepped or stopped at some intermediate height, where for a short distance it is fitted horizontally in the form of a watertight flat, the sides of which are connected to the deck and frames of the vessel in a watertight manner by means of iron collars, chocks, etc., such as will presently be described.

102. Bulkheads to Deep Water Ballast Tanks.—The bulkheads to deep water ballast tanks, either at the middle of the vessel, or, as more frequently fitted, at the extremities, are provided with additional stiffeners in order to enable them to satisfactorily endure the pressure to which they are submitted when the tank is nearly full of water. It is evident that in either case the pressure on the bulkhead, tending to buckle it, is considerable; but when the tank is not completely full of water the pressure is supplemented by a momentum due to the movement of the water as the vessel pitches and scends. Such bulkheads are, therefore, additionally stiffened with bulb plates riveted to the vertical stiffening angle irons, and these are sometimes further supported by bracket plates at the bottom of the bulkhead.

103. Construction of Bulkheads. — The materials for bulkheads are ordered in accordance with measurements taken from sketches prepared by the draughtsmen, who obtain the form of the bulkhead from the body plan of the vessel.

Bulkheads are generally put together temporarily upon the ground, and the positions of the rivet holes for edge and butt laps, stiffeners, and frame angle irons, are then lined in and set off upon the plates. When these rivet holes have been punched and the edge and butt laps correctly sheared, the whole is erected in place.

104. Partial Bulkheads.—These have been already considered under the name of web frames, which designation has latterly been given to transverse stiffeners formed with plates riveted between the frames and reverse frames. Sometimes, however, the sides of vessels between a main and middle or lower deck are stiffened by partial bulkheads which do not extend into the hold. This is done, for instance, in the case of awning decked vessels to give greater stiffening to the side plating under a deck erection. Other circumstances sometimes occur in which partial bulkheads are considered necessary to supplement the ordinary frames and reverse frames.

105. Structural Value of Bulkheads.—As is the case with almost every other portion of an iron or steel vessel, the bulkheads are not only useful as a contingent means for keeping her afloat, but they also have valuable structural purposes. The transverse stiffness may be considered to reach almost perfect rigidity at each properly constructed and stiffened transverse bulkhead, and very considerable longitudinal stiffness is afforded by the strongly plated and stiffened longitudinal bulkheads of Her Majesty's ships.

The great service rendered to the entire structure of a vessel by her transverse bulkheads, not only in binding the two sides together after the manner of a huge beam, but also in resisting the numerous stresses which are encountered when rolling and plunging in a seaway, will be obvious. This resistance is, however, under ordinary circumstances principally confined to the locality of the bulkhead itself, and upon this account it is important to distribute it as much as possible to the intersecting plate stringers by means of horizontal bracket or gusset plates, whenever the internal arrangements of the vessel will permit. For, since the bulkhead is a source of great transverse stiffness, it is necessary to adopt such measures as will prevent it from being a locality of discontinuity in regard to other elements of resistance. Hence longitudinal girders in water ballast tanks, as previously stated, should either be extended through the transverse bulkheads for a short distance, or be connected to the latter, and continued on the opposite side in the form of substantial bracket knees.

Similarly, side and bilge keelsons are extended through the transverse bulkheads, for a short distance, into water ballast tanks.

106. Watertight Flats.—This name is given to the upper sides or "crowns" of deep water ballast tanks or other compartments which are required to be perfectly watertight. In the Royal Navy powder and shell are stowed in iron tanks, built as components of the entire structure, and lined with wood. In the mercantile marine, "peak tanks" are often built at the extremities of steamers, and sometimes deep tanks are constructed at other parts of the vessel for holding cargo at one time and water ballast at another.

The upper surfaces of these tanks are often laid at the level of a tier of beams, either hold or orlop, and in small vessels the crown of a peak tank is often at the level of the upper deck. In most cases the top of the tank serves as a "flat" to a storeroom or cabin. It is always stiffened with angle irons which serve as beams, and in most cases the watertight flat extends to the sides of the vessel, where it becomes necessary to make watertight connections with the shell plating similar to that at the margin of a water ballast tank or cellular double bottom.

There are several methods of making the watertight connection, each of which was considered in connection with water ballast tanks. Two of these are, however, more frequently adopted than the others. By both methods the reverse frames are cut in two; and compensation is afforded in the one case by fitting short lengths of double frame angle iron, back to back with the main frames, while in the other, bracket plates are fitted above and below the crown of the tank, connecting it to the framing. These bracket plates are secured to the plating of the tank top by means of short pieces of angle iron, which, in conjunction with the bracket plates, restore the transverse connection at the severed reverse frames. The latter appears to be the most satisfactory in yielding a watertight connection, and is usually adopted in cases wherein the bracket plates above the crown are not found to be objectionable. In both cases watertightness is obtained by fitting collar pieces around the frames and shell plating, as shown in fig. 2 of Plate XVII.

The angle iron beams or stiffeners to watertight flats are situated at every frame space, and they should be efficiently pillared at the middle line of the vessel, unless the functions of pillars are performed by a middle line longitudinal partition bulkhead, such as is often fitted in wide tanks of this description.

When pillars are fitted it is necessary that double angle irons, fitted back to back, should be riveted on the under side of the tank crown, running fore and aft at the middle line, to distribute the support of the pillars. These double angle irons may be connected to the transverse stiffeners of the flat by short lug pieces of angle iron.

When a middle line partition bulkhead is not fitted in a deep watertight tank, a deep "wash plate" should be fitted fore and aft near the middle line, and attached to the under side of the tank top, to break the wash of the water in the tank (when the latter is not quite full) as the vessel rolls from side to side. Otherwise the momentum dne to the movement of the water is liable to damage the top of the tank and its connection with the sides of the vessel.

Watertight flats and the bulkheads of deep tanks should always be tested and proved to watertightness when completed, under water pressure in the usual manner, by filling the compartment with water, closing all manholes and scuttles in it, and raising the water to a certain height in a vertical tube standing above the tank. The water in the tube is, of course, in communication with the water in the tank. When the level of the tank is below the water line of the vessel, the water in the tube is filled to the level of the load line, and when the tank top is above the water line a pressure of eight feet head of water is given to the tank.

107. Pillars are the vertical supports to the several decks, and are in most cases placed under the centres of the beams. When of sufficient strength and so situated they reduce the span of the beam by one half, and correspondingly strengthen the entire structure. But pillars are intended as vertical ties as well as supports, and consequently both the heads and heels are riveted with not less than two rivets in each. A and A′, fig. 20, show the usual mode of connecting the head of an iron pillar to a bulb beam; and E on the same figure shows the rivets at the heel for connecting it to the beam or keelson below. When the beam which is supported is formed with double angle irons on its lower edge, the head and heel connections of the pillar will be both similar to the heel shown by fig. 20.

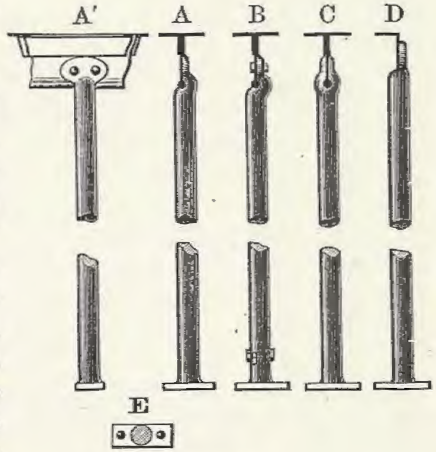


Fig. 20.

Pillars are of two principal kinds, viz., solid and hollow. In each case they have solid heads and heels, which should be forged in one piece and not "jump" welded together. With the same sectional area of material, the hollow pillar is the stronger of the two, and for that reason hollow pillars are more frequently employed than solid ones in the Royal Navy. But as hollow pillars occupy more space than solid pillars of equal strength, and therefore interfere more with the stowage of a vessel, they are not so frequently employed in the mercantile marine. Both solid and hollow pillars are made of wrought iron, and have welded heads and heels.

Solid pillars are sometimes split, or rather two half round pillars are fitted in lieu of one circular pillar. These so-called "split pillars" are fitted for the purpose of securing shifting boards when grain cargoes are carried.

When split pillars are used, each half should be half an inch larger than the half of the corresponding single pillar, and the parts should be efficiently connected by bolts or otherwise.

It should be remarked that similar split pillars joined by horizontal bars are fitted at the hatchways of most vessels to serve as ladders to the several decks and holds.

Lloyd's Rules require all beams for at least three-fourths the length of the vessel amidships to be pillared. They further require the alternate beams before and abaft that length, all carlings of hatchways exceeding in length six spaces of frames, also the beams under deck houses, bowsprit, pall hitt, windlass, steam winches, and capstan to be similarly supported.

Pillars to the several decks and in the hold should be placed vertically under each other, so as to give a continuous tie from the uppermost deck to the keelson. The diameters of the hold pillars are the greatest, those under the uppermost tier of beams the least, in each vessel, and the pillars to the intermediate decks should vary regularly in diameter between these extremes. When the lowest pillars extend above the hold beams, or are otherwise unduly long, their diameters should be increased in order to stiffen them.

In broad vessels it is not unusual to fit a double row of pillars, termed "quarter stanchions," one on each side of the middle line, stepped upon the side keelsons, in preference to a single row stepped upon the middle line keelson; and Lloyd's Rules encourage that arrangement in all vessels of 43 feet and upwards in breadth by slightly reducing the sizes of the beams when the double tier of pillars is fitted.

Before fitting the pillars under deck and hold beams, it is necessary that the shores under the latter should be so set and adjusted that the beams are at their proper round-up and their surfaces fair. The lengths of the pillars may then be measured with battens, upon which are marked the distance from the under side of each pillared beam to the beam or keelson upon which the heel is to rest. The necessary lap is afterwards added at the head of the pillar for riveting it to the side of a bulb or angle iron beam in one or other of the modes shown by fig. 20. As will be seen, the head of the pillar is so formed as to allow the bulb of the beam to rest upon it, and so relieve the rivets

from the stresses due to downward thrusts on the pillar. B on fig. 20 shows a hinged or portable pillar, and in that case the head is fastened to the side of the beam with two nut and screw bolts in lieu of rivets.

The method of attachment at the head, shown by C of fig. 20, is sometimes, but not often, adopted. The head of the pillar is made with two open jaws, which are heated and then closed upon the sides of the beam. No rivets are required at the head of the pillar in this case.

D of fig. 20 is simply the mode of connecting the pillar to an ordinary angle iron beam.

Lloyd's Rules require that when double pillars are fitted for the purpose of securing shifting boards, they are to be not less than three-fourths the diameter for single pillars.

For further details regarding watertight bulkheads and the pillaring of deck beams, see Appendix.

CHAPTER XI.

108. Shell Plating.—This is the most important part of structure of an iron or steel vessel, not only because it is essential to her flotation, but because it is the chief source of her strength, and is the largest item in the weight of her materials. The importance of the shell plating in regard to the remainder of the hull of a vessel is shown by the classification requirements of Lloyd's Register, which demand the same scantlings for the 100A, 90A, and 80A classes, except so far as regards the bottom and side plating, the thicknesses of which alone determine the particular class of the vessel, when the other requirements for any classification are fulfilled. It is true that this is in some respects due to the great durability of the thicker shell; but as other parts of the vessel are found to oxidise with equal rapidity to the plating, it must be inferred that the higher class indicates not only longer life but greater structural efficiency.

109. Modes of Arrangement.—In the early days of iron shipbuilding, several methods of fitting the bottom plating were tried, and vessels plated in these different ways are still in existence. The clencher system, with alternate raised and sunken strakes, has been found the most desirable, except in special cases, and is consequently now almost invariably adopted. Before examining the mode of plating a ship by that system, it is desirable to call attention to the others, and briefly describe them.

110. Flush Plating.—By this system the outer surface of the shell plating is smooth, the edges and butts being united by edge strips and butt straps on the inside. This method of plating is still at times applied to yachts, being preferred on account of its appearance. When a vessel is flush plated, the edge strips are sometimes fitted in short

lengths between the frames, and in other cases these strips are continuous. In the former system no liners are required between the plates and the frames, and in the latter the whole of the frames have to be linered. Notwithstanding this objection, the continuous edge strips are to be preferred, especially in small vessels with thin plating, for by the other method there is always a risk of leakage occurring where the plate edges cross the frames, and this can be prevented only by planing the ends of the edge strips and fitting them closely against the sides of the frame angle irons. When this is done, by carefully fitting the plate edges and caulking them, watertight work will be obtained.

The riveting of the edge strips will be single or double, just as the requirements of the case would determine, supposing lap joints were adopted. It will therefore be seen that a much greater number of rivets is required by the flush system, and that the quantity of material in the plating is greater than by the ordinary methods, for the edge strips are double the width of the ordinary plate laps, and have twice the number of rivets in them. The weight of materials is still further increased by the additional liners required when continuous edge strips are used.

There can be no doubt that the edges of the plating, when well fitted, afford much support to the riveting in resisting shearing stresses, but as the work of fitting is very difficult, it too often happens that the joints are closed by the caulking tool only. On the whole, therefore, this system is not to be recommended upon any other grounds than that of the smooth appearance it gives to the outer surface of the plating, and this is a consideration which operates only in vessels built for pleasure.

111. Lamb's System is the name sometimes given to a mode of plating very similar to the preceding, the difference between the two being found in the fact that in this system the edge strips are fitted on the outside of the plating, the inside surface of which is therefore flush. No liners are required between the frames and the plating when the latter is arranged in this way. When the edges of the adjacent strakes are closely fitted against each other they afford valuable succour to the edge riveting in resisting shearing stresses, in the same way as was described when referring to the system just noticed. But as water-tightness is obtained by caulking the edges of the edge strips, the shipbuilder has not the same inducement to carefully fit the edges of adjacent strakes as when the outside surface of the plating is flush. Hence the flush system is to be preferred to Lamb's upon that account. On the other hand, by fitting the edge strips on the outside, they can be made continuous without necessitating the great weight of liners required by the flush system when the edge strips are continuous. The cost of riveting by both methods is however much greater than by the ordinary clencher system of plating, and if the plates are well fitted at the edges the cost of plating the vessel is also greater. This method has been somewhat extensively adopted of late in large ocean steamers.

112. The Clencher System.—The ordinary method of arranging the strakes of plating upon the bottom and sides of iron and steel vessels is distinguished by the above designation, which, however, is also applied to a variation of the system that is now rarely met with except in very old ships. This variation was copied from the well-known mode of fitting boat's planks, the lower edge of each strake overlapping the upper edge of the next lower strake. The chief objection to this description of clencher plating is found in the necessity for tapering the liners between the plates and the frames. Not only is additional expense involved in the preparation of tapered as compared with parallel liners, but experience shows that the tapered liners are not, as a rule, so well fitted as those which are required to be of parallel thickness.

The commonly practised form of the clencher system of plating is sometimes described as the "raised and sunken plate system." Examples of it are to be seen in the several sketches of midship sections shown in Plates II., III., IV, and V. The edges or "laps" are single riveted in small vessels, but otherwise they are double riveted, and the butts are either double or treble riveted, the "chain" system of riveting being almost invariably adopted. The butt straps are fitted on the inside of the vessel, those of the inside strakes extending the entire breadth of the plate, and those of the outside strakes fitting closely against the edges of the adjacent outside strakes.

113. Thicknesses of Shell Plating.—The thicknesses of the several strakes of plating in classed vessels are determined by the second or plating number, subject to certain additions in large vessels, cases of extreme proportions, and in the vicinity of breaks or considerable deck erections. The plating number fixes the thickness for one half the vessel's length amidships, subject to the above named modifications, and a reduction in thickness is allowed in some cases towards the extremities. The thickest plates in the bottom and sides are the garboard and sheer strakes, these being at the upper and lower sides of the girder which the entire structure may be assumed to represent. Between these two extremes, the plates are in many cases varied in thickness, the scantlings given upon the table in Lloyd's Rules, being a foundation upon which the several additions, due to the dimensions and proportions, are built. The thickness of tbe sheer strake and garboards stated upon the table are likewise a foundation upon which additional thicknesses are laid in certain cases. It will be convenient to consider these several strakes in detail.

114. The Sheer Strake is, as already mentioned, the uppermost strake of the shell plating, and is therefore adjacent to the upper deck beams and stringer plate, forming, in conjunction with the latter and its angle iron bars, a rigid girder-like arrangement at that part of the vessel where hogging and sagging moments are first experienced.

The special cases of spar-decked vessels with their sheer strakes will be the subject of separate consideration hereafter.

Starting with the breadth and thickness of sheer strake determined by the plating number according to Lloyd's Rules, it may be remarked that these are considered sufficient for all vessels under eleven depths in length, the depth in this case being measured from the top of keel to top of upper deck beams.

When the vessel is between eleven and twelve depths in length, the thickness of the sheer strake is increased $\frac{1}{20}$ inch for three-fourths her length amidships, when her plating number is under 18,700. Between 18,700 and 26,000, an additional thickness of $\frac{1}{20}$ inch is required for the three-fourths length; and from the latter number to 35,000 the strake below is also increased $\frac{2}{20}$ inch for half the length amidships.

Let us next consider the requirements when the proportions are about 12 and not exceeding 13 depths in length. In this case the sheer strake is increased $\frac{2}{16}$ of an inch for three-fourths the vessel's length amidships, until the number 10,450 is reached. Between 10,450 and 18,700 the strake below is also made $\frac{1}{20}$ inch thicker for half the length, and from 18,700 to 26,000 both sheer strake and strake below are made $\frac{2}{20}$ inch thicker than is stated in the Tables for plating for three-fourths and one-half the vessel's length amidships respectively. When the plating number in a vessel of these proportions is between 35,000 and 40,000, the sheer strake is required to be doubled for its whole width below the stringer plate through three-fourths her length amidships.

This is not the place in which to state in detail all the requirements of Lloyd's Rules for the plating of classed vessels; sufficient has, perhaps, been said to show the value which is attached to extra scantling at this part of the shell of a vessel, in order to enable her to endure the additional stresses due to increase in size and in proportion of length to depth.

Having particularised, however, the additions to the sheer strake and strake below, which are required for vessels of from 11 to 13 depths in length, it may be of interest to compare these with the other extreme of the extra proportion scale, viz.—that of between 15 and 16 depths in length.

In this case, vessels with a plating number under 15,500 are to have their sheer strake doubled, for its entire width below the stringer plate, with doubling of the thickness of the strake next below it, this to be extended for three-fourths the vessel's length amidships. When the plating number is between 15,500 and 18,700, the strake below the sheer strake is increased $\frac{2}{20}$ inch in thickness for one half the vessel's length amidships, and in addition to the sheer-strake doubling, the strake next below is to be doubled its entire breadth throughout three-fifths of the vessel's length, when the number is between 26,000 and 35,000.

Finally, when the number is from 35,000 to 40,000, and the vessel has the before-mentioned proportions of length to depth, the sheer strake and two strakes below it are to be doubled for three-fourths, three-fifths, and one-half the vessel's length amidships respectively.

115. Bilge Plates.—The plating of a ship's bottom at the curvature of the bilge is, under many conditions in which she may encounter stresses, of considerable structural importance. For, while the sheer strake is at the greatest upper limit of distance from the neutral axis, the plating at the flat of bottom and turn of bilge is at, or about, the greatest lower limit, and consequently subject to considerable extensive and compressive stresses. Moreover, the bilge strakes of plating are situated at the extremities of the floor plates, where the frames and reverse frames meet and are riveted together, and where there is in conseqnence a break in the continuity of the transverse strength. The discontinnity is much greater in the framing of vessels fitted with ballast tanks or cellular double bottoms when the frames and reverse frames are cut as in the M'Intyre and similar systeus. In such cases it is obvious that the bilge plating affords the most important transverse connection to the several parts, notwithstanding the special precautions observed in fitting bracket plates riveted as strongly as possible to the margin plates. But, under any circumstances, the stresses at the bilges of a laden vessel are considerable, and it is therefore necessary that in large or long vessels additional strength should be afforded thereat, as compared with portions of the structure nearer the neutral axis.

Lloyd's Rules, consequently, make provision for these requirements, either by fitting thicker bilge plates or by the introduction of intercostal plates at the bilge keelsons, and sometimes by combining the two. Further support is afforded to the bilges in some cases by increasing the efficiency of the butt straps. The keelsons have already been considered, and the shell plate butt straps will come under notice later on.

Considering the case of sailing ships first, these Rules require three strakes of plating at the bilges to be increased in thickness one-twentieth of an inch throughout when the plating number is 16,000 or above, and it may be remarked that when that number is 22,000 and above, the strake of plating in the way of the hold beams is increased one-twentieth of an inch in thickness for one half the vessel's length amidships. The reason for this special provision in the case of sailing ships may doubtless be found in the peculiar stresses communicated to the hull by the rigging, which, in wood sailing vessels, leave that distinct indication of strain so often to be seen in the alteration of their sheer. These extra thicknesses of bilge plating are required for sailing vessels when under eleven depths in length; but as such vessels rarely, if ever, exceed these proportions, it is not necessary to particularise the additions at the bilge required when these proportions are exceeded. So far as Lloyd's Rules insist upon extra bilge plating in cases of extreme proportions, it may be assumed that they relate to steamers.

For one and two decked steamers under eleven depths in length, measured from the upper part of keel to the top of the upper deck beam amidships, and for three decked steamers of the same proportions, but measuring the depth to the top of the middle deck beams, no extra strength at the bilges is required.

Measuring the depth as just described, Lloyd's Rules require one strake of plating at the bilges to be one-twentieth inch thicker than stated upon their Tables for half the length amidships when the vessel is between eleven and twelve depths in length, and her plating number is under 18,700. Two strakes are similarly increased when the number is between 18,700 and 26,000, but when the number is higher than 26,000, the additional strength at the bilges is furnished in the form of an intercostal bilge keelson. The same principle is observed in cases of higher proportions, but it is not necessary to further specify these requirements.

116. The Tapering of the Plating towards the extremities is modified according to the situation of the strake and its thickness amidships. For instance, strakes of less than $\frac{6}{20}$ in. amidship are not tapered at the bow and stern, and in screw steamers whose plating number is 16,600 (rather more than 1000 tons under deck), the after hoods attached to the stern frame are retained the same thickness as the midship plates of the strakes. The same precaution is observed in regard to the garboard and boss plates of *all* screw steamers. It is scarcely necessary to call attention to the wisdom of these regulations, considering the extent and nature of the stresses at the after part of such vessels. Indeed, so much importance is attached to the structural value of the plating in the neighbourhood of the stern frame, that when the plating number is 13,900 and under 18,700, the boss plates are required to be $\frac{1}{20}$ inch thicker than the plates in the corresponding strake amidships. Further, when the number is 18,700 and under 26,500, the plates are not only $\frac{1}{20}$ in. thicker than amidships, but their butts are treble riveted. In larger vessels the boss plates and the plates above and below them are $\frac{2}{20}$ of an inch thicker than the midship plating, and their butts double strapped, or lapped and treble riveted, or the boss plates are doubled.

Other special provisions for the diminution or increase of the thicknesses of the plates in the several strakes are made in these Rules, the particulars of which need not further be noticed.

Before concluding these remarks upon the thickness of shell plating, it is, however, necessary to mention that in arranging the scantlings for ships of different sizes, the Committee of Lloyd's Register have graduated them in the following manner. For instance, a vessel whose plating number is between 2600 and 3300 to class 100A should have strakes of plating alternately $\frac{5}{20}$ in. and $\frac{6}{20}$ in. in thickness. When the number is between 3300 and 4200, all the strakes are $\frac{6}{20}$ in.; between 4200 and 5100 one bilge strake is increased to $\frac{7}{20}$ in., and between 5100 and 6000 the strakes are alternately $\frac{6}{20}$ inch and $\frac{7}{20}$ inch in thickness. In these cases of unequal thickness, the outer strakes of plating are the thicker of the two, because they are more exposed than the inner strakes to wear and tear and to injury.

117. Breadths of Strakes of Shell Plating.—In the early days of iron shipbuilding, both the lengths and the breadths of plates were limited by the capabilities of the iron manufacturer. At the present day iron and steel plates can be produced so wide that it has been necessary to insist upon certain limitations of breadth in the interest of structural efficiency, or else to provide superior butt connection. It will be readily seen that by widening the plates the number of lap joints in the girth of a vessel may be diminished, and at the same time the weight of hull and expense of riveting. But, from a structural point of view, it is undesirable to unduly widen the plates on a ship's bottom and sides; for it will be observed that every lap joint is a source of stiffening to the plating in consequence of the thickness of the material at that part. It cannot be doubted that the great strength displayed by many of the early iron ships is largely due to the narrowness of their strakes of plating, and consequent number of lines of stiffening afforded by the laps, to say nothing of the greater transverse sectional area of the plating, even after allowing for the rivet holes. The support thus rendered has been sufficient to compensate for faults in the structure which have been made apparent by later experience and therefore avoided.

In H.M. ships wider plates are used than in the mercantile marine, the object being to minimise as much as possible the weight of the hull proper, and so leave the largest possible portion of the displacement available for carrying armour plates, guns, coals, etc.

The requirements of commerce render it necessary, however, to insist upon a greater stiffness in the bottom plating than is provided in most ships of war.

When plates forming the outside strakes of plating of steel vessels are above forty inches but not exceeding forty-six inches, or those forming the inside strakes are forty-eight inches and not exceeding fifty-four inches, Lloyd's

Rules require their butts to be treble riveted with straps $\frac{1}{20}$ of an inch thicker than the plates they connect. When the butt straps of such strakes are required to be treble riveted in consequence of the size of the vessel, then they are still to be of this increased thickness except when the straps are otherwise required to be $\frac{4}{20}$ inch thicker than the plates. When for special reasons broader plates are required, the sanction of the Committee must be obtained. It will be observed that a greater breadth is allowed to inside than to outside strakes in order to provide for the general desire to make the apparent breadths of the strakes equal, as seen from the outside of the vessel.

The manner in which Lloyd's Rules provide for the cases in which wide plates are employed in the bottoms and sides of ships, is suggestive of another structural objection to the widening of the strakes besides that to which reference has already been made. It is impossible to make any riveted connection equal in tensile strength to the parts joined, and consequently every butt is a place of relative longitudinal weakness in the strake. By widening the strakes we increase the lengths of these lines of relative weakness in transverse sections of the vessel, and therefore render it more than ever necessary to make the butt connections as efficient as possible.

The minimnm breadths of sheer strakes and garboard strakes are fixed by Lloyd's Rules; for as these strakes are thicker than the others, it is necessary in forming any regulations for the scantlings of a ship to ensure that the additional thickness required at these parts shall be extended over a sufficient portion of her transverse girth.

118. Shifts of Butts.—The relative weakness of a butt connection, as compared with the remainder of a strake of plating, makes it important to so arrange the butts of the plating as to minimise their effect upon the strength of the entire structure. The shell plating of a vessel is butted at about midway between the transverse frames, in order to obtain space for fitting the butt straps, which are placed on the inside surface. The lengths of the plates are, therefore, multiples of the frame spacing.

In the early days of iron shipbuilding, the dimensions of plates, as already remarked, were limited by the capabilities of the iron manufacturers, so that it was not unusual to fit them in lengths of six or seven feet. Under such circumstances what is termed a "brick shift" was very common; that is to say, the butts of alternate strakes were fitted opposite the middle of the length of the plates in the intermediate strakes. This is not a satisfactory arrangement, as it produces transverse sections of considerable relative weakness at the butts. Indeed one half of each of such sections will consist of butts when this arrangement is adopted.

More recent developments in iron and steel manufacture have resulted in the production of plates quite as long as can be conveniently handled by the shipbuilders, and even longer. The usual length of plate now used is seven times that of the frame space, but sometimes, and especially in small vessels, eight and nine frame space, or even greater, lengths are wrought.

It need scarcely be pointed out that the use of long plates is conducive to a satisfactory arrangement of butts. There are, however, certain considerations, to be presently attended to, which do not point to the desirability of increasing the number of "passing strakes" between consecutive butts in the same transverse sections, beyond that which results from a five or six frame length of plate.

Lloyd's Rules insist upon shell plates being not less than six spaces of frames in length, and further stipulate that the butts in adjoining strakes shall not be nearer each other than two spaces of frames, also that the butts of alternate strakes shall not be under each other, as in the brick shift, but be shifted not less than one frame space. The butts of the sheer strake are to be shifted two spaces of frames clear of the butts of upper, main, and spar deck stringer plates, and the butts of the garboard strakes on opposite sides of the vessel are not to be nearer to each other than two spaces of frames, while in both cases these garboard butts are to be kept clear of the keel scarphs.

Plate XXVIII. shows various shifts of butts which either have been or are still adopted for the shell plating of ships. Fig. 1 represents the brick shift to which allusion has been

made. Fig. 2 is a five-frame shift which formerly satisfied Lloyd's Rules. Fig. 3 is a six-frame shift, such as is often adopted in mercantile ships, and fig. 4 is the more general seven-frame shift.

In the arrangement shown by fig. 1 there is only one passing strake between consecutive butts in the same transverse section, and consequently, as already remarked, there are, at alternate frame spaces, transverse sections of which a half consists of butts.

In the five frame space shift, shown by fig. 2, there are four passing strakes between consecutive butts in the same transverse section, and consequently one-fifth of the area of plating in that transverse section consists of butts.

The six and seven frame shifts, shown on the Plate by figs. 3 and 4, are such as are usually employed. Their efficiency is about the same as that of the five frame space shift, there being four passing strakes between consecutive butts in the same transverse section. The number of these passing strakes might be increased to five and six respectively if thought desirable, but in so doing a "step" arrangement of butts would be produced which is in many respects objectionable.

In considering the efficiency of a shift of butts of shell plating, two very important considerations should be borne in mind.

The object of shifting the butts is not only to obtain a maximum of effective sectional area of plating in each transverse section of the vessel, but also to equalise the strength, so that no one section shall be much weaker or stronger than any other. There are, of course, certain sections of the shell plating of the vessel which are of necessity weaker than the remainder—these being the sections through the frame rivets and the butts; and the object of the shipbuilder should be as much as possible to equalise the strength of these. Now the effective sectional area of the plating through a line of transverse frame rivets may be taken as a standard with which to compare the effective areas and the strengths of other sections. The strength of this section cannot be increased without fitting wide liners or doubling plates, as is done at the bulkheads, or increasing the spacing of the frame rivets, which is undesirable. Hence it is not necessary to make the strength through a section at the butts any greater than this fixed quantity. But in estimating the strength of an individual butt connection (except that of a sheer strake), we must not neglect the support which is given to the butt by the edge riveting above and below it. Hence, although the efficiency of the butt strap taken by itself may be only sixty per cent., yet when the support of the edge riveting is added thereto, the loss of effective sectional area due to the butt is considerably diminished. It will therefore be seen that a five frame space shift, with four passing strakes between consecutive butts in the same transverse section, will yield a not less effective area of plating at that section than is provided at a frame section of the vessel.

119. Stealers.—The girth of a vessel amidships, measuring from the keel to the upper deck stringer, is almost always very much in excess of that at either the forward or aftermost extremities, and consequently if all the strakes of plating amidships be extended to the stem and stern post their breadths must be diminished. In vessels of ordinary proportions of breadth to depth, and with midship sections of the usual form, the difference in the girths is not so great as to result in an undue narrowness of the strakes at the extremities. But when the vessel is very broad in proportion to her depth, or when the midship section approximates closely to a rectangular form, the difference in the girths is so great as to render it necessary to reduce the number of strakes at either one or both of the extremities. In this case one or more of the strakes of plating will be terminated at some distance from the bow or stern, by merging two strakes into one where the termination occurs. Where this branching of the strakes occurs a "stealer" is said to be wrought, this term having perhaps been originally applied because a strake is there stolen from the number which elsewhere existed.

A sketch of a stealer in the after body is shown by fig. 21, where strakes F and G are merged into the single strake F G.

The arrangement of plating in this case shows that

another stealer had previously occurred nearer towards midships than the one shown, for the alternation of inner and outer strakes has been broken, as will be seen by the laps of strakes F and G. The stealing of another strake has restored the alternation, as shown by strakes E, F G, and H. For a short distance before the strakes F and G terminate at the butt S, their edges in contact are thinned and halved together until at S their united thickness is equal to that of the plate F G. By this means a flush surface is formed on the inside of the vessel, so that the one butt strap serves to connect the three plates. This strap should extend from frame to frame and be additionally riveted.

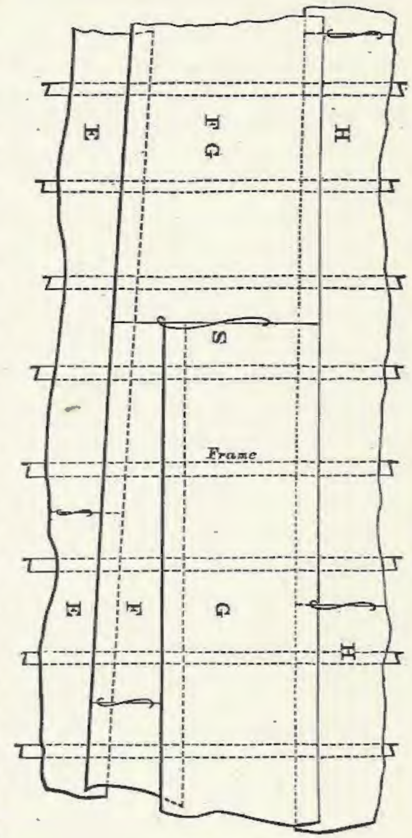


Fig. 21.

120. Preparation of Edges and Butts.—To obtain sound, well fitted, and finished work in the plating of a vessel, it is necessary that the edges of outer strakes and the butts of all strakes should be planed. Further than this, the edges of inside strakes of plating should be sheared from the faying surfaces, in order that the laps may fit perfectly close. If this latter precaution is not taken it becomes necessary to carefully chip off the burr produced by shearing. Indeed in all cases of lapped joints, or when angle bars are riveted against the edges of plates, as, for instance, those of floors, etc., care should be taken to so shear the plates that the surfaces in contact may be flat and free from burrs.

By planing the edges of outer strakes a better finish is given to them than by chipping, unless the latter be performed with more than ordinary care. But when the edges are planed, it is important to line them correctly, so that those of adjacent plates in the same strake may exactly correspond in breadth at their butts and lie in a fair curve. If this is not done, it becomes necessary to reconcile them by chipping. In every case either chipping or planing or both must be resorted to, as it would be difficult to obtain satisfactory caulking at the laps if the plate edges were rough from the shearing machine. Some remarks regarding caulking will be made later on (see Art. 137).

In the earliest iron ships the butts were fitted by chipping and sometimes by "jumping." A "jumped butt" is prepared by hammering the butt until it is straight and square to the surface. A burr is thereby produced on both edges of the butt, and the inner burr is chipped off in order to fit the butt strap, while the burr on the outer edge is allowed to remain. After the butt is riveted the burr is hammered over and the butt caulked; the surplus material in the burr being removed by chipping. The disturbance in the fibrous structure of the iron, produced by "jumping" the butt, is found to induce rapid corrosion, so that jumped butts are liable to waste rapidly, and thereby require frequent "stopping" when the vessel is docked for painting. It is worthy of remark, here, that in any case of a butt of bottom plating showing dampness upon a vessel's return from a voyage, it is improper to caulk it, as frequent caulking leads to rapid corrosion from the same causes as already stated. A careful cleaning with a wire brush, and subsequent stopping with a well-known cement used for the purpose, is the best remedy in such circumstances.

Butts should be planed and closely fitted in the first instance, so that caulking may be rather a precautionary measure than one of necessity. If butts are planed and their surfaces are in contact before the plates are riveted

the process of riveting will cause a sufficient amount of stretching in the plates to make a watertight joint. The caulking required in such a case is very slight and not destructive in its after effects.

121. Edge Riveting.—In the early days of iron shipbuilding zig-zag riveting was commonly employed for double riveted laps, and for all butts of shell plating. This practice has long since been almost wholly discontinued, and Lloyd's Rules now require that the butts shall be chain riveted, as shown by figs. 5, 6, and 7 of Plate XV. In regard to edge riveting these Rules recommend the chain system when a double row is required, but do not insist upon it.

The chain arrangement of rivets is, for the following reasons, the most likely to result in an efficient connection of the laps of shell plating.

I. When the zig-zag system is employed, it is difficult, and indeed practically impossible, to prevent occasional edge rivets from breaking into a butt, whereas with the chain system this can only happen through carelessness.

II. As only one frame rivet passes through the lap of the plating, and that always on the caulking edge of the lap, it consequently happens that the zig-zag arrangement is broken at every frame space, and between each pair of consecutive frames there is one more rivet on one edge of the lap than there is on the other edge. When the chain arrangement is adopted there is the same number of rivets on both edges of each lap between consecutive frames, and that number is the maximum possible for the spacing of rivets employed. In other words, there are more rivets in the lap with chain than with zig-zag riveting.

Lloyd's Rules require that the landing edges of shell plating, when seven-twentieths of an inch in thickness and above from the keel to the upper turn of bilge and of the sheer strake, and when nine-twentieths of an inch and above from the upper turn of bilge to the gunwale, must be double riveted; below these thicknesses the edges may be single riveted. In all cases the thicker of two plates is to regulate the requirements of their landing edge connections, and when the plating is of a thickness amidships to require the edges to be double riveted, the same is to be continued fore and aft.

The considerations which fix the diameters of the rivets and other matters in connection with the question of riveted joints will be discussed at a later stage of this Work (see Chap. XII.). It will be sufficient now to indicate the general practice in regard to the spacing of rivets, and the breadths of the laps of shell plating.

Lloyd's Rules upon this, as upon most other details in iron and steel shipbuilding, are the almost universal practice of the country.

The breadths of the laps are not less than six times the diameter of the rivets when double chain riveting is adopted, and for single riveting the overlap is not less than three and a half times the diameter of the rivet. *

These breadths are determined by the two following essential conditions for sound and good riveted connections.

I. The rivets must not be nearer to the edge of the plating than a space equal to their own diameter, as otherwise the resistance of the plating to shearing would be less than that offered by the rivets.

II. The space between any two consecutive rows of rivets must not be less than once and a half their diameter, for the same reason as just stated, and in order that the structure of the iron may not be seriously impaired by the process of punching. *

The rivets in landing edges of shell plating are spaced from four to four and a half diameters apart, from centre to centre, and this spacing should not be exceeded in any case when plates are riveted together and the riveted work is afterwards to be caulked.

The number of rivets in the landing edges between consecutive frames will evidently be determined, within certain limits, by the spacing apart of the frames. For this reason Lloyd's Rules contain a tabulated statement of the number of rivets of each description which should be placed in a row of edge riveting between the various spacings of frames at amidships. This Table is given on the opposite page, and as will be seen it provides for all sizes of rivets between $\frac{5}{8}$ inch and 1 inch in diameter, and

SHOWING DIAMETERS AND SPACING OF RIVETS AND BREADTHS OF STRAPS AND LAPS.

	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins	Ins.	Ins.	Ins.	Ins.
Thickness of Steel Plates	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{6 \& 7}{20}$ alter'ly	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{20}$	$\frac{9 \& 10}{20}$ alter'ly	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{12 \& 13}{20}$ alter'ly	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{15}{20}$	$\frac{16}{20}$
Diameter of Rivets	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	1	1	1
Breadth of Treble riveted Straps	—	—	—	—	$14\frac{1}{4}$	$14\frac{1}{4}$	$14\frac{1}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	19	19	19
" Double " "	8	8	$9\frac{3}{4}$	$9\frac{3}{4}$	$9\frac{3}{4}$	$9\frac{3}{4}$	$9\frac{3}{4}$	$11\frac{1}{4}$	$11\frac{1}{4}$	$11\frac{1}{4}$	$11\frac{1}{4}$	$11\frac{1}{4}$	—	—	—
" Treble " Butt laps	—	—	—	—	$7\frac{1}{2}$	$7\frac{1}{2}$	$7\frac{1}{2}$	9	9	9	9	9	$10\frac{1}{2}$	$10\frac{1}{2}$	$10\frac{1}{2}$
" Double " "	$4\frac{1}{4}$	$4\frac{1}{4}$	5	5	5	5	5	6	6	6	6	6	—	—	—
" Double " Laps	$3\frac{3}{4}$	$3\frac{3}{4}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	6	6	6
" Single " "	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{4}$	—	—	—	—	—	—	—	—	—	—
Maximum Spacing of Rivets from centre to centre — in Butts of outside plating ...	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{5}{8}$	$2\frac{5}{8}$	$2\frac{5}{8}$	$2\frac{5}{8}$	$2\frac{5}{8}$	$3\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{1}{8}$	$3\frac{1}{2}$	$3\frac{1}{2}$	$3\frac{1}{2}$
" in Edges " " ...	$2\frac{3}{4}$	$2\frac{3}{4}$	$3\frac{3}{8}$	$3\frac{3}{8}$	$3\frac{3}{8}$	$3\frac{3}{8}$	$3\frac{3}{8}$	4	4	4	4	4	$4\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{2}$
" in Frames, Reverse Frames, Floors, Keelsons, and Beam Angles.	$4\frac{1}{2}$	$4\frac{1}{2}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{4}$	$6\frac{1}{4}$	$6\frac{1}{4}$	$6\frac{1}{4}$	$6\frac{1}{4}$	7	7	7

MINIMUM NUMBER OF RIVETS IN EDGES OF PLATING BETWEEN FRAMES AMIDSHIPS.

Diameter of Rivets	Number of Rivets in Each Row.														
	Ins. 5/8	Ins. 5/8	Ins. 3/4	Ins. 3/4	Ins. 3/4	Ins. 3/4	Ins. 3/4	Ins. 7/8	Ins. 7/8	Ins. 7/8	Ins. 7/8	Ins. 7/8	Ins. 1	Ins. 1	Ins. 1
Spacing of Frames ... ... 20 ins. ...	7	7	5	5	5	5	—	—	—	—	—	—	—	—	—
" " ... ... 21 " ...	—	7	6	6	6	6	6	5	5	—	—	—	—	—	—
" " ... ... 22 " ...	—	—	6	6	6	6	6	5	5	5	5	5	—	—	—
" " ... ... 23 " ...	—	[redacted]	[redacted]	[redacted]	[redacted]	6	6	5	5	5	5	5	5	5	5
" " ... ... 24 " ...	—	—	7	7	7	7	7	6	6	6	6	6	5	5	5
" " ... ... 25 " ...	—	—	—	—	—	—	—	6	6	6	6	6	5	5	5
" " ... ... 26 " ...	—	—	—	—	—	—	—	—	—	—	6	6	5	5	5

for all spaces of frames between 20 inch and 26 inch inclusive.

The spacing of the edge rivets in any case may be computed from this Table by dividing the frame spacing by the number of rivets plus one. For instance, consider the very common case of a 24 inch frame space and a $\frac{7}{8}$ inch rivet. The Table shows six rivets *between the frames*, and therefore upon dividing twenty-four by six plus one, *i.e.*, seven, we have three and three-sevenths of an inch which is the distance from centre to centre of the edge riveting amidships. This space is about four times the diameter of the rivet.

122. Butt Straps.—The connection of the butts of shell plating is made by straps fitted on the inside of the vessel, and either double or treble riveted. The butt straps extend the full breadth of inner strakes, and those to outer strakes are fitted between the edges of consecutive inner strakes. The thickness of the butt straps to the greater part of the shell plating of small vessels is the same as that of the plates they connect. But for the sheer strake and one or more bilge strakes the straps are usually rather thicker, and in large vessels all the butt straps to the shell plating are thicker than the plates they connect, even to the extent of $\frac{4}{20}$ of an inch when of steel, and $\frac{2}{16}$ of an inch when of iron. This attempt to obtain greater efficiency in the butt connections is supplemented, in all but small vessels, by employing treble riveting and sometimes by double straps.

As already remarked, Lloyd's Rules require all butts to be chain riveted, and this course is now universally adopted. Figs. 5, 6, and 7 of Plate XV., show the arrangements of rivets in single, double, and treble riveted butt straps. Alternate rivets are often omitted in the row furthest from the butt on each side in treble riveted straps as shown by fig. 7 of this Plate, but more frequently the back row is spaced $5\frac{1}{4}$ diameters apart for greater efficiency.

The table given upon the preceding page shows Lloyd's requirements as regards the breadths of butt straps for steel ships, and the spacing of rivets in them. In such vessels the rivets of the butts of outside plating and deck stringers should not be spaced more than three and a half diameters apart from centre to centre. The breadth of the butt strap is determined by similar considerations to those which fix the breadth of the plate lap, but the space between the columns of rivets is increased from once and a half to two diameters of the rivet. This precaution is very necessary, as the puncturing of the butt strap is considerable, and calculated to damage the materials of which it is composed, especially if the rows of rivets are very closely spaced.

This deterioration is particularly exhibited in the case of steel butt straps of above half an inch in thickness, which, through molecular changes set up in punching, lose a great part of the natural ductility and tenacity of the mild steel of which they are composed. Fortunately this can be almost, if not entirely, restored by subsequent annealing or rimeing, one of which courses, preferably the former, is always resorted to before the strap is riveted.

In fitting butt straps to outside strakes of plating, it is particularly desirable to fit them *closely* against the edges of the adjacent inside strakes, in consequence of the support which these straps afford to the edge riveting under such circumstances. Formerly it was the practice to extend these straps and joggle them over the laps above and below, so as to receive edge rivets on each side of the butt, but this course has long since been discontinued.

The manner of fitting butt straps to sheer strake plates should be separately noticed. The stringer plating of the upper deck is connected to the sheer strake by a gunwale angle iron, as shown upon Plate XXIII., and it is in consequence of this arrangement that a difference in the mode of fitting the butt straps to that strake is sometimes observed. According to one method, which is undoubtedly the best, the sheer strake is made an outer strake, and its butt straps extend to the gunwale. Between the butt straps lining pieces are fitted of the breadth of the gunwale angle bar and of the thickness of the butt straps. In this way a flush surface is provided against which to fit the gunwale angle bar; the latter is then riveted to the sheer strake and stringer, and the whole carefully caulked. The same course may be adopted when the sheer strake is an inner strake, by scoring the stringer plate over the sheer strake butt straps, and making the stringer correspondingly wider to allow for the weakening at the scored places.

These butt straps of sheer strakes are, however, more frequently fitted in two breadths, one below and one above the stringer plate; but in that case the sheer strake should extend sufficiently high above the stringer plate to take two rows of rivets, vertically, in the butts, above the upper flange of the gunwale angle iron.

Before concluding our remarks upon butt straps, it is necessary to mention that they should be cut out of the rolled plate in such a way that the fibre of the material is in the direction of the fibre in the plates they connect.

123. Frame Riveting.—The spacing of rivets connecting the frames to the shell plating was much greater in the early iron ships than is now found to be essential to good workmanship. The same observation will apply to the spacing of the rivets connecting the frames with the reverse frames. It was probably considered that as a close spacing of rivets in the frames and shell plating would result in sections of weakness, it would therefore be advisable to make the connection between the frame and shell no greater than was absolutely necessary in order that the frames might develope the stiffening qualities desired of them. Experience with these old iron ships has shown that among other objections to the open spacing of frame rivets, is the very serious one of rapid and considerable oxidation between the surfaces, which are not in sufficiently intimate contact to prevent moisture from getting at and acting upon them.

The spacing of frame rivets now adopted is seven diameters, or as near thereto as can be arranged, having regard to the breadths of the strakes of plating. One frame rivet passes through each landing edge, and when there is a double row of rivets, the frame rivet is in the row nearest the caulking.

124. Punching and Countersinking.—The surface of the bottom plating should be as smooth as possible in order to avoid unnecessary friction when passing through the water, and that of the top sides should be finished in a similar manner for the sake of appearance. This is obtained by countersinking the rivet holes on the outside, and chipping the hammered points of the rivets flush, or nearly so, with the surface of the plating. It is not desirable to make the riveting perfectly flush, especially when the plates are thin, for a slight fulness, or rather convexity, of the clench adds to its strength without detracting much or at all from the vessel's appearance and speed. The countersinking of shell plating should extend throughout the entire thickness of the plate, and the angle of the countersink should be varied in accordance with that thickness. When the diameter of the clenched point of the rivet is much greater than that of the rivet itself, the countersink is said to be "bold." A thin plate requires a "bolder" countersink than a thick one; for with the same angle of taper, the excess of diameter on the outside over that on the inside of the plate is less in the former than in the latter. At the same time, it is necessary not to make the countersink too "bold," for in that case a form of weakness at the clenched point will be produced, and the strength of the rivet will be injuriously diminished. The countersink taper once varied very considerably in different shipyards, and the result of inquiries instituted into the subject about three years ago, showed that whereas some builders allowed three-eighths of an inch excess in diameter at the outside of countersink for 1 inch plates, others allowed no less than 1 inch excess. Between these two extremes there were nearly all possible shades of gradation, but the majority approached about midway between these two extremes in their practice. For plates of one quarter of an inch in thickness, the excess of diameter at the outside of the countersink varied from $\frac{2}{16}$ to [illegible]/16 inch, the usual practice being $\frac{4}{16}$. Lloyd's present requirements vary from $\frac{5}{16}$ inch for a $\frac{5}{8}$ inch rivet to $\frac{8}{16}$ inch for 1 inch.

A very satisfactory form of countersink was adopted by Messrs. Denny, the well-known shipbuilders of Dumbarton, and the proportions used by many other builders of repute were very similar to them. The following figures show Messrs. Denny's practice; the "angle of countersink" being that given to the drill with which the countersinking is performed, and therefore the angle at the apex of a cone which fits into the countersink when finished:—

Diameter of Rivet, - -	$\frac{1}{4}''$	$\frac{3}{8}''$	$\frac{1}{2}''$	$\frac{5}{8}''$	$\frac{3}{4}''$	$\frac{7}{8}''$	1″	$1\frac{1}{8}''$
Angle of Countersink, -	65°	65°	55°	55°	45°	35°	35°	35°

With regard to the rivet holes in the shell plating, it is sufficient to mention now that they are always punched from the faying surface, in order that they may be accurately filled by the rivets, which, as previously stated, are made of a conical form under the head (see fig. 6 on page 37). The enlargement on the outside due to punching will, of course, be further increased by the countersink drill.

125. Fore and After Hoods.—The rules which limit the lengths of shell plates do not extend to those which terminate upon the stem and stern posts, as it is evident that some of these must either be longer or shorter than the five frame space limit. At the extremities of the vessel, the structural strength, especially as regards the stresses due to bending moments, is not affected by a few short shifts.

The landing edges of the plates, where they terminate upon the stem and stern post, are chased or rabetted into each other, thinned and tapered, so that the inside surfaces of both outer and inner strakes are flush, and fit closely against the above named forgings. The rivets in the stem and stern post are of the same diameter as those in the keel, and the work is so arranged that one of these rivets may pass through a landing edge, and thereby bind the whole together sufficiently close to be caulked. At the after part of the vessel, especially in screw steamers, some of the "hoods" are much flanged and twisted, in order to form the boundary of the screw aperture and the under side of the counter. One of these plates on each side is known as the "oxter" plate, from its resemblance both in function and appearance to the piece of linen connecting the sleeve of a shirt on its under side to the body of that garment. The term "oxter" is an old English word, still used in the northern counties of England and in Scotland, meaning the arm-pit, and hence its application in this instance. It is important that these plates should be fitted accurately before being riveted, so as not to bring any undue initial strain upon the rivets which connect them to the stern post; for that strain will afterwards be much increased by the working of the propeller, etc., in a sea way. The countersinking of these plates should also be carefully attended to, and the rivet holes be reconciled through the two thicknesses of plating, one on each side of the stern post, and the stern post itself.

The special requirements in regard to careful fitting and riveting are equally applicable to the boss plating, and the remainder of the after hoods in screw propelled vessels.

126. Lining Pieces.—With every system of plating, except that known as Lamb's, which was described at 140— page 140, it is necessary to fit lining pieces or "liners" between the frames and a part at least of the shell plating. When the boat system of clencher plating is adopted, the liners are necessarily of wedge form; but with the alternate raised and sunken strake system, as commonly practised, liners are required between the frames and outer strakes only, and these are mostly of parallel thickness, or approximately so. When consecutive inner strakes are of different thicknesses, the liners to the intermediate outer strake will, of course, be somewhat tapered. In connection with flush shell plating, with edge strips on the inside of the vessel, it is desirable, and indeed usual, as already stated, to make these edge strips continuous, and not to fit them in short lengths between the frames. This course necessitates the fitting of liners throughout the vessel, between the frames and all the strakes of plating. These liners are parallel, except where the strakes are of unequal thickness, as in the case of the sheer and adjacent strakes, and then the liners are necessarily of tapered form.

Lining pieces behind frames are of the same breadth as the frames, except in the way of transverse watertight bulkheads, when they extend over rather more than two frame spaces, as described at page 130. All liners are solid, and should be carefully fitted, so as to completely fill the spaces between the frames and the plates. Special care is therefore necessary when they are required to be of

a tapered form, and no more than one thickness of liner should be allowed.

It sometimes happens that, through the unfairness of the frames, it is necessary to fit liner pieces between inner strakes of plating and some of the frames, but this can only occur through negligence in the processes of framing, and cannot he considered satisfactory, nor should it be allowed to any considerable extent.

127. Processes and Order of Work in Plating a Vessel.—The landing edges of the shell plating are got in upon the model, and the plates ordered therefrom as already explained. From the model they are copied upon the scrive board, and as each frame is bent and adjusted, the position of the plate laps which cross it are marked with notches.

When the vessel has been framed, ribbanded, and faired, the decks sheered in, and the beams riveted, also when the keelsons, bilge, hold and deck stringers have been riveted, the structure is in a fit state to receive the shell plating. It often happens that the bulkheads are well advanced, or even nearly completed when the process of plating commences.

128. Fairing Plate Edges.—The first step to be attended to is the fairing of the lines of the plate edges as marked upon the frames. Sheering battens are bent upon the outside of the frames for this purpose, with their edges approximating as closely as possible, consistent with fairness, to the marks upon the frames, to indicate the position of the laps. When these lines are got in, the position of the frame rivets which pass through the plate laps are set off upon the frame angle bars and either punched with a "bear" or drilled.

129. Garboards.—Unless they happen to be arranged as outside strakes, the garboards are the first plates wrought upon the bottom; otherwise a commencement is made with one of the inner strakes in the flat of the bottom. It need scarcely be remarked that the inner strakes must be in place before the adjacent outer ones can be fitted.

The garboards are flanged against the keel in all cases, except when the vessel has a flat plate keel, and they have therefore to be first heated and bent to their proper form.

The garboard plates of iron ships should be of extra ductile quality across the fibre, and when steel garboard plates are to be bent cold they should be slightly softer than is elsewhere used in the shell.

In taking account of a garboard plate, the workman prepares a set iron for each extremity of it. This set iron is made from the ship or the scrive board, and shows the angle between the frame and the bar keel at that place, together with the breadths of the two portions of the plate —the flat and the flanged. After being heated in a furnace, the plates are bent or flanged upon a solid block with a rounded edge prepared for the purpose, and are set to the angle or angles shown by the set irons. When bent and cooled they should be carefully examined, in order to ensure that no plates cracked at the angle may be wrought into the vessel.

130. Templating is a process devised for the purpose of avoiding the labour which would be involved in marking the rivet holes upon plates, angle bars, etc., by first holding them in the place where they are ultimately to be riveted. A template is, in fact, a transfer mould, and is used simply because a few fir battens nailed together are more conveniently handled than a heavy plate or bar. Fig. 22 shows an ordinary template used in the plating of ships. Other

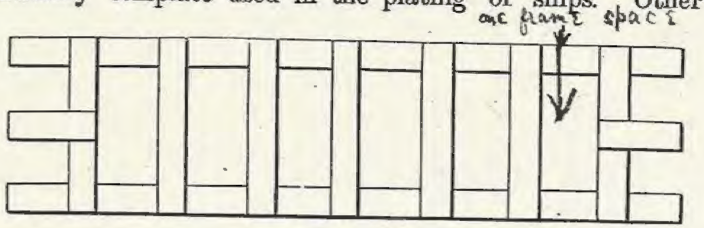


Fig. 22.

kinds of templates are required for other descriptions of work some of which have already been described. The process of plating a vessel is one which, however, brings the template into special requisition, and a description of its use in this department of shipbuilding will serve, with but few modifications, to explain templating generally.

131. Templating an Inner Strake.—Commencing with a plate in an inner strake of plating, we will suppose the

lines for its edges faired on the frame surface, and an adjacent plate in the same strake to be already fitted in place. The batten template, as shown in fig. 22, is then fixed against the frames by means of iron "clips" or "hutch hooks," and so held in position that its surface includes that which is to be occupied by the plate to be fitted, while each of the cross battens is on a frame. It should here be remarked that the spacing between these cross battens is equal to that of the frames of the vessel. The butt of the adjacent plate is then marked across the upper and lower fore and aft battens and the centre one; also the edges of the plate are marked upon the upper and lower battens. The rivet holes in the frames are next copied upon the cross battens by means of the usual cylinder of wood or tin dipped in whiting, and the line for the other butt is set off upon the battens at the corresponding end of the template, so as to be midway between the frames. If there are any intercostal keelsons, margin plates of water ballast tanks, or stringers in the way of the plate, the positions of the rivet holes in their angle irons must be copied upon a piece of batten nailed to the template for the purpose.

All these holes are punched from the inside, or faying, surface of the plate, and therefore the template is laid upon that surface, so that the lines and rivet hole marks may be copied upon it.

In transferring the positions of rivet holes, from the template to the plate, the following expedients are usually adopted:—The template is first laid accurately upon the plate so that all the marks upon the former may be included in the surface of the latter, and the two are then joined by "clips" or "hutch hooks" at the edges. This being done, and the plate being proved to be in every way fitted for the place where it is required, the clips on one edge are removed, the template slightly lifted, and the position of the rivets copied upon the plate by means of a "marker" or "reversing tool," as shown by fig. 23. (In some shipyards blocks are placed between the template and plate as shown in this figure). This is done by dipping the projection A in whiting, and then holding the reversing tool as shown; the hole B being immediately over the whiting mark which indicates the rivet in the template. Then, by pressing the lower fork, or, indeed, the template and marker, down upon the plate, a circular mark is made, which, when punched out, gives the rivet hole in its correct position.

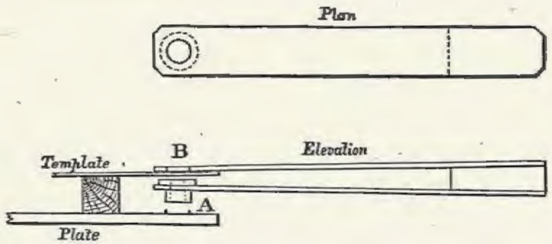


Fig. 23.

It should be remarked here that in some yards a reversing tool is frequently, or entirely, dispensed with, and instead of copying the positions of rivet holes from the template upon the plates in that way, a sharp centre punch is held over the centre of the mark for the rivet on the wood template, whereupon a smart blow from a hammer drives it through the wood, so as to make a mark upon the plate. The rivet holes are then set off upon the plate by means of a hollow tin cylinder, dipped in whiting, and held with the centre of the cylinder as nearly as possible upon the punch mark on the plate. Although satisfactory results may be obtained in this way by practised workmen, yet, on the whole, the before mentioned method of copying is much to be preferred.

The rivet holes for the butts are lined off and spaced upon the inside surface of the plate. The arrangement of rivets in each row of the butt which is adjacent to the plate being fitted, is copied upon a stick and so transferred to the lines for the butt fastenings of the last named plate. This precaution is observed in order that the rivets on both sides of the butt shall approximately correspond.

When these things have been done the rivet holes are punched.

The plate is then turned over and the edge rivets are lined in and spaced between the frame rivets, whereupon

these holes are punched from the outer, which in this case is the faying surface.

The butts are planed and the edges sheared to the lines marked upon the plate from the template, after which the plate is ready for fairing, bending or twisting in the rolls—a process to be described hereafter.

132. Templating an Outer Strake.—Some shipbuilders do not template outer strakes of plating, but having bent or twisted the plate to its required form they fix it in place, and so mark its butts, and transfer upon it the positions of the rivet holes in the edges of the adjacent inner strakes and those of the frames.

The usual practice is, however, to work with a template, and experience shows that in the hands of good workmen the most satisfactory results are thus attained.

A similar template is used, as already described, but in addition to the frame rivet holes, the holes already punched in the edges of the adjacent inner strakes have now to be copied upon the template. Moreover, the positions of the edges must be carefully marked so that they may be planed fair and correspond with the lines sheered upon the frames. All the rivet boles in an outer strake plate must be punched from the inner surface, and therefore the plate is templated upon that surface. The butts are marked in the manner already described, care being taken to arrange that they shall pass midway between consecutive rivet holes in the landing edges of the adjacent inner strakes.

The template for a garboard plate is in two pieces, one being for the portion fitting upon the frames, and the other for that fitting against the keel. Two check marks are made upon these pieces so that they may be set accurately in regard to each other when transferring the rivet holes to the bent plate.

A patented template has for many years past been used on the Thames, for outer strakes of plating, having a number of sliding and 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 positions of the rivet holes in the edges of the adjacent inner strakes; hence no reverser is required when this template is employed.

133. Butt Strap Templates.—In small vessels, the butt straps of which are light and easily handled, the latter are bent to their required form, and the position of their rivets marked upon them in place.

But, ordinarily, the positions of the rivets in the butts of shell plates are copied upon thin wood templates, and thence transferred to the butt straps.

The templates by which the rivet holes are set off are also used for measuring the lengths of the butt straps, which must be carefully determined in the case of outside strakes, for the reasons already mentioned. Butt straps are, of course, always punched from their faying surface.

134. Bending and Fairing Plates.—This is the final process in the preparation of shell plating. Throughout a great part of the vessel individual plates will not contain much twist or curvature, but, notwithstanding this, it is almost invariably necessary to submit the plate to a fairing process before screwing it in place. Bending, twisting, and fairing are all performed with the same machine, except when the deviation from a plane surface is so considerable as to require the plate to be made red hot, in which case it is treated in a totally different way.

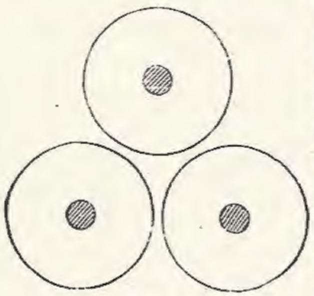


Fig. 24.

Fig. 24 shows a sectional view of the set of chilled cast iron rollers belonging to the plate bending and fairing machine. Each of these rollers is about 20 inches in diameter, and its length is determined by that of the longest plates which it will be employed upon. An ordinary length of roller is about 16 feet. 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 requirements of the case, this being done by means of a screw or

lever at each end. If it is required to simply flatten or straighten a plate, the lowest part of the upper roller is kept at just the thickness of the plate above the upper part of the lower rollers. The more the upper roller is depressed the greater is the curvature given to the plate, which is passed edgewise through the rolls; the largest dimensions of the plate being in the direction of the length of the rollers.

A limit to the bending capability of the machine is, of course, fixed by the upper roller coming nearly in contact with both the lower ones; but by properly adjusting the distance between the centres of the lower rollers, it is possible to give fully as much curvature to a plate with this machine as an unheated sheet of iron is capable of enduring after being punched at the butts. Indeed, the plate bending rolls are capable of giving all the curvature which is required at the bilge of a ship; and cases like the boss and oxter plates, and plates generally which stop on the stem and stern post, have to be heated before being bent.

If a parallel curvature is to be given to the plate, the upper roller is depressed to the same extent at each of its extremities, and if the curvature is not parallel, then the upper roller is depressed more at the one end than at the other. If the plate is to "wind" or twist, it is passed through the rolls in an angular manner, accompanied with an unequal depression of the ends of the upper roller, such as will be suggested by the experience of the workman. The ordinary process of passing a plate through the rolls after being templated and punched, when it is not required to be curved or twisted, is carried out with a view to correct and fair the unevenness in the surface, due to carelessness in the manufacture; it being not unusual to throw the newly rolled plate aside to cool without taking adequate steps to ensure that its surface shall be flat when cooled.

Having thus explained the *modus operandi* of the bending and fairing process, so far as regards the working with the bending machine, we will consider the manner of taking account of the required twist and curvature at the ship, so as to ensure that the plate shall fit accurately in place when attached to the frames.

When the workman marks the template, he makes a mould to the curvature of the plate at each extremity with a thin piece of batten or a strip of thin "set iron." If there is much twist in the plate, two wood moulds are held in place, and their opposite edges are cut so as to be "out of winding" or lie in a plane. In bending the plates the upper roll is screwed down gradually, so that the plate has to he passed through a great many times before the entire curvature and twist is given to it. The moulds just referred to are tried in place, and if there is much twist the upper edges of the section moulds are looked out of winding from time to time as the process of bending proceeds, until the plate is found to be of the form required. The system just described is, however, not always carried out, it being very usual for the workman to observe at the ship the amount of twist required for the plate, and then to fashion the latter at the rolls to the remembered form. It need scarcely be said that much practice and experience are required in order to successfully prepare twisted plates in that way.

When a plate requires very considerable curvature, twist, or other alteration of form, it is usual to make a skeleton mould of small iron rods bent and welded together, and the plate is heated and sometimes forged to the required form. In such cases the plate should he ordered of more than the finished thickness, to allow for the wasting which takes place through frequent heating. It is very usual to employ steel for such plates, even in iron ships, in consequence of the superior ductile qualities of that material. When a plate has to be heated before being bent to its required form, its rivet holes should be marked in place after the plate is prepared, and the latter should then be taken down and the holes punched.

135. Screwing Shell Plates in Place.—The inner or sunken strakes of plating having been prepared, they are secured to the frames by means of nut and screw bolts and "cotters;" the latter being tightened with a thin wedge of iron instead of with a screw nut. Nut and screw bolts

are, however, most frequently employed. It is most important that the process of "screwing up" should be carefully and thoroughly done, so that the strakes may be set closely against the frames, and the butt straps against the plates.

After this is done, the outer plates should be screwed up with equal thoroughness. When the butt straps to the outer strakes have been fitted and temporarily secured, the work of riveting may be commenced. It is, indeed, desirable that the riveting should not be unduly delayed after the plates are screwed together in place, for since the nut and screw bolts do not fill the rivet holes, there is always a tendency for the plates to drop somewhat out of their places. When some of the rivet holes in a plate do not accurately coincide with the corresponding holes in the plate to which it is riveted, agreement should be obtained by rimeing the partially "blind" holes, taking care to re-countersink the holes after rimeing. The use of the gouge for reconciling unsatisfactory holes is most objectionable, and it is equally improper to fair such holes by the excessive use of the "drift" punch. The latter is a tapered steel pin which is sometimes driven into the rivet hole with great violence in order to prepare it for receiving the rivet. "Drifting" holes is necessary in order to get the parts to be riveted together in their correct relative positions, but beyond that the use of this tool should be forbidden, as it injuriously disturbs the molecular structure of the iron in the vicinity of the rivet hole and renders it brittle. As already remarked, it is essential to satisfactory work that the parts to be riveted should be first properly fitted and closed, so that there may he no greater initial tension upon the head or point of the rivet than that due to its normal contraction in cooling.

136. Riveting.—The arrangement of rivets in frames, edges, and butts of the shell plating has already been described. The process of riveting is one which requires to be studied by personal engagement in it, or by observation, rather than in the pages of a book. There are, however, one or two points in connection with the riveting of the shell plating which deserve a little consideration. The frame rivets should be first put in, next the edge rivets, and finally the butts should be riveted; for the riveting of the frames and edges causes a slight expansion in the plate, so that if the butts were first riveted the plating would not be quite smooth. Moreover, the expansion alluded to is generally very advantageous in closing the butts, which are further tightened by the stretching due to the butt riveting.

After each rivet is knocked up at the point, and the surplus portion cut off, the adjacent rivet should be again gone over; for the hammering up of the last rivet tends to slacken the preceding one.

A rivet is not satisfactorily clenched and finished unless it is well "laid up" on the inside of the vessel, so as to cause the conical part under the head to entirely fill the rivet hole, and the head itself to fit closely against the plating.

Rivets should not be over-heated or burnt, and consequently when they present the appearance of fusion at the point, however slight that may be, they should be rejected. A burnt rivet is always brittle when cold, so that while the head of a properly heated rivet will, when cold, endure a dozen or more vigorous blows applied to a stout cold chisel held against it, the head of a burnt rivet will often come off at the first blow. There should always be plenty of head room provided under the flat of a vessel's bottom to enable the riveters to work freely, and so not encourage the use of overheated rivets.

The point of the rivet in flush riveting should be left rather full than hollow for the reasons already stated. Keel, stem and stern post rivets, except in the case of small vessels, should be heated only at their extremities; for when heated throughout their entire length, the great contraction in cooling brings an undue strain upon the rivet, tending to break it in the hole. In H.M. dockyards, and some private establishments, it is usual to heat the head of the rivet first, and then fit it to the hole by hammering. The rivet is then removed, and its other extremity is heated, whereupon the rivet is again put into the hole and finally hammered up and finished.

Keel riveting is very satisfactorily performed with a riveting machine. Indeed, such riveting is usually to be preferred to that done by hand, especially in side bar keels, in consequence of the excellent way in which the machine closes the work.

"Tap" or screw riveting has been, of late, applied to stern posts with satisfactory results, but it is necessary that the work should be performed with great accuracy in order that this may be the case. The adjoining tabular statement shows the proportions and spacings adopted in the instances referred to.

TABLE SHOWING DIAMETER OF TAP RIVETS FOR STERN POSTS, ETC., ETC.

	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Maximum thickness of iron plates on post	$\frac{8}{16}$	$\frac{9}{16}$	$\frac{10}{16}$	$\frac{11}{16}$	$\frac{12}{16}$	$\frac{13}{16}$	$\frac{14}{16}$	$\frac{15}{16}$	$\frac{16}{16}$
,, ,, steel ,,	$\frac{13}{32}$	$\frac{14\ 15}{32}$	$\frac{16}{32}$	$\frac{17\ 18}{32}$	$\frac{19}{32}$	$\frac{20\ 21}{32}$	$\frac{22\ 23}{32}$	$\frac{24}{32}$	$\frac{25\ 26}{32}$
Diameter under thread ..	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	1	1	$1\frac{1}{8}$	$1\frac{1}{8}$
Spacing Centre to Centre ..	$3\frac{1}{4}$	$3\frac{1}{4}$	$3\frac{7}{8}$	$3\frac{7}{8}$	$3\frac{7}{8}$	$4\frac{1}{2}$	$4\frac{1}{2}$	$5\frac{1}{8}$	$5\frac{1}{8}$
Length of Screwed Portion	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{3}{4}$
Angle of Countersink ..	45°	45°	35°	35°	35°	35°	35°	35°	35°

137. Caulking Laps and Butts.—The operation of caulking the landing edges and butts of bottom plating, and indeed of all joints in the iron or steel work of a vessel which are required to be watertight, is necessarily performed after the parts have been riveted together. The landing edges of plating and the edges of angle bars are treated alike, and in both cases the edges, if not already planed, should be chipped square and smooth preparatory to caulking. The caulking tool is a steel chisel with an obtuse edge, and the object of the caulker is to squeeze the faying surfaces together at the outside of the joint. This is done by cutting a slight groove in the chipped edge near the faying surface, and at the same time setting the displaced material towards that surface. Fig. 25 shows a landing edge as caulked in this way. It is, of course, essential to good work that the surfaces shall be already in close contact by reason of the riveting; and the spacing of the rivets, together with their distance from the caulked edge should, as previously described, be such as to properly close the work, and resist the separating pressure due to the caulking.

Fig. 26 shows the caulking of a butt, which, as will be seen, is closed by the caulking tool on both sides of the joint. The same conditions are necessary for good workmanship as previously named in regard to landing edges, viz., that the joints shall be close and the rivets properly spaced.

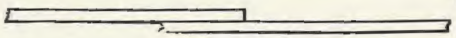


Fig. 25.

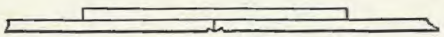


Fig. 26.

The riveting of the edges of shell plating, as by Lamb's system, is similar to that of the lap joint shown by fig. 25; but when the edge strips are on the inside, the caulking will be as in fig. 26. The nature of a flush joint is such as not to lend itself so satisfactorily as a lap joint to the attainment of good caulking; for the tendency, if any, to movement of the parts in the latter case is of a sliding or frictional character which would not open the joint, whereas any movement in a caulked butt or other flush joint results in opening it at once. Hence, while flush joints support the rivets under certain stresses, yet, on the other hand, lap joints assist the caulking. During recent years there has been a growing tendency to employ lap butts, and it has been considered an advantage that the caulking of these butts does not subsequently show any dampness, as indicative of straining, such as is often seen at ordinary flush butts; but it must be remembered that all longitudinal stresses in such cases are borne by the rivets, which are not supported by the butts being in contact, as in the common system. Moreover, although such marked indications of strain are not exhibited by lapped as by flush butts, it by no means follows, as already explained, that a slight movement has not occurred. Were it not for

the resistance to the vessel's motion offered by butt straps on the outside of a vessel, and their objectionable appearance, besides the risk of injury to them should the vessel rub the ground, there can be no doubt that the outside would be the best place for the straps, both as better supports to the butts and in consequence of the edge caulking which would be given to them.

While referring to the matter of caulking, it may be mentioned that when making the lower landing edges of strakes of plating above the bilges watertight by caulking, the workmen frequently use a small mirror in which they examine the reflection of their work, in order to avoid the constant stooping and bending in a painful posture which would otherwise be necessary.

For further particulars regarding shell plating, see Appendix.

CHAPTER XII.

138. Rivets and Riveted Joints.—Reference has frequently been made in the preceding pages to the rivets, which are such an important and, indeed, essential element in iron and steel shipbuilding. Without the rivet it would be impossible to build an iron or steel ship; for the welding of so many pieces together would be utterly impracticable. It is desirable, then, to offer a few remarks regarding the various kinds of rivets which are used in a ship, and afterwards to consider somewhat more fully than hitherto the nature and the value of different riveted joints.

But before so doing, a word or two is necessary regarding the materials of which rivets are, or should be, made.

Iron rivets should be manufactured from a ductile and high-class quality of material, free from sulphur, phosphorus, and all other impurities, and the bars should not be over-heated in the manufacture of the rivets from them. Under ordinary circumstances bars are always more fibrous than plates, in consequence of the extent of drawing out which takes place in rolling. But this is not sufficient; the iron should be inherently good, and equal to a tensile strain of about 22 tons to the square inch.

It is not unusual to put iron rivets in steel ships, and when that is done, the rivets are of the same diameter as would be required if the plates were of iron, and therefore of additional thickness. But the tendency to use steel rivets in steel ships is increasing; it being found, as will be shown hereafter, that more satisfactory results are thereby obtained.

139. Forms of Rivets.—There are several forms of rivets employed at different parts of a ship, the most usual being the pan-head rivet shown by fig. 6, page 37, and *A*, Plate XXIX. This rivet is of a conical form under the

head to fit into the conical punched hole, and its point is hammered up either to the "flush," "boiler point," or "snap" form as may be required. The hammered end of a rivet is often termed the "bat"; but this name is mostly applied when the "boiler point" form is alluded to.

Flush riveting (*D*, Plate XXIX.) requires countersunk holes, and is adopted for such parts as the inner and outer bottoms, deck plating, etc. Its efficiency depends entirely upon the countersink, and the latter should, therefore, be the subject of much care. Moreover, the clench should, as before remarked, be rather full than hollow when completed.

The "boiler point" form of "bat" (see *B*, Plate XXIX.) is adopted in the hand riveting of frames, keelsons, and longitudinals. When, however, frames are machine riveted, the snap form of "bat" and head is preferred—see *E*, Plate XXIX.

Snap riveting, when performed by hand, is applied to such parts as bulkheads, beams, etc., which are in sight, and it is there preferred because of its more finished appearance. The rivet point is first roughly beaten down, and then the clench is completed by the aid of a "snap punch," which is a tool with a hollow cup-like face that is held over the hammered point, and struck with a heavy hammer until the clench of the rivet is rounded and finished. Sometimes both the head and bat of the rivet are given the snap form, as at *E* and *K*, Plate XXIX., but usually the head is pan-shaped as at *C*. Occasionally the shell plating of vessels has been countersunk on both the inside and outside the surfaces, the rivet being of the form shown by *F*, of Plate XXIX., which, when hammered up, is shown by *G*. This system is more expensive than that ordinarily adopted, and on that account it is not often applied. Some weight is saved in the rivets, and the results obtained are very satisfactory.

Tap or screw riveting (Figs. J and H, Plate XXIX.) is very seldom resorted to in shipbuilding, being more costly and less trustworthy than clenched work. Occasionally shell plating has been tap riveted to the stern posts of steamers, especially in the way of the boss (see Art. 136).

The stud shown on the head of the rivet at J is for the purpose of screwing it up, and when the rivet is in place the stud is cut off.

Machine riveting has been alluded to in connection with the framing of a vessel. Such rivets are always finished of snap form, both at heads and bats. The thoroughly sound character of general machine riveting supplies a reason for desiring that the riveting machine should be used at other parts of the vessel. The difficulties in the way of riveting the shell plating by machine appears so far to be insuperable, but the riveting of keelsons, stringers, tie plates, etc., seems to be quite practicable, and if simple and inexpensive means for taking the weight of the riveting machine and transporting it fore and aft and across a vessel can be devised, something will be done towards increasing the efficiency of those parts of the structure.

140. Diameters and Spacing of Rivets Theoretically Considered.—The regulations affecting the diameters and spacings of rivets have already been considered, and by referring to the tabulated statement upon page 155 it will be seen that while the diameter of the rivet is more than double that of the steel plate at the lower limit of the scale, it is but very little in excess at the upper limit.

A theoretical investigation of the principles which underlie this question scarcely falls within the compass of this Work, which is concerned rather with the practical operations of shipbuilding. Upon page 246 *et seq.* of *Theoretical Naval Architecture** will be found calculations bearing upon this question. Assuming that the shearing strength of the rivet iron is such that a $\frac{3}{4}$ inch rivet is equal to 10 tons (about 22 tons to the square inch), also that the strength of the iron in the way of the punched holes is equal to 18 tons per square inch; then, supposing that the rivet is on the point of shearing when the iron is on the point of bursting out in front of the rivet, we shall get the following result, viz.:—That under no circumstances should the diameter of an iron rivet exceed twice the thickness of the iron plate.

Lloyd's Rules adopt this result for the rivets of $\frac{5}{16}$ inch

* Glasgow: William Collins, Sons, & Co., Limited.

iron plates, and require the same diameter of rivet for $\frac{5}{20}$ inch steel plates. To continue the application of the same ratio to thicker plates would lead to very unsatisfactory results from another point of view, viz., that of watertightness. For instance, the rivet in a $\frac{3}{4}$ in. plate would be $1\frac{1}{2}$ in. diameter, and should be therefore $1\frac{1}{2}$ inches from the edge of the plate, which, under such circumstances, could not be closed sufficiently for caulking.

The theoretical diameter of rivets, based upon the conditions assumed, is therefore inapplicable to the shell plating of ships, except when very thin plates are being used.

The calculations alluded to result in the following formulæ whereby the theoretical spacing of rivets may be determined:

If t = the thickness of either of the plates in inches.
,, d = the diameter of the rivet in inches.
,, p = the pitch of the rivets in inches.

Then in single riveted joints—

$$p = d + \cdot 96\,\frac{d^2}{t}$$

In double riveted joints—

$$p = d + \frac{1\cdot 92\,d^2}{t}$$

And, in treble riveted joints—

$$p = d + \frac{2\cdot 88\,d^2}{t}$$

Supposing the plates to be $\frac{1}{2}$ inch thick, and the rivets $\frac{3}{4}$ in. in diameter, as is usual for that thickness, we find from these formulæ that the pitch in a

Single riveted joint should be 2·44 diameters.
In a double riveted joint 3·88 diameters.
And in a treble riveted joint 5·32 diameters.

Here, again, we obtain results which are inapplicable in the case of the butt straps of a vessel's shell plating, when more than two rows of rivets are employed. The result for single riveting may be neglected, as such riveting is never adopted for butts, and that for double riveting agrees very closely with the usual practice. But the theoretically best spacing for treble riveting is much too open for watertight work.

Upon page 253 of the Work already quoted, it is shown that the maximum "efficiency" which any butt connection can have, in which the rivets are spaced four diameters from centre to centre, is ·61.

To obtain this result it is assumed that the shearing strength of the rivet is 22 tons and the tensile strength of the plate 18 tons per square inch in the way of the punched holes. By the term "efficiency" is meant the ratio of the strength of the butt connection to that of the unpierced plate.

"But this efficiency can exist only when the shearing strength of the rivet is equal to the tensile strength of the iron between the holes. If the one rivet is equal to the strength of the plate between consecutive holes, double riveting is unnecessary when the pitch is four diameters; and, if adopted, the pitch must be increased in order to obtain the requisite equality. To a greater degree the same remark applies to treble riveting."

From these considerations it is shown that for a single riveted butt strap, with rivets spaced four diameters apart (for caulking), to have an efficiency of ·61 the diameter of the rivet must be 3·12 times the diameter of the plate.

This is another impracticable resnlt, so that when the diameter is of the regulation size—say $\frac{3}{4}$ inch rivet for a $\frac{1}{2}$ inch plate—the efficiency of the joint instead of being ·61 is found to be only ·3.

Had the butt been double riveted the efficiency in that case would have been ·59.

The general results of these investigations are thus stated:—

1. "That a closer pitch should be adopted in single than in double riveted butts, and in double than in treble riveted butts.

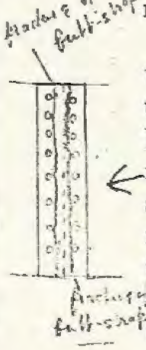
2. "That with a four diameter pitch the efficiency of a single riveted butt joint is very small, especially when the plates are thick.

3. "That with a four diameter pitch the efficiency of a double riveted butt is about a maximum for that pitch when the plates are not more than $\frac{1}{2}$ inch thick, and the value of the strap may be improved by increasing the spacing to $4\frac{1}{2}$ diameters in the case of very thick plates, if that pitch will permit satisfactory caulking. But the

efficiency is very low when thick plates are used; and at least three complete rows of rivets are necessary in order to obtain the efficiency due to the pitch.

4. "That, other things being the same, it is desirable to put larger rivets in plates of more than $\frac{3}{4}$ in. thickness than are now commonly used."

With reference to (4), it is right to mention that in the year 1877, when these words were penned, the diameters of rivets for plates of $\frac{7}{8}$ inch and upwards in thickness were not so large as are now adopted.



141. Butt Connections.—The fracture of a riveted butt with a single butt strap will occur either by the fracture of the material in one of the lines of rivets farthest from the butt, by the fracture of the butt strap in a line of rivets nearest to the butt, by the shearing of all the rivets on one side of the butt, or by a combination of plate fracture and rivet shearing. The fracture will evidently take place in the mode which offers least resistance; and supposing the rivets to be sufficiently numerous to resist shearing, it will be found that either one of the plates joined will be torn in a line of rivet holes farthest from the butt, or the butt strap will be torn in a line of rivet boles nearest to the butt. If the butt is watertight the spacing of the adjacent line of rivets will determine the strength of the strap to resist tearing. But in cases wherein extra butt efficiency is desired the butt strap is made somewhat thicker than the plates which it joins, and if that additional thickness be sufficient to save the butt strap from fracture it will follow that the tendency to rupture is thrown upon the plates joined together, and the rupture will probably occur at the line of rivets which is farthest from the butt. For, if fracture were to occur in the plate at any other line of rivets it would be necessary to shear another line of rivets before the joint would be torn asunder. It is an important object, then, when more than two rows of rivets are used, to weaken the plates joined together as little as possible at this row of rivets in each of them, and for that purpose butt straps of diamond shape have been sometimes adopted for girder work, wherein the number of rivets in the rows are continually increased as the butt is approached. In the shell plating of ships the principle has been applied, when treble and quadruple riveted straps have been fitted, by omitting alternate rivets in the outer row (see fig. 7, Plate XV., also Art. 122), and in that way, and by increasing the thickness of the butt strap, the efficiency of the joint has been much improved. For further discussion of this important subject the reader is referred to Chapter VII. of the work on *Theoretical Naval Architecture* already referred to.

The most efficient butt connections are, however, obtained by using double butt straps, each rather more than one-half the thickness of the plates they unite. When double butt straps are used each rivet must be sheared twice, if sheared at all, and so the strength of the joint is determined by the tensile resistance offered by the plates in one of the lines of rivet holes which are farthest from the butt, or by the tensile strength of the two butt covers in a line of rivets nearest the butt.

Double butt straps cannot, however, be satisfactorily applied in their most efficient form to the butts of shell plating, for, in order to caulk the outer strap, the rows of rivets farthest from the butt must be spaced closely for watertightness, and that close spacing must necessarily diminish the tensile strength of the connection.

The only satisfactory way of investigating the strength of a vessel's shell plating is by considering a shift of plating across the various lines of possible or probable fracture; and for such an investigation reference may be made to page 262 of the Work already quoted.

It is important to notice in connection with all such theoretical discussions regarding the strength of riveted joints that the value of the results obtained from these calculations is determined by the accuracy or otherwise of the assumptions made in regard to the tensile and shearing resistances of the several parts under stress. These will be governed by the quality of the material and the workmanship, both of which are variable quantities. Moreover, there are essential elements in the problem which are frequently neglected—such as the friction between the surfaces in contact, and the variable resistances offered by the

several parts of the joint through the slight stretching of the material, and the distortion of the rivet holes which occur before the breaking stress is reached. Mr. J. Milton, of Lloyd's Register, in a valuable paper read before the Institution of Naval Architects in 1885, called attention to the latter of these phenomena. In this paper Mr. Milton shows that the unequal stretch which takes place at the different lines of rivet holes in double, treble, etc., riveted joints, causes an unequal distribution of the stress upon the corresponding rivets, and therefore the butt connection is weaker than would appear from theoretical considerations in which this stretch is neglected. As, however, Mr. Martell, the Chief Surveyor to Lloyd's Register, pointed out at the time, such stresses as would produce distortion of the rivet holes are beyond the limits of elasticity of the material, and therefore are not endured by the riveted joints in the hull of a vessel under ordinary circumstances. But in all investigations relating to the ultimate strength of butt strap connections the suggestion of Mr. Milton demand attention.

142. Experimental Results.—The question is, properly, an experimental one, and even experimental results will vary very much in consequence of differences of workmanship.

A very valuable paper upon this subject was read before the Institution of Naval Architects, in March 1885, by Mr. J. G. Wildish of the Admiralty, in which the results were given of tests made at Pembroke Dockyard to determine the shearing resistance of the different kinds of rivets and riveting used in H.M. Service.

Mr. Wildish mentions also in that paper the results obtained in the year 1858 in regard to the strength of iron rivets of Bowling or Lowmoor quality. These have been already referred to and employed in the preceding calculations; the shearing strength of a $\frac{3}{4}$ inch iron rivet being 10 tons when connecting two plates together, and that of the other sizes being assumed to vary in proportion to their sectional areas. The double shearing strength of the $\frac{3}{4}$ inch rivet was found by these experiments to be 18 tons.

The Pembroke experiments of 1878 showed that the average shearing strength of $\frac{3}{4}$ inch iron rivets in steel plates is only 8·4 tons as compared with 10 tons for the same rivets in iron plates. The mean shearing strength of the $\frac{7}{8}$ inch iron rivet in steel plates was found to be $11\frac{1}{2}$ tons, being 2·1 tons less than for the same rivets in iron plates. Experiments made in 1880 at the same dockyard, with steel rivets in steel plates, showed that $11\frac{1}{2}$ to $11\frac{3}{4}$ tons might be allowed for the single shear of a $\frac{3}{4}$ inch rivet, and $14\frac{3}{4}$ tons for a $\frac{7}{8}$ inch rivet.

In the years 1883 and 1884 further experiments were made at Pembroke Dockyard to ascertain the effects of punching and drilling holes in steel plates upon the tenacity and ductility of the material, and these led to results very similar to those determined by the experiments previously made under the directions of the Committee of Lloyd's Register of Shipping. They tend generally to show that punching diminishes the tenacity and ductility of mild steel, and that these qualities are restored to their normal value by subsequently rimeing the holes; also that drilling does not impair the quality of the steel in the neighbourhood of the holes.

The tests made upon riveted joints yielded some very interestiug results. For instance:—steel plates of $\frac{1}{2}$ inch in thickness were punched and not afterwards rimed, thereby reducing the tensile strength of the material between the punched holes from $28\frac{1}{4}$ to 22 tons per square inch. Two of these plates were connected by a double riveted strap, and the breaking strain showed a resistance of the steel between the rivet holes amounting to 24·9 tons per square inch, or 2·9 tons more than the plates stood before being riveted. As Mr. Wildish remarks: "This recuperative effect apparently of the riveting on the strength of the plates at the section across the punched boles is difficult to explain." That gentlemen goes on, however, to say, "Being connected by a single strap, the test pieces would bend somewhat at the holes before finally separating, and the section there would be subjected to a tearing stress. This latter might have been expected to still further degrade the ultimate strength of the section, as in the case of iron plates. It may, however, be that with such ductile material

the bending referred to had the effect of reducing the injury done by the punch, and that this reduction was not due to the mere process of riveting. This view is supported by two cases in which the plates, which were connected by double straps, broke across the punched holes, at a stress per square inch of about 23 tons." Mr. Wildish mentions that "All the test pieces in this set of tests were cut from the same plate, in order to attain the most reliable results."

Tests made at the same time upon iron screw rivets in steel plates, tapped into both the plate and strap, and cut off flush, showed that the continuous screw and the screw-pointed and hexagonal-headed rivets are about 30 per cent. weaker than the hammered rivets of the same nominal size, and that the countersunk headed and screw-pointed rivets are about 17 per cent. weaker. But "the stress per square inch of net sectional area of the iron screw rivets is in excess of the stress per square inch for the hammered iron rivets in steel plates; from which it may be inferred that the weakness of the screw rivets, as compared with the hammered, is wholly due to the loss of sectional area from cutting the thread, and not from any loss of friction between the plates and straps."

Upon testing the strength of steel screw rivets in steel plates, the results showed that these were "practically in proportion to the net sectional area of the rivets, and on the whole they are about 12 per cent. in excess of the results obtained with the iron rivets in steel plates."

These experimental values are interesting in connection with the tendency manifested by some builders to use tap rivets for fastening bottom plating to stern posts, as mentioned at Art. 136.

Mr. Wildish gives in this paper some valuable experimental data in regard to the efficiency of different forms of rivet and modes of riveting.

Considering, first, steel rivets with pan heads and countersunk points (D, Plate XXIX.), the shearing stresses are—

$\frac{3}{4}$ inch.	$\frac{7}{8}$ inch.	1 inch.
11·5 tons.	15·25 tons.	20·25 tons.
	(15·28)	(19·65)

The figures in brackets are in exact proportion to the sectional areas of the rivets, the stress for the $\frac{3}{4}$ inch rivets being taken as a basis.

Countersunk headed and pointed rivets (*G*, Plate XXIX.) under 1 inch in diameter did not, on the whole, yield such good results; as they gave out more readily in some cases, and without being sheared, many of the rivets being drawn through the holes. The mean ultimate stresses applied before the joints parted were, however, just over 11 tons for the $\frac{3}{4}$ inch rivet, and 13·6 tons for the $\frac{7}{8}$ inch rivet. The 1 inch rivets were sheared in all cases, and at a mean stress per rivet of 20·9 tons, which is rather better than for the pan-headed and countersunk pointed rivets.

Snap-headed and snap-pointed rivets (*E*, Plate XXIX.) do not seem to give such good work as the pan-headed and countersunk pointed, the following being the mean shearing stresses:—

$\frac{3}{4}$ inch.	$\frac{7}{8}$ inch.	1 inch.
11·0	14·75 tons.	19·0 tons.
	(14·62)	(18·79)

The figures in brackets, as before, are in exact proportion to the net sectional areas of the rivets, taking the $\frac{3}{4}$ inch rivet as a standard.

The next set of tests described by Mr. Wildish in this valuable paper refers to the frictional resistance of various kinds of riveted joints.

To make these experiments, double covering straps were employed, but the middle plate had the material cut away opposite the rivets, to allow it to slip from between the other two without shearing the rivets.

The rivets were of steel, and of two sizes, viz., 1 inch and $\frac{3}{4}$ inch, the former being used for $\frac{3}{4}$ inch steel plates, and the latter for $\frac{1}{2}$ inch steel plates.

The breadth of the lap was three diameters, and the length of joint or lap was eleven diameters, the pitch of the rivets being four diameters.

There were four kinds of "hand" hammered rivets employed of each size, viz.—

(1) Snap-headed and pointed.
(2) Pan-headed and boiler or conical pointed.
(3) Pan-headed and countersunk pointed.
And (4) Countersunk headed and pointed.

The experiments were made in duplicate, and the mean frictional stress per rivet was as follows:—

	1 in. rivet.	$\frac{3}{4}$ in. rivet.
With Snap-head and Point, ...	6·4 tons.	4·72 tons.
,, Pan-head and Boiler Point, ...	7·36 ,,	4·52 ,,
,, Pan-head and Countersunk Point,	8·55 ,,	6·25 ,,
,, Countersunk Head and Point, ...	9·04 ,,	4·95 ,,

The machine clenched rivets had, as usual, snap heads and points, and the mean friction per rivet was, 9·6 tons for the 1 inch rivet, and 5·9 tons for the $\frac{3}{4}$ inch rivet.

These results show the superiority of the machine riveting over all others, but at the same time, they demonstrate the great efficiency of the pan-headed and flush pointed riveting, which is almost always adopted for the shell plating of ships.

143. Stiffened Butt Straps.—Mr. Mumford, late Principal Surveyor to Lloyd's Register at Glasgow, has devised a simple yet effective means for stiffening, and therefore succouring, ordinary butt strap connections in the shell plating of ships. Indications of movement at the butts of the bottom plating of large and, especially, long vessels are very commonly observed when under survey in dry dock, but such indications are not necessarily accompanied by signs of straining in the rivets. Indeed, the butts are very often found to have leaked and corroded to such an extent as to lend countenance to the suggestion that they were never properly fitted or caulked. It has been sometimes argued in regard to such appearances, that had any movement really occurred in the several parts, however small, the rivets must have been started. That this is not a legitimate inference is shown by the results of the experiments upon riveted joints made by Mr. Staveley Taylor, of Greenock, and communicated by him in a paper read in March, 1885, before the Institution of Engineers and Shipbuilders of Scotland. Mr. Taylor found that, in testing certain machine riveted joints, there was a slip of about one-eighth of an inch, which was wholly recovered when the load was removed, without in any way disturbing the rivets. But in this case, the load applied was from 70 to 80 per cent. of the breaking stress, which is presumably very much in excess of anything experienced by the butt straps of a ship when at sea. The fact is, however, deserving of notice as illustrative of the elasticity which may be possessed by a well riveted butt connection. The appearances so often observed, especially at the bilge butts of steamers having considerable proportions, may be attributed to other than purely tensile stresses. This view of the case is supported by the special evidence furnished by steel as compared with iron steamers. The ability of steel vessels, built upon the reduced scantlings permitted when that material is employed, to resist purely tensile stresses is fully as great as that of iron vessels of the same dimensions; and, having regard to the greater ductility and other valuable qualities of steel, the vessel built of that material is even better able to resist such stresses. But owing to the plates of steel being thinner than if of iron, there is a greater flexibility in the plating, which is more likely to show itself at the butts than elsewhere, and this probability is borne out by actual observation. The stresses which would produce such a movement at the outside of a butt in the bottom plating are of a compressive and torsional character; and these are continually being set up when a vessel is labouring in a sea-way.

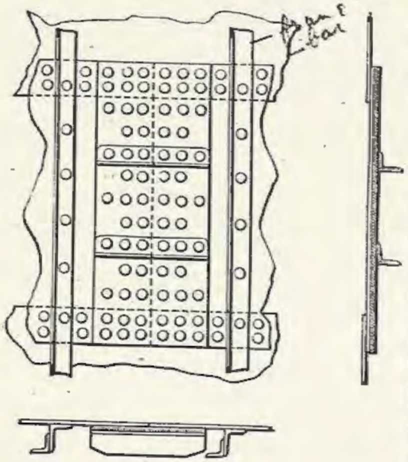


Fig. 27.

Mr. Mumford's proposed method of stiffening butt straps is intended to meet the demands arising out of the above-mentioned circumstances. He assumes—and apparently with good reason—

that by sufficiently increasing the rigidity of a butt strap, he will be able to prevent the butt from opening on the outside; for such a movement in the butt can only occur with a simultaneous bending of the strap He therefore proposes to rivet two pieces of angle iron across the strap, in a fore and aft direction, as shown by fig. 27. The rivets connecting the angle irons will be a part of the ordinary riveting of the butt, so that the scheme is very simple and inexpensive, and involves merely the additional weight of the pieces of angle iron. As only the butts of a few of the strakes in the neighbourhood of the bilges will require this stiffening, judging by the symptoms generally observed, neither the additional weight nor cost will be of any considerable moment.

It may be remarked that experiments made with butt strap connections stiffened in this way are wholly confirmatory of the efficiency of the scheme.

The Rules of Lloyd's Register for building steel ships make special provision against flexibility at the butts by requiring the butt straps of steel plating to be from $\frac{1}{20}$ in. to $\frac{4}{20}$ in. thicker than the plates they connect, according to the size of the vessel. In the smallest vessels the butt straps of the sheer strake, deck stringer plate, and one strake at the bilge for one half length amidships, are to be $\frac{1}{20}$ in. thicker than the plates they connect; and in the largest vessels the whole of the strakes of shell plating, together with the upper and middle deck stringer plates, are to have butt straps $\frac{4}{20}$ in. thicker than the plates they connect for three-fourths length amidships, and $\frac{2}{20}$ in. thicker at the ends. Between the two extremes the requirement for butt straps varies to $\frac{2}{20}$ in. and $\frac{3}{20}$ in. thicker than the plates, and the extent of application varies also. Also, when the outside strakes of shell plating are above 40 in., but not exceeding 46 in., and the inside strakes are 48 in. in breadth, but not exceeding 54, their butt straps are to be an additional $\frac{1}{20}$ in. in thickness and treble riveted. The use of wider plates than these is discouraged; but when the excess of breadth is inconsiderable, the straps are further increased in thickness, or, preferably, are stiffened with angles, as shown in fig. 27, three stiffening angles being generally employed.

CHAPTER XIII.

144. Bulwarks.—In all iron and steel sailing vessels, and in most steamers except those with spar and awning decks (see Arts. 160 and 163), the comfort and safety of the crew, when on the upper deck, is provided for by fitting bulwarks, which are usually formed with thin plates in some such a manner as is shown by Plates II. and V., also by figs. 1 and 2 of Plate XXIII. Stanchions and rails are fitted for the same purpose upon poops, forecastles, bridge-houses, and upon spar and awning decks. Spar and awning decked vessels have greater freeboard than ordinary one, two, and three-decked vessels of the same dimensions; and upon this account, and because, strictly speaking, such platforms are the upper boundaries of continuous deck erections, the same provision for the safety of the crew is made as in the case of discontinuous erections, such as poops, bridge-houses, and forecastles. It is not unusual, however, to fit low bulwarks to a raised quarter deck, which latter is merely a continuation of the upper deck, but raised to a short height above it at the break.

Although, primarily, the bulwarks are intended as a protection for the crew, yet at the same time they serve in some degree to prevent the fall of large bodies of water upon the deck, and therefore, to that extent, contribute to her safety. Upon these accounts the bulwarks, although not a component part of the hull proper, should nevertheless be substantial and strong, and all necessary precautions be therefore taken to stiffen and support them, so that they may satisfactorily endure the stresses which they have to encounter. When a vessel is considerably inclined through the pressure of wind on her sails, or by any other cause, the bulwarks on one side

may be partially immersed; and although it would be dangerous to credit her with any stability arising therefrom, it is yet important that the bulwarks should resist the pressure thereby brought upon them.

The surface of the upper deck forms the upper side of a vessel so far as her buoyancy is concerned, and the top of the sheer strake is the upper limit of the structure so far as her strength is concerned, but the bulwarks have many useful functions to perform, and consequently demand our attention. Many ropes of the running rigging are belayed at the main rail; the skids which carry the boats are often rested upon the bulwarks, and the davits for the boats are also supported thereby. Sheaves and blocks for the rigging are attached to the bulwarks, and in many other ways they serve a useful purpose, especially in sailing vessels.

The bulwark plating is usually about $\frac{4}{16}$ in. to $\frac{5}{16}$ in. thick, fitted in lengths of about ten to twelve feet, and joined by single riveted butt straps. The bulwark plating is connected to the upper edge of sheer strake by a single row of rivets, and when a moulding is fitted, as in Plate XXIII., some of these rivets pass through the three thicknesses. The bulwark plate may be arranged as an outside or an inside strake, but in either case the sheer strake butt straps extend to the top of the latter strake, and consequently the upper row of rivets in those straps pass through the bulwark plate.

145. Bulwark Stays.—The bulwark stays or stanchions are placed against the butts and at the middles of the bulwark plates, and are therefore spaced from about five to six feet apart. Their diameters vary from $1\frac{3}{8}$ to $2\frac{1}{4}$ inches, according to the length of the stay and the size of the vessel. Where the bulwark plating and the rail are cut through to form a cargo port, the bulwark stay at each end of the port should be of increased strength. In such cases it is usual to form plate stays, lightened with holes, and stiffened by angle irons on their edges. Horizontal arms, known as "spurs," are placed at the middle of the height of ordinary bulwark stays, to distribute the support as much as possible over the whole of the plate. These arms are riveted to the bulwark plating, as indicated by Plate

XXIII., and the upper part of the stay is riveted to the iron work which forms a part of the main rail.

When the vessel has an iron upper deck and no gutter waterway, the lower part of the bulwark stay is necessarily riveted to the deck plating (see Plate V.); but when, as in the cases shown by Plate II., the vessel has a gutter water-way there are several modes of fastening the lower ends of the stays. Fig. 2, Plate XXIII., shows the stay riveted through the stringer plate and horizontal flange of the gutter angle bar, while fig. 1 shows the stay riveted to the vertical flange of that angle bar, which is either stouter than usual, or else stiffened with a narrow strip of plate, or a short piece of angle iron thereat.

In comparing these methods it should be remarked that in the event of the bulwark receiving damage, through a blow from the sea or any other cause, so as to start or break the rivets in the heels of the stays, water would be admitted to the cargo in the case shown by fig. 2, whereas no leakage in the deck would result from damage to the rivet in the heel when secured as shown by fig. 1. On the other hand, it will be noticed that repairs may easily be effected in the former case, but either the whole or a portion of the margin plank of the deck in the way of the damage must be removed in order to renew the rivet in the latter case.

The best method of securing the heels of bulwark stays is by using tapped instead of clenched rivets, and then fitting them as shown by fig. 2 of the Plate. In that case should the bulwarks and stays be struck with sufficient force to break the rivet, its screwed portion will remain in the gutter bar and stringer plate and stop the hole.

146. Bulwark Rails.—Different modes of forming the main and top-gallant rails are shown by figs. 1 and 2 of Plate XXIII., by Plate II., and by Plate V. In Plate II. the rail is formed with rolled bars known as "channel bars;" and it is found that such a rail is very strong in itself, and a source of great stiffening to the bulwark. The rail shown by fig. 1 of Plate XXIII. is correspondingly strong, and the top-gallant rail in the same case is also very rigid, and calculated to maintain the fairness of the surface of

the bulwark. The rails are faced or covered with hard wood; generally teak or greenheart.

147. Bulwark Mouldings.—The half round mouldings at the top of the sheer strake should be of solid and not hollow section, as in the latter case leakage is liable to occur at the butts of the sheer strake. The rivet holes in the hollow mouldings above the sheer strake should be drilled and not punched, as it is found the stretching which takes place in punching long lengths of these bars makes it impossible to get good holes for riveting, but solid mouldings are drilled in all cases.

148. Fairing Bulwarks.—Bulwark plates are rolled of a slightly convex form, and the bars used for the rails should be bent to shape before being fitted in place. The stays are not fitted until the bulwark is otherwise completed, when the whole is set fair by means of screws and chains, and the stays are then made to moulds so as to fit in their several places. This system ensures a satisfactory and fair finish to the work. When the stays are fastened, the water-tightness of the stringer should be carefully ascertained, whereupon it is usual to complete the watercourse by cementing it.

149. Bulwark Ports.—Hinged ports are fitted in the bul-warks to relieve the deck of larger bodies of water than would readily escape by the scuppers. Such ports are fitted with lids which are hinged at the upper side; some-times the lids are in two halves, hinged together at the middle, and occasionally the lids are hung at their lower sides. Port lids should always open outwards so as to readily relieve the deck of water, and not admit any from the outside. Means are provided for fastening the lids, or for tricing them up when thought proper.

While bulwarks are a source of safety and convenience to the crew, it is very necessary that they should not, by reason of their great height, enclose a large body of water, especially in the limited spaces between the forecastles and bridge-houses of some types of steamers, and between the bridge-houses and poops of others. For this reason it is desirable that the freeing port area should bear at least a certain ratio to that of the bulwarks, and this is especially the case in "well-deck" vessels, for which the freeing port area should vary from 9·5 sq. ft. on each side, when the well is 30 ft. long. to 12·5 sq. ft. when it is 60 ft. long. For "wells" of 65 ft. in length and above there should be one square foot of freeing port area on each side for each five feet length of well.

150. Scuppers.—Scupper holes are cut in the upper part of the sheer strake with their lower surfaces flush with the stringer plate. It is very usual to weld a piece of plate to the vertical flange of the gunwale bar at a scupper, cut a hole for the scupper through it, and round it off at the top with a margin above the hole equal in breadth to the vertical flange of the gunwale bar. Other builders cut the gunwale bar at the scupper, and compensate for so doing by fitting an angle bar from frame to frame under the stringer, and riveting it to the stringer and sheer strake.

In either case great care must be taken to make the sheer strake and stringer watertight at the scupper.

Scuppers should be sufficiently numerous to readily free the gutter watercourse of water under ordinary circumstances.

151. Hatchways.—Hatchways are formed with coaming plates which extend to the required height above the deck, and are firmly connected to the beams, carlings, and other portions of the deck framing. The coaming plates are sometimes connected at their extremities with angle irons, so as to form hatchways with angular corners, but it is more usual to round the corners of the hatchways, and connect the four coaming plates with butt straps.

When beams form the fore and after boundaries of hatchways, only one large angle iron should be fitted on their upper edges, instead of two angle irons of the ordinary size; for if there were angle irons on both sides of the beam, the hatchway would be unnecessarily shortened thereby, and the angle irons between the coamings would be liable to be knocked away when loading or discharging cargo. Whenever the hatchway is greater in length than two frame spaces of the vessel, it becomes necessary to fit half beams, which are attached to the frames at one extremity, and at the other extremity to a fore and aft

carling on each side of the hatchway. These fore and aft carlings should be of the same size and description as the hatchway beams, and be connected to the latter by turning the angle irons on their upper edges down against the hatchway beams and riveting them thereto.

There is, however, an alternative and superior mode of forming the sides of the hatchway, which is done by fitting stout coaming plates extending from the top of the hatchway to the level of the underside of the beams, and to these the half beams may be connected by turning down their upper angle irons against the coaming plate in the form of a knee, as shown at the upper deck in the midship section on Plate [illegible]II. The athwartship coamings, or head-ledges, are riveted to the fronts of the beams, the lower part of the head-ledge being extended down to the top of the bulb. The upper part of the head-ledge is either curved to a rounded form like that of the deck surface, or it is given the roof shape shown by fig. 3, Plate XXX., the latter being a very usual form in the wide hatchways of steamers. The object in both cases is to quickly relieve the hatches of water which may fall upon them.

Whenever a wood deck is laid, an iron plate is riveted upon the beams at the ends of the hatchways, and fore and aft tie plates are similarly fitted at the sides of the hatchways to receive the fastenings of the deck planks, and enable them to be properly caulked. These plates are connected to the coamings and head-ledges with angle irons of sufficient depth to extend half an inch above the deck plank, their upper edges are properly caulked, and the rivets in the vertical flange are countersunk and flush.

When the vessel has an iron or steel deck, the vertical flange of the angle iron is not necessarily so deep, but both flanges are then caulked.

The lower edges of fore and aft coaming plates, which extend to the lower edges of the beams, should be protected with half round iron against injury from the cargo when getting the latter in and out of the hatchway. Small angle or stout flat bars are fitted at about three or four inches below the upper edges of the coaming plates upon which to rest the wood hatches.

When upper deck hatchways are above sixteen and not exceeding twenty feet in length, the fore and aft tie plates are, by Lloyd's Rules, to be double the ordinary width for two spaces of beams beyond each end of the hatchway opening, and when the hatchway is more than twenty feet long, still further additions are required to these tie plates; also should the deck be of iron, it must either be doubled in the way of the hatchway and for some distance beyond its extremities, or thicker plating must be fitted at that part. The object of these requirements is evidently to restore the longitudinal strength which is forfeited by cutting so large a hole in the deck of the vessel.

152. Shifting Beams and Fore and Afters.—It is necessary for the safety of a vessel that the hatches should be capable of resisting the weight of heavy seas falling upon them. It is equally necessary that the coamings should effectually withstand the force of blows against their sides, due to the rush of large bodies of water across the deck. Further than that, when the hatchways are long it is desirable to strengthen the deck of the vessel, transversely, by temporary, yet effectual, ties joining the opposite fore and aft carlings and coamings together.

For all these purposes a portable framing of shifting beams and fore and afters is fitted inside large hatchways. When an upper deck hatchway is above twelve feet and not exceeding sixteen feet in length, a strong shifting beam is fitted joining the two fore and aft coamings together. Such a shifting beam should be of equal strength to an ordinary beam, with its angle irons turned down in the form of a knee, and it should be secured to the fore and aft coamings by nut and screw bolts.

When the length of the hatchway is above sixteen feet and not exceeding twenty feet, a web-plate beam takes the place of the shifting beam. Such a web-plate beam is marked *W* in figs. 1, 2, and 3 of Plate XXX.—fig. 1 being a longitudinal section, fig. 2 a plan, and fig. 3 a transverse section of the vessel, showing an elevation of the web-plate beam. In the case shown by this Plate two web-plate

beams are required, the hatchway being more than twenty feet in length. The number of these beams and other additional strengthenings to the hatchway will be determined by the length of the latter. The web-plate beam extends the full depth of the coaming as shown; is lightened with holes so as to reduce as much as possible the labour of getting it in and out of place, and is connected to the coamings by nut and screw bolts passing through double vertical angle irons at the sides of the hatchway. Other modes of connecting the web-plate beams with the coamings are adopted, the object in each case being to effect a secure connection, and facilitate speedy removal when getting cargo in and out of the vessel.

The wood fore and afters marked *F* rest upon collar-shaped lugs riveted to the head-ledges and web-plate beams, and are placed at such a height as to just bear the weight of the hatches. The whole forms a substantial framework which is intended to give such a support to the hatches as will prevent a sea from bursting them in.

153. Hatches.—These were formerly made with comparatively thin deals nailed upon wood hatch carlings; but that practice has been discontinued except for small coasting vessels, and solid hatches are now almost invariably fitted in sea-going sailing ships and steamers. These are usually of either red or pitch pine, and vary in thickness from 2½ inches in small vessels to 4 inches in those of larger size. The pieces composing the hatches are tie bolted together.

154. Mast Partners.—The purpose of the mast partners is to enable the masts to be efficiently wedged at a deck, and to distribute the stresses brought upon that wedging. The arrangement of mast partners in an iron or steel ship is very simple. If a beam is cut, in order that the mast may pass through the deck in the required position, carlings are fitted to receive the midship ends of the half beams in the same manner as at a hatchway. The mast hole is, in fact, framed like any other deck opening. But the partners, proper, consist of iron plates riveted upon the beams and half beams, and usually extending in length over a beam space before and abaft the mast space. Hence a mast partner will generally extend over from three to four beam spaces. The breadth of the plate partner should be at least twice the diameter of the mast at the deck, and when the plate is fitted in two breadths, each half is in breadth equal to at least the diameter of the mast. The thickness of the plate partners should be equal to that of the stringer plate, and, if in two pieces, they should be properly strapped together and riveted to the beams and carlings.

Mast partners are always fitted to the upper deck, and when the mast is wedged at a deck below, a similar partner should be fitted there also.

In order to resist the wedging, an angle iron ring is riveted to the partner plating, the diameter of the ring being equal to that of the mast at the deck, together with the double thickness of the wedge. It is usual in sailing vessels to fit a plate-bulb ring in addition to the ring of angle iron, and riveted to the latter, in order to obtain a good rigid surface against which to wedge. Plate VII. shows a plan of the mast partners, etc., of an iron sailing vessel of about 1500 tons. Partners and diagonal tie plates are shown upon both the upper and lower decks in the Plate, but the vessel in question was wedged upon the upper deck only (see fig. 1 of the Plate), which has an arrangement of partners suited for the purpose. Those on the lower deck are not so well adapted, being both narrower and shorter.

CHAPTER XIV.

155. Topgallant Forecastles.—The representations of vessels of the sixteenth and seventeenth centuries which are to be seen in contemporary pictures and book illustrations, show towering castles both at the bow and stern, upon which guns were mounted for chasing purposes. The term forecastle, applied to the former of these erections, still survives in current naval nomenclature, but the portion of the hull now bearing that name is intended to serve very different uses. The forecastle of a modern mercantile ship is useful.

1st. As providing a platform for working and stowing the anchors.

2nd. As a habitation in many cases for the crew.

3rd. As a means of keeping seas from breaking over the bow and getting on the fore deck.

The sides and deck of the forecastle must, therefore, be of substantial construction, and when the crew are to be berthed therein a bulkhead must be fitted at its after end.

Lloyd's Rules allow a reduction of one-fourth from the scantlings which would be reqnired in the same range, if the vessel were flush decked (exclusive of additions for extreme proportions) in the outside plating, stringer and tie plates, stringer angle irons, and deck plank of forecastle. A special Table is prepared for the beams, which are also somewhat lighter than for the upper deck. All the frames are carried up to the forecastle deck, and, in vessels whose plating number exceeds 18,000, alternate reverse frames are extended to the same height, or in lieu thereof a double angle iron stringer is fitted inside the frames, midway between the forecastle and upper deck, the angle iron being of the same size as the frames. Such stringers should terminate at the fore end in the form of a breasthook. The object in either of these arrangements is to stiffen the framing of the forecastle, so as to enable it to effectually resist blows from the sea. The margin plank of the forecastle deck should be of hard wood to receive the fastenings of the guard rail stanchions, and the plating of the side of the forecastle should extend to three or four inches above the stringer plate, so as to admit a stringer angle iron on its upper edge, whereby a watertight connection may be made and resistance provided against the set of the deck caulking. The beams should be effectually pillared, as they have to support considerable weights and endure great stresses in working the capstan, windlass, and anchors.

It is very usual to fit iron bulkheads at the after ends of forecastles, especially in steamers, and in such cases the bulkheads are constructed and stiffened with angle bars in the usual manner.

The sheer strake is usually given a greater sheer than the deck beams, and consequently a substantial thickness is offered for fitting and fastening the hawse pipes. As, however, the frames must be cut in the way of the hawse pipes, compensation must be provided by fitting horizontal frames above and below the pipes, and the locality is further stiffened by fitting either doubling plates or wood chocks thereat. Whatever may be the particular arrangement adopted, the object sought is to obtain a stiff and substantial foundation for the pipes, capable of resisting the local stresses set up when the vessel is riding at an anchor.

The windlass, bitts, chain stoppers, and other similar fittings within the forecastle and above the upper deck, should be laid upon iron plates riveted to the beams, and succoured by chocks, carlings, pillars, etc., in every practicable way.

The knight head of an iron sailing ship is an iron bulkhead at the fore end of the forecastle, with a hole in it to allow the bowsprit to pass through and be wedged thereat; for which latter purpose double angle iron rings are riveted around the hole. The heel of the bowsprit steps against a vertical plate extending from forecastle to upper deck, and supported by vertical brackets. The plate and brackets are efficiently connected to the beams above and below.

It is not unusual to plant the heel of the bowsprit upon the forecastle deck, which in that case is plated over, so that the obliquely cut bowsprit heel may be connected thereto by angle irons. When this course is adopted, the forecastle beams under the plating are of angle iron placed at every frame, and supported by diagonal stays below, riveted to the forecastle frames. The connection of the heel of the bowsprit to the deck plating must be so thoroughly effected by the aid of stout angle irons that the strength of the joint is equal to that of the bowsprit itself at any section. The forward butts of the forecastle deck plank are stopped against an angle iron riveted around the bowsprit heel, and the surface between the angle iron and bowsprit heel is flushed with Portland cement.

It is not desirable to fit wood ceiling or lining inside a forecastle, in consequence of the corrosion which takes place behind the wood. Even when the crew are berthed in the forecastle, it is better to expose the inner surface of the frames and plating, so that they may be continually under observation, and painted when required.

156. **Sunk Forecastles.**—When the forecastle deck is at so small a height above the upper deck as not to provide head room within, it is necessary to stop the upper deck at the forecastle bulkhead, and recommence it at a lower level. Such an arrangement is known as a "Sunk forecastle." In these cases alternate reverse frames are extended to the forecastle deck, and when the topside plating is $\frac{7}{16}$ in. or more in thickness, a reduction of $\frac{1}{16}$ in. is allowed for the forecastle plating.

Care must be taken not to stop the upper deck stringer plate suddenly at the sunk forecastle bulkhead, but to carry it through, and gradually reduce its breadth on the fore side. When the vessel has an iron deck, the continuity of strength is to be preserved as much as possible by fitting brackets on each side of the break bulkhead, and in some cases it becomes necessary to double a strake of the side plating thereat. The length of a sunk forecastle is usually small when compared with that of the vessel, so that the stresses at the break are not in that case so considerable as at the fore end of a raised quarter deck, which case will be presently considered.

157. **Poops.**—A poop is considered as a "full" poop when it is high enough for a man to walk under the beams, standing upright, and when its length is such as must inevitably be required for the accommodation of the officers and stowage of stores. The full poop is, in fact, structurally to the after part of the vessel that which the top-gallant forecastle is at the other extremity, and the Rules for its framing, plating, stringers, and deck planks are the same as have already been described in Art. 155. The beams are, however, lighter, and in no case is it required that reverse frames should be carried up above the upper deck. The pillars under the poop are disposed according to the facilities afforded by the cabin arrangements, and at least one should be fitted under alternate beams, taking care to place a substantial pillar under the steering apparatus. Bulkheads are always fitted at the fronts of poops. In steamers they are always of iron, and in sailing vessels they are usually of that material. Indeed it may be said that at the present day only iron bulkheads are fitted to poops, and in steamers they are of the thickness of the poop plating, with coaming plates $\frac{1}{16}$ in. thicker. The stiffening of poop bulkheads is a matter of great importance, more particnlarly in steamers, in order that they may resist the force of large bodies of water falling on the deck and rushing aft. Consequently plate bulbs are riveted to the ordinary angle iron stiffeners, and brackets are fitted above and below connecting the stiffeners, and therefore the bulkheads, with iron plates riveted upon the poop and upper deck beams in the way of the bulkhead. The bulkhead itself is connected by angle irons to both of these plates.

In sailing ships a portion of this stiffening may be dispensed with, especially when the bulkhead receives support from iron wing houses at each end.

When a poop exceeds one-fourth of the vessel's length, the upper deck stringer plate and sheer strake are either increased in thickness or doubled in way of the front of poop for a length of from twenty to thirty feet, or increased strength obtained in some other approved way.

158. **Raised Quarter Decks.**—The name raised quarter deck was originally given to a poop when so low that if the upper deck were continued beneath it there would not be enough height for cabin accommodation. The upper deck was in that case stopped at a bulkhead, forming the front of the erection, and a deck flat was placed at a lower level, extending from that bulkhead to right aft. Such an arrangement was, and still is, termed a "raised quarter deck," to distinguish it from the full poop under which the upper deck is continuous at its original level to right aft.

Raised quarter decks originated in wood sailing ships, and are still sometimes adopted in small sailing vessels of iron and steel. It is in steamers, however, that they most commonly occur, and that, too, without any reference whatever to cabin accommodation, but solely to serve purposes of cargo carrying in reference to tonnage measurement. Raised quarter decks in steamers are often associated with bridge-houses, but for the present the former will be considered alone.

The raised quarter deck takes the place of the upper deck, and should be treated as such in all the structural arrangements associated with it. Very often there is no other deck laid in the vessel at that part, an instance of this kind being shown by Plate VI., where there is a strong stringer and a widely spaced tier of beams below the raised quarter deck, but no deck flat. The bulkhead forming the front of the raised deck, *i.e.* the "break bulkhead," is very often a principal bulkhead of the ship, at a boundary of the machinery compartment. This bulkhead, whether it serves any other purpose or not, is stiffened with an athwartship plate at the level of the upper deck, the plate being of the same thickness as the tie plates, and connected to the bulkhead by an angle bar. If possible the plate should be riveted to a beam, and when this cannot be done it should be supported by bracket plates. The purpose of the athwartship plate is not only to stiffen the bulkhead, but to receive the fastenings of the wood deck. When an iron deck is laid, only the brackets are, of course, necessary.

As in the case of sunk forecastles, the side plating of the raised quarter deck is allowed to be $\frac{1}{16}$ in. less in thickness than the topside plating below it when the latter is $\frac{7}{16}$ in. in thickness and upwards. The frames in all cases and the reverse angle irons to alternate frames are extended to the raised quarter deck stringer plate. When the raised quarter deck is in length more than one-fourth that of the vessel, the number and arrangement of the hold beams, beam stringers, and stringers in hold, in way of the same, are regulated by the increased depth of the vessel; and the height to which the reverse frames are extended is regulated by the increased number for scantlings which the greater depth would give.

In all cases the upper deck sheer strake is extended right aft to the stern in the same way as if there were no raised quarter deck fitted, so that the upper strake in way of that deck is not the sheer strake of the vessel.

When the raised quarter deck is less than one-fourth of the vessel's length, the upper deck stringer plate maintains its breadth to the break of the quarter deck, and may then be gradually reduced in breadth until it terminates at the fourth frame abaft the break. The stringer is throughout to be riveted to the shell plating. But when the raised quarter deck is more than one-fourth the vessel's length, the upper deck stringer plate extends seven frame spaces abaft the break, the raised deck stringer extends about four frame spaces before the break, and the stringers below the upper deck are allowed a shift of about sixteen feet overlap. This scarphing and overlapping of the deck and hold stringers, in order to assist in preserving continuity of strength at the break, is shown by Plate VI.

When an iron deck is required, and is severed at the break, its continuity of strength is as much as possible maintained by a short overlapping and by fitting efficient brackets, securely attached to the break bulkhead and to the iron deck before and abaft the same.

Upon Plate VI. the sheer strake is shown to be doubled in the way of the break of raised quarter deck. This arrangement, or an equivalent, is required for all cases in which the raised quarter deck is more than one-fourth the length of the vessel; the side plating of the raised

deck is also increased in thickness at the break, and for some distance on each side of it. Besides these measures, the butt straps of the raised deck side plating, sheer strake, and strake of plating next below, are treble riveted in the neighbourhood of the break, the straps being one-sixteenth of an inch thicker than the plates they connect. All these additions indicate the importance attached to the maintenance of uniformity of longitudinal strength, especially in iron and steel steamers; and when we consider the different structural resistances due to the unequal depths before and abaft the break, the abrupt termination of decks at that part, and the probably unequal stresses due to the weights carried on the two sides of the bulkhead, it will be seen that the precautionary measures against discontinuity of strength are no more than are necessary.

159. **Bridge-Houses.**—These often occur in conjunction with either poops or raised quarter decks, as in the case shown by Plate VI.

When the combined length of poop or raised quarter deck and enclosed bridge-house is two-fifths of the vessel's length, and the plating number is 15,000 and above, Lloyd's Rules requires the sheer strake to be doubled for half the vessel's length amidships, or other equivalent strength is to be added.

In the case shown by Plate VI., the plating number is less than 15,000, but the sheer strake, as indicated, is doubled at two places—viz., the break of the raised quarter deck, and at the front of the bridge.

The Rules applying to the outside stringer, the plates and stringer angle irons of bridge-houses are the same as those to poops and forecastles already referred to. The construction, stiffening, etc., of bridge-house bulkheads of steam vessels are identical with those for the bulkheads of poops which were described at Art. 157.

All bridge-house frames extend to the bridge decks, or else the frames are built upon the upper deck, and connected to the stringer plate by knees and bracket plates. By fitting partial bulkheads at proper intervals, only alternate frames need extend to the bridge deck, and this course is frequently adopted when it is necessary to cut large illuminating holes in the plating for lighting cabins under a bridge, as ample space is thereby found for the lights and the frames to them, while the partial bulkheads are arranged to serve as the divisions between the cabins.

As already remarked at page 1[illegible], when the frames extend through the upper deck stringer, a continuous stringer angle iron is wrought on the upper deck stringer plate inside the frames, as shown inside the bridge-house in Plate III.

Bridge-houses are the most useful deck erections in a steamer, as they serve to enclose the machinery casing, and increase the freeboard of the ventilating gratings to stokehold. What would otherwise be the most vulnerable parts of a steamer, are, hy virtue of the bridge-houses, placed fairly beyond the reach of injury from the sea. But that this advantage may be obtained, it is necessary the bridge-house should be substantially constructed, more especially in regard to the bulkhead at its fore extremity, which should be so stiffened as to effectually resist all blows from seas falling upon the deck. Any openings in that bulkhead should be carefully protected by iron doors, and these latter, when open, should lead into a narrow bulkheaded alleyway, and not into an open space capable of receiving large bodies of water. The casing of machinery space should reach from upper deck to above the bridge deck, and all openings in that casing should be properly protected with iron doors. All the bulkheads and casings should be efficiently stiffened, and the whole disposed with a view to the vessel's safety when laden and labouring in a sea-way.

160. Awning Decked Vessels.—The only deck erections peculiar to sailing vessels are a topgallant forecastle at the one end, and a poop or raised quarter deck at the other. The purposes of both of these have already been described, and in the only instance in which a sailing vessel has a bridge deck there is no poop fitted, nor are there any deck houses, so that the bridge-house furnishes accommodation to the officers and crew, and has no other function.

But in steamers, as has been seen, deck erections are more varied and extensive in their character and uses.

Indeed, it is not uncommon to see a long poop, bridge-house and topgallant forecastle, which together are nearly equal in length to the vessel, there being only small open spaces between the erections. To such an extent is this the case, that one not acquainted with the operating causes which lead to such arrangements would at once enquire why the whole was not closed in by making a continuous deck above the upper deck. Under certain special circumstances this is sometimes done, and the deck is described as an "awning deck." Vessels so built are known as "awning decked vessels," but only steamers are constructed in this way. The whole of the space between the awning deck and main deck is measured for tonnage, and of course all dues are paid thereon, whether cargo be carried in the space or not. Now, it is quite clear that a vessel with a continuous erection such as this is much safer against risks due to shipping heavy seas, than one in which there are open spaces between forecastle and bridge-house, and between bridge-house and poop, provided both vessels have the same freeboard. But in the latter case, it is possible by leaving unenclosed spaces under the decks of the several erections, to very considerably minimise the portion measured for tonnage, and advantage is sometimes taken of this to a very dangerous extent. Generally speaking, it may be said that the operation of the tonnage laws in regard to the deck erections of steamers is not in the direction of increased safety. Under proper structural and loading limitations, an awning decked vessel is superior to one with discontinuous structures upon the main deck, and the building of such should therefore be encouraged.

Lloyd's Rules describe an awning decked vessel as "one having a comparatively light superstructure fore and aft on the main deck proper of the vessel, intended to shelter passengers or cattle, or for the conveyance of cargo, either light in its nature or limited in its quantity." By this we understand that such a vessel is not to he loaded as if the awning deck were the main deck, but that advantage may be taken of the latter being covered in, to the extent of carrying only a small additional cargo in the covered space.

All the scantlings for an awning-decked vessel are based upon the dimensions under the main deck, as in an ordinary one or two-decked vessel. The awning-deck being itself a continuous erection, no erections are in general allowed to be placed above it except such as are necessary for the navigation of the vessel. Should anything more than that be desired, it would be necessary to strengthen the deck and the plating and frames beneath it. The side plating from the main deck upwards in vessels of this description must be unbroken by scuppers, and if cargo ports are fitted, means must be adopted for effectually closing them in a watertight manner on the inside, and of stiffening the plating in their vicinity.

Only the main frames extend from the main to the awning-decks, but all the reverse frames extend to the main deck stringer. The side plating between the main sheer strake and awning-deck varies from $\frac{5}{20}$ in. to $\frac{7}{20}$ in. in thickness, and the awning-deck stringer plate is from $\frac{6}{20}$ in. to $\frac{7}{20}$ in. in thickness, according to the size of the vessel. If the latter has considerable proportion of depth to length, special provisions are made for giving longitudinal strength at the gunwale. The butts of the awning-deck side plating are double riveted, and the flat of awning-deck is allowed to be one-fourth less in thickness than that of the main deck. The main deck stringer plate is attached to the shell plating by short pieces of angle iron fitted between the frames, and a stringer angle iron is fitted fore and aft against the frames, and riveted to the portions of the reverse frames which extend a few inches above the stringer plate. The spaces between this angle iron and the sheer strake all fore and aft are filled in with chocks, cemented, and made watertight.

As already remarked, it is necessary to limit the loading of awning-decked vessels, in consequence of the disposition to treat the awning deck as a main deck by giving only as much freeboard as in an ordinary one or two decked vessel of the same dimensions and form. The strains brought upon the upper works of the vessel, if thus loaded, would be dangerous, and, therefore, Lloyd's Committee insist, as a condition of classification of awning decked vessels, that each shall be marked with a load line

assigned by them, and vessels loading below that line forfeit their classification in the Register Book.

The main decks of some vessels are only partially covered with a deck of light construction, the sides, etc., under that deck being formed as already described. These are known as "Partial awning decked vessels."

161. Shelter Decked Vessels have still lighter continuous erections than those known as awning decked, the space between the upper and shelter deck being entirely closed in as in the last named.

162. Shade Decked Vessels have a very light deck above the main deck, generally extending over the whole length of the vessel, but the space between the decks is not enclosed at the sides above the level of the main rail or bulwark. It is, really, only a protection from the weather.

163. Spar Decked Vessels.—These are steam vessels whose upper decks and side plating above their main decks are more substantial than in awning decked vessels, but not equal to the case of ordinary vessels built upon the three decked rule. They are described by Lloyd's Rules as "Those which are of lighter construction than vessels built under the Three Decked Rule, having the same dimensions, taken with reference to the total depth to the spar or upper deck in either case." And in a foot-note it is said "This does not necessarily imply that the vessel is of less strength in relation to the amount of dead weight carried at a suitable load line." From this it appears that a spar decked vessel should, by reason of her lighter construction, be given a greater freeboard than an ordinary three decked vessel.

Spar decked vessels must have three tiers of beams, and be not less than 17 feet in depth from top of keel to the main deck. If of less depth, a minimum freeboard is fixed as a condition of classification.

The spar deck being a continuous erection, albeit a very substantial one, if other erections are built upon it, additional strengthening to deck and sides are necessary.

The scantlings of a spar decked vessel are fixed by the dimensions under the main deck, but it is assumed that the height of the spar deck above the main deck will not exceed eight feet, as otherwise additional transverse strength is necessary.

All the main frames extend to the spar deck stringer plate, and the reverse frames extend to the main and spar deck stringers alternately.

The side plating between the main deck and spar deck sheer strake varies in thickness from $\frac{7}{20}$ inch to $\frac{9}{20}$ inch, according to the size of the vessel; also the spar deck sheer strake may be $\frac{1}{10}$ inch and the stringer plate $\frac{1}{20}$ inch less in thickness than those of the main deck. A side intercostal keelson is fitted in spar decked vessels, and the lower edge of the main sheer strake must not be more than half its depth below the main deck stringer plate.

The main deck stringer angle irons are fitted as described for awning decked vessels, and similar precautions taken to make the spaces between the frames watertight.

The measurement of depth for regulating the additional strength required for vessels of extreme proportions are taken from the upper part of keel to the top of the *main deck beams.* The extra strength at bilge and bottom is proportionate to the relation of length to depth from main deck, but in regard to the remaining elements of extra strength, a spar decked vessel may be 13 and under 14 depths in length before requiring those additions prescribed for ordinary vessels of 11 to 12 depths in length. Spar decked vessels exceeding these proportions are to have extra strength in the same relation as that prescribed for one and two decked vessels.

These modifications in the Rules for extra proportions will indicate the relation which spar decked vessels bear to those of the ordinary type. They are very usual in passenger lines of steamers to India, Australia, etc., wherein deep loading is not desired, and very heavy work has not to be performed. Plate IV., fig. 1, shows the midship section, and fig. 2 of the Plate, a web frame of a spar decked steamer. In this case a special arrangement of box waterway is fitted to the spar deck, but this is not a necessary nor usual feature in vessels of this class.

CHAPTER XV.

164. Deck Planking.—In wooden ships the deck planking is of important structural value, besides serving as a platform for the crew, and a watertight covering to the hull of the vessel. For the physical properties of the materials of which the deck is formed do not differ much from those composing the remainder of the vessel, and consequently the deck planks act in association with the other parts, and contribute their due share to the strength of the structure.

But the wood deck of an iron ship is little else than a platform and a watertight covering, for the difference in the elasticities of wood and iron are so great that the former will yield before the latter has developed but a small fraction of its ultimate tenacity. Hence the structural arrangements of an iron or steel vessel should be made without much reference to any actual strength possessed by the wood work that enters into her construction. The only way in which a wood deck can develop considerable efficiency is when it is laid upon an iron deck and properly fastened thereto, as in that case the wood stiffens the iron plating, and keeps it to its work without allowing it to buckle.

The simplest and most ordinary case of a wood deck in an iron ship, is when the said deck is laid upon beams formed with bulb plates and donble angle bars, or upon rolled beams of the Butterly pattern (see B, fig. 12). The deck planks are in that case fastened to the beams with iron nut and screw bolts. But when the wood deck is laid upon an iron deck, the nut and screw bolt fastenings are arranged to come between the beams, with about two fastenings in each plank in the length of a beam space.

Wood decks are usually of yellow pine, or, as it is sometimes termed, "Quebec white pine." This material is light, tolerably free from knots and rents, does not shrink much when well seasoned, has a satisfactory appearance, is fairly durable, especially when frequently oiled, and wears evenly.

Pitch pine is sometimes employed, chiefly because it is cheaper than yellow pine, and available in longer lengths. Pitch pine is however heavier, more liable to split and shrink, and generally does not endure great changes of temperature so satisfactorily as yellow pine. Moreover, pitch pine contains a great qnantity of resin, which, under the influence of a tropical sun, is forced out, leaving empty cells, which at once absorb water, and sometimes cause leaks. Pitch pine does not wear evenly, and is very liable to strip off in flakes and long splinters. On the whole, pitch pine is inferior to yellow pine as a material for the upper decks of vessels.

In the Royal Navy, and a few vessels of the mercantile marine, Dantzic and Riga crown deals are used for decks. This material is very durable, and forms a good watertight deck, but the deals are too broad to give an agreeable appearance to the deck, and they are heavier than yellow pine. For wear they are unsurpassed by any other of the fir species.

The decks of vessels trading much in tropical climates are very often of East India teak, which is the most durable and the least disposed to shrink of all woods employed in shipbuilding. Teak decks are heavy, but some of the additional weight, due to higher specific gravity, is saved by thinner planks being sanctioned, as will be seen presently. No deck material wears better, or is more durable and free from defects than well selected East India teak. Care has, however, to be taken to ensure freedom from the worm holes which are very common in that timber.

In the Royal Navy Dantzic oak is sometimes used for decks in consequence of its hardness and the long straight lengths in which that variety of oak can be obtained, but the use of this material for decks is unknown in the mercantile marine.

Care should always be taken in the selection of the

material for a wood deck. It should be free from objectionable knots, that is to say knots which are large, which cut across the grain of the wood, which are liable to fall out, or which are at all defective. Indeed, as a rule, knots should be avoided as much as possible. It is further necessary to avoid sap, which quickly decays and causes leakage. In all cases the margin or boundary planks of weather decks are required to be of teak or greenheart, preferably the former; and it is further desirable to fit teak or greenheart planks around hatchway and deck-house iron coamings, and the iron bulkheads of poops, forecastles, and raised quarter decks. The margin planks of poops, bridge-houses, and forecastles should be of teak or greenheart, there being the additional necessity in these cases in order to secure good fastening for the guard rail stanchions.

The thickness of upper deck planks is governed by the size of the vessel, and varies from 2½ inches in the smaller coasters, to 4 inches in vessels of about 1000 tons and upwards.

When the deck is of teak a reduction in thickness of one-seventh is allowed, and when a wood deck is laid upon an iron one, a reduction of half an inch in its thickness is permitted.

The holes for deck fastenings are punched in the beam angle irons before they are raised in place, as already explained. When the deck planks are six inches wide, and under, a single fastening is placed in each plank in each beam; when they are above six inches, and not exceeding eight inches in width, there must be two bolts in each plank in each beam, one of which may be a short screw bolt from below; and planks exceeding eight inches in width must be double fastened with nut and screw bolts.

The upper deck is fastened by screw bolts with nuts on the under side of the angle iron of the beams, stringers, tie plates, and deck plates. It is desirable that these bolts should be galvanised, in order that they may not induce early decay in the wood through corrosion. The bolts are properly sunk in dowel holes bored for the purpose, so that when the bolts are driven and screwed up there shall be sufficient space above the head for fitting a substantial turned dowel over it. Oakum and white lead are placed under the heads of the bolts, and the dowels are bedded in white lead, or some suitable composition, so as to ensure watertightness. It is desirable that the deck may stand considerable wear before the bolt heads are exposed, and for that purpose the bolt heads are sunk into the deck, so that their heads are one inch beneath the surface in a 4 inch deck, and slightly less in $3\frac{1}{2}$ inch and 3 inch decks. The dowels are cut so that the grain of the wood in them may correspond in direction with that of the deck planks, and they are generally made from teak, although some shipowners prefer them to be of the same material as the decks.

The nut and screw bolts for deck fastenings are of the following sizes in vessels classed at Lloyd's:—

For decks of 3 inch and under $3\frac{1}{2}$ inch,	- -	$\frac{1}{2}$ inch.
" $3\frac{1}{2}$ " " 4 "	- -	$\frac{9}{16}$ "
" 4 "	- - - - -	$\frac{5}{8}$ "

Deck planks are butted upon the beams, except in the way of tie plates and stringer plates, or when an iron deck is fitted under the wood deck. If the beam is formed with plate bulb and double angle irons on the upper edge, there is sufficient breadth in it to receive the fastening on each side of the butt (fig. 28); but when a rolled section of beam

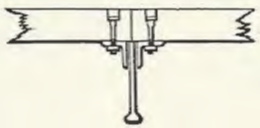


Fig. 28.

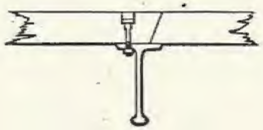


Fig. 29.

is adopted, the breadth of the upper surface is not generally sufficient for the purpose without placing the bolts too close to the butts. In the latter case the butts of the planks are so cut and fitted that one bolt serves for both (see figs. 29 and 30). Through butt fastenings are found by experience to be a source of decay, for the wood speedily becomes discoloured by the iron bolts thereat, and this is followed by softening of the material and slight leakage. This defect occurs more readily and to a greater extent at the butt than at the other fastenings, so, with a view to make wood decks more durable and avoid unsightly grav-

ing pieces at the butts, the latter are sometimes fastened with galvanised iron "coach screws" from the under side. This kind of fastening is, however, limited to the butts (see fig. 31).

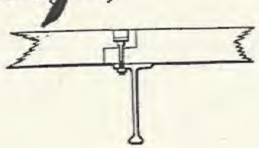


Fig. 30.

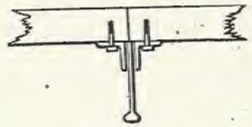


Fig. 31.

The usual breadth of deck planks is five inches, and sometimes planks as narrow as four inches are used, but breadths of six inches to eight inches are not uncommon. An advantage is found in using planks of the same breadth and thickness, as either of the four sides of the planks which happens to be the best may then be placed uppermost. The butts of a wood deck are so arranged that there are three passing strakes between consecutive butts on the same beam or in the same transverse section of the vessel.

When a wood deck is laid upon an iron one, there should be, as already mentioned, two rows of fastenings in each beam space, so that the bolts in each plank are about two feet apart. The planks must, in all cases, be carefully scored over laps or butts of tie plates and closely fitted upon the iron; the surfaces in contact being coated with lead paint, so that no water may lie between them. It is further necessary to have the wood and iron in intimate union, in order that the former may effectually stiffen the latter.

165. Ceiling and Sparring.—Although performing some of the same functions as devolve upon the ceiling of a wood ship, that of an iron vessel has no structural importance whatever. It is useful only in keeping the cargo from getting between the frames, or from resting upon double bottom plating, in the flat portion of the vessel; and above the bilge the cargo is to some extent kept off the shell of the vessel by the horizontal battens known as the "sparring."

The ceiling is of red or pitch pine, and it varies in thickness from 2 inches in vessels under about 300 tons to $2\frac{1}{2}$ inches in those of larger size. Close ceiling is usually limited to the upper surface of ballast tanks, and elsewhere to the height at which the bottom and bilges are connected. Beyond those limits sparring battens are fitted.

As much as possible of the ceiling should be portable, in order to afford ready access to the limbers, or to the surface of inner bottom when a ballast tank is fitted. The whole of the ceiling resting upon double bottoms is laid in such a way that it may be easily lifted, and no fastenings are put into it and the inner bottom. Man-hole covers are surrounded with a portable framing and covered with small hatches. In ordinary cases, when there is no double bottom, a strake of ceiling is laid on each side of each keelson right fore and aft, and these are usually fastened to the reverse frames with nut and screw bolts. The remainder of the ceiling in flat of hold is fitted in short hatches, formed with planks tie bolted together; but the whole of the close ceiling at the bilges is in most cases fastened with nut and screw bolts to the reverse frames. The upper limit of the ceiling is closed in with covering boards scored between the frames, and made tight with wood chocks, oakum, cement, etc., in order to prevent water rolling in the limbers from escaping thereat, and damaging cargo. Ring bolts are fitted in the ceiling hatches for convenience in lifting them in and out of place. Ceiling in hold must be closely fitted at the edges and butts, in order to prevent any portion of cargo or ballast from getting down and damaging the cement by continually rolling upon it. It is undesirable to fit close ceiling above the limits to which the cement extends, as iron is very liable to corrode when so confined unless protected with cement or an equivalent coating. Paint is not sufficient to prevent corrosion under such circumstances, and for that reason floors, frames, and reverse frames under the ceiling should be washed with a solution of cement and size rather than be painted.

The cargo battens or sparring are sometimes fastened to the reverse frames with nut and screw bolts, but it is preferable to fit them in a portable manner, so that the iron work may be easily accessible for cleaning and painting. It is not unusual to rivet iron cleats to the reverse frames, into which the sparring in hold and 'tween decks is dropped, and thereby secured in a portable manner.

In the case of water ballast tanks, ceiling hatches are fitted over the side limbers to keep cargo from the drainage and so prevent it from being damaged.

To prevent the corrosion which is usually found to take place in the angle irons of keelsons against the edges of the continuous ceiling strakes, it is found advantageous to leave a space of about two inches between the edges of these strakes and the vertical flanges of the keelson angle irons, and fill the space with Portland cement.

166. Cementing and Drainage.—The earliest experience with iron ships showed that corrosion was more rapid in the inside than on the outside surface, and this was more especially found to be the case in the flat of the bottom, where condensed moisture from the cargo and other drainage collected and rolled about from side to side between the floors with every movement of the vessel. This water almost invariably holds acids in solution, resulting generally from chemical changes in the organic matter of that part of the cargo which finds its way between the interstices of the ceiling. This is especially the case with sugar, and it also occurs to a lesser extent with grain cargoes of all descriptions. The drainage from nitrate of soda, nitrate of potash and common salt is destructive to iron, and even greater damage is done by iron and copper pyrites when they get into the limbers.

To prevent damage to the inside surface of the plating, etc., from such causes as these, asphalte was at one time laid upon the flat of the bottom plating and the frames, extending to the upper turn of the bilge, but this was often found to be so softened through the ordinary heating of the cargo, that in time it left the more elevated surfaces, such as butt straps, unprotected, and flowed into the lower levels.

Portland cement mixed with sand is the material which is now most frequently employed for covering the inside surface of the shell and frames, and a coating of this is laid as high as the close ceiling extends. About equal proportions of the cement and sharp clean river sand should be employed, and any difference in the proportions should be rather in excess of cement than otherwise. Salt water sand should be avoided, in consequence of the great affinity of salt for water, which tends to arrest the chemical action known as "setting." It is not desirable to incorporate large pebbles, or even brick or any other similar material in the cement, for should these become subsequently loosened, they are a source of injury to the cement by cutting it up through the rolling motion of the vessel.

The drainage holes in the frames for establishing an uninterrupted communication between the pumps and every frame space are shown upon the several sketches of midship sections in the accompanying Plate volume. These holes are usually circular, and about three inches in diameter, the holes being cut in the floor plates immediately above the frame angle irons. Similar holes, at a corresponding level, are cut in intercostal middle line and side keelson plates below the bilges.

The cement at the middle line of the vessel is in most cases laid sufficiently thick to form a level surface right fore and aft, flush with the lower part of the limber holes, so that water may not collect in any individual frame space without spreading throughout the whole length of the vessel and thereby coming under the influence of the pumps.

In the ships of the Royal Navy, and some mercantile vessels, small drainage holes, measuring from about 2 in. × 1 in. to 3 in. × $1\frac{1}{2}$ in., are cut in the frames below the 3 inch limber holes, and the cement is then laid only so thick as to reach the under side of these smaller holes. This is done with a view to reduce the weight of cement, and therefore add to the vessel's carrying power in other respects. The small holes must, however, be cut smooth at their edges to prevent them from becoming speedily choked; and considering the foul state in which the limbers of vessels are frequently found when examined after the completion of a voyage, it is questionable whether any real gain is effected by this measure in mercantile ships not having double bottoms, for the small holes will frequently be choked, and consequently in that case water will be carried in each frame space as high as the large limber holes. Inside double bottoms, however,

the reduction in weight will doubtless prove as real as in the similar cases of the Royal Navy.

The cement is usually laid with a flat surface at the middle line, but towards the sides of the vessel it is rounded up so as to cover the frame angle bars and protect them from corrosion. The thickness of cement should not be less than three-quarters of an inch over the rivet heads of the butt straps or [illegible] and correspondingly thicker elsewhere. As already remarked, the floors are better protected by a coating of cement wash than by any paint or other composition. The upper surface of inner bottom plating should be thinly coated with cement to prevent corrosion between the surfaces of the iron and the ceiling planks.

It is necessary to carefully examine the spaces between the frames, before closing in the ceiling, to ensure that no rivets, bolts, or pieces of wood are left to roll upon the cement and destroy it. Instances are not unknown in which a bolt has cut, not only through the cement, but also deeply into the shell plating itself during a voyage.

Before concluding these remarks upon cementing, it is desirable to point out the extreme importance of cleaning the surface of the plates before laying on the cement, which should adhere closely to the iron. The use of ashes or any other such substance in association with cement cannot be too strongly condemned.

167. Sluice Valves, Pumps, etc.—Sluice valves, if fitted at the limbers to engine room bulkheads, should be in accessible positions, but no sluice valve or cock should be fitted to the collision bulkhead. In this way the circulating pump in engine room may be used to clear the adjacent cargo holds of water. The sluice valve should be placed just above the cement level, and be opened and shut by a rod worked with a spanner at the upper deck, or at some other available position above the load water line. [It is a great advantage to fit the deck plate arrangement for receiving the spanner in such a way as to show by an indicator whether the valve is open or shut.] The same holds good in regard to watertight doors, and the covers to all other openings which it is found necessary to cut in watertight bulkheads. Sluice valve rods should always be effectively protected with a trunk or casing.

The arrangement for pumping a steam ship is both more complete and more complex than that for a sailing vessel, for in the former case steam power is available, whereas in the latter dependence has usually to be placed upon the hand pumps only.

In a sailing ship there is always a pair of hand pumps with suctions reaching down close upon the cement at the middle line, and often with additional suctions reaching to the bilges.

In a steamer an engine suction is carried into every compartment both of the hold and double bottom, and in addition an efficient hand pump to the bilges is required on each side of the vessel in each cargo compartment, capable of being worked from the upper and main decks.

The engine suctions are worked by a donkey engine supplied with steam from a donkey boiler; and it is therefore most important that both the donkey boiler and the engine should be placed at such a height in the vessel as to be available for pumping water out of her even when the latter has risen to the level of the main boiler furnaces. By placing a donkey boiler and engine in the lowest part of the vessel, no advantage can be derived from them at the time when they are most needed.

The height of water in the limbers is ascertained by dropping a sounding rod and line through a sounding tube, one of which is fitted against a bulkhead in every compartment, both of the hold and double bottom. These tubes extend to the weather deck, and are accessible by deck plates with screw covers.

An iron doubling plate should be fitted below each sounding tube, in order to protect the shell plating thereat from injury through the frequent dropping of the sounding rod.

CHAPTER XVI.

168. Iron and Steel Masts.—The lower and topmasts, bowsprits, and principal yards of iron and steel vessels are now almost invariably made of the same material as that of which the ship is built. Such masts and spars are both lighter, stronger, and more durable than those made of wood. Large wooden masts are necessarily built with many pieces, and the existence of so many joints and surfaces in contact, at which water may be admitted, is found to be a source of decay, so that built masts are not, as a rule, so durable as those made with a single spar. Sailing ships are now usually of so large a size that if their masts were of wood they must necessarily be built, and on this account, if for no other reason, the use of iron and steel masts has become an economical necessity. Indeed the advantage of iron and steel masts in regard to strength, weight, and durability is so well established that it is very usual to fit them in the large wooden ships of North American build which are commonly employed in the timber trade.

169. Quality of Mast Materials.—In consequence of the great amount of bending which the plates of iron masts have to undergo in order to produce the required cylindrical form, it is necessary that the material should be of excellent quality, and free from lamination, blisters, or other defects. Not only is this desirable with a view to the proper working of the material, but also in order that the masts may be strong and free from brittleness when made. The iron should be capable of enduring a tensile stress of 20 tons to the square inch, and should also stand the following bending tests when cold without fracture; the plates being bent over a slab, the corner of which is rounded with a radius of half an inch:—

Thickness of Plates.	To Bend Cold through an Angle of	
	With the Grain.	Across the Grain.
$\frac{9}{16}$	25°	8°
$\frac{8}{16}$	30°	11°
$\frac{7}{16}$	37°	13°
$\frac{6}{16}$	47°	15°
$\frac{5}{16}$	55°	17°
$\frac{4}{16}$	65°	20°
$\frac{3}{16}$	70°	25°

170. Lower Masts.—Iron and steel lower masts are made of varying diameters, the greatest being at the wedging of the upper deck, and the least at the mast head. Other fixed points in regulating the diameter of a mast are the "hounds" or "top" and the heel. The diameters and the thicknesses of plating at each of these portions are regulated by the total length of the mast. For instance, according to Lloyd's Rules, a sailing ship's lower mast, of iron, which is 78 feet in length over all, is 26 inches in diameter at the upper deck mast partners, 21½ inches in diameter at the "hounds," 20 inches in diameter at the heel, and 17½ inches in diameter at the head. The section is, of course, everywhere circular, and in this particular case the plating, when of iron, is $\frac{7}{16}$ in. thick at the deck and $\frac{6}{16}$ in. in thickness elsewhere. The plating is, however, doubled at the wedging. As a comparison between this and other lengths of sailing ships' masts, it may be remarked that the several specified diameters of a 48 feet iron or steel mast are 16 inches, 13½ inches, 13 inches, and 11 inches at the deck, hounds, heel, and head; also that the thicknesses of plating, when of iron, are, respectively, $\frac{5}{16}$ in., $\frac{4}{16}$ in., $\frac{4}{16}$ in., and $\frac{3}{16}$ in. Also a mast 96 feet in length has diameters of 32 inches, 26½ inches, 25 inches, and 21 inches; while the thicknesses are $\frac{9}{16}$ in., $\frac{7}{16}$ in., $\frac{7}{16}$ in., and $\frac{6}{16}$ in., respectively. These are all minimum scantlings when iron is

employed, and if the material be steel a slight reduction is permitted, but not so much as is allowed for the hull of the vessel, because of the great ductility of mild steel. For, although this material has great ultimate tenacity, it is yet desirable to provide against any alteration of form whatever in the mast or spar, except that due to elasticity alone.

Lower masts of from 48 to 72 feet in length may, by Lloyd's Rules, be made with two plates in the round, those of from 72 to 96 feet in length may be formed with three plates in the round, and longer masts should be formed with four plates in the round. It is, however, essential in all cases wherein there are less than three plates in the round, that the material shall be of such a good quality as to admit of its being bent to the required form without undue heating, and without fracture or tendency thereto.

Lower masts of 84 feet and upwards in length should be stiffened with angle bars, one being placed throughout the entire length of the mast at the middle of each breadth of plating. The angle bars are increased in size with the increase in the mast's length.

The plating of lower masts is lapped at the edges and double riveted, the rivets being pan headed, countersunk and chipped flush on the outside. The butts are usually connected with butt straps $\frac{1}{16}$ inch thicker than the plates, and it is recommended that these should be placed on the outside of the mast. Some builders, however, prefer to lap both butts and edges, but this method is not recommended, in consequence of the greater shearing stresses endured by the butt rivets. When the butts are closely fitted against each other, as they always should be, they render support to the butt rivets against the shearing stresses set up by the downward forces acting upon the masts.

The butt straps may be double riveted below the upper deck, but they should always be at least treble riveted above, in order to offer as much resistance as possible against the tendency to open the butts which is due to the bending of the masts. It is with a further view to secure this result that the butt straps are placed upon the outside rather than upon the inside of the mast. Moreover, when butt straps are placed on the outside, the fitting of the stiffening angle bars on the inside is much simplified.

It need scarcely be pointed out that the butts of plates and angle bars should be carefully shifted, and every care taken to maintain such a continuity of strength as shall cause the mast to behave as if formed of one unjointed length of wrought iron or steel tube.

The masts of steamers when intended for auxiliary purposes are permitted by Lloyd's Rules to be one-eighth less in diameter than those for sailing ships, and the mizen masts of barques may be reduced one-fifth in diameter, with the thickness of plating corresponding to the reduced diameters. also bowsprits

* The doubling plates of masts are extended several feet above and below the deck, and must stop clear of the butts in the vicinity. When the mast is wedged at two decks, the doubling should extend from several feet above the upper, to as many below the lower of the two decks.

Fig. 1, of Plate XXXIII., shows the construction of an ordinary iron or steel lower mast.

Sometimes lower masts and top masts are made in one length, and in that case the scantlings of the portion corresponding with the ordinary lower mast are determined by the length from the heel to the ordinary height above the hounds at which the mast head is situated. The scantlings of the topmast portion are, of course, increased at the lower part, in order that there may be continuity of strength throughout the entire cylindrical tube, which is tapered fairly from the hounds upwards. The stiffening angle bars should be extended as far as practicable through the topmast, and the upper parts of the angle bars should terminate at different heights.

171. Iron and Steel Bowsprits.—The three positions in an iron or steel bowsprit at which the diameters are regulated by Rule are the "bed," or wedging at the knight head, the heel, and the cap. The bowsprit is put together similarly to the lower mast, but in every case stiffening bars are fitted through its length at the middle of each strake of plating composing the round. It is unnecessary to quote any of the scantlings required by

Lloyd's Rules for bowsprits of different sizes, but it may be remarked that although very much shorter than the lower masts of the same vessel, the diameters and thicknesses of plating are about the same. The necessity of this will be seen when we consider the great bending stresses endured by a bowsprit in comparison with the support which can be afforded to it in the form of shrouds and stays. To further strengthen large bowsprits, it is required that when they exceed 28 inches in diameter, they shall have a vertical diaphragm plate extending from within the wedging at the knight head to the "gammoning," or security of the bowsprit above the cutwater. This diaphragm is connected to the plating of the bowsprit by continuous single angle irons, in addition to the usual stiffening angle irons fitted to bowsprits of lesser diameter. The edges of the plates are double riveted, and the butts are treble riveted outside the wedging, but they may be double riveted on the inside of the vessel. The plates of the bowsprit, like those of the lower masts, are doubled at the wedging. Bowsprits & lower masts of steamers rigged for auxiliary purposes may be one-eighth less in diameter than those for sailing vessels.

Of late it has been very usual to make the bowsprit and jibboom in one length, the result being known as a "spike" bowsprit. When this is done, the diameters and the scantlings of the bowsprit proper are determined by the length measured to the bobstay hoop, which corresponds with the usual position of the cap. Beyond that point the spar is considerably tapered, and the total length of bowsprit and jibboom thus formed in one, is much less than the collective lengths of the two as ordinarily fitted. It need scarcely be remarked that the foremast is placed * rather further aft in vessels so rigged than would otherwise be the case, in order to obtain the necessary area of headsail for manœuvring the ship. A bowsprit of this kind is fitted in the four-masted sailing vessel shown upon Plate XXXIV.

As was mentioned at Art. 155, bowsprits are sometimes bevelled at the heel, and planted upon iron plating laid upon the forecastle beams, instead of passing through a hole in the knight head and being wedged thereat. The mode of securing such a bowsprit at the heel, and of supporting the deck plating to which it is connected, has already been described. It is necessary, however, to mention that the length of such a bowsprit should be measured along its longitudinal axis, from the forecastle plating to the bobstay hoop, and the scantlings arranged according to the requirements for that length. Fig. 4, Plate XXXIII., shows the mode of connecting the parts of an ordinary iron or steel bowsprit which is not of large size.

172. Iron and Steel Topmasts (Fig. 2, Plate XXXIII).—The parts of an iron or steel topmast at which the diameters are measured are the heel, the topmast trestle trees, and the head. They have usually two plates in the round, and are not commonly stiffened with angle bars. The laps of the edges are single riveted, and the butts are connected by treble riveted straps, which are $\frac{1}{16}$ in. thicker than the plates they connect.

The butt straps to topmasts should be fitted in the inside, in order that the outer surface of the mast may be smooth, both in view of the raising and lowering it through the lower mast cap, and the raising and lowering of the topsail yards.

The plating of topmasts is doubled in the way of the lower mast cap, and at the fid and sheave holes.

Should stiffening angle bars be put into a topmast, it is necessary that they should be so arranged as to pass continuously by the sides of the sheaves and not be severed thereat, as in the latter case the inevitable discontinuity of strength at the sheave holes is much increased and the mast relatively weakened.

173. Iron or Steel Yards (Fig. 3, Plate XXXIII).—These are cylindrical tubes, tapered towards both extremities, and formed with two plates in the round, lap jointed at both edges and butts. The edges are single and the butts treble riveted. The scantlings of each half of a yard are fixed at the centre—first, second, and third quarters and the ends—the taper being fair throughout. The plating of lower yards is doubled at the centre to beyond the truss hoops.

174. Lower Mast Cheeks, Caps, etc.—The "tops" are

supported by cheek plates, riveted against the sides of the masts, and having angle irons riveted upon their upper edges. The cheeks thus formed serve the combined purpose of the "bibs" and "trestle trees" of wood masts. The cheek plates vary in thickness from about $\frac{7}{16}$ in. to $\frac{11}{16}$ in., according to the size of the mast, and the angle irons on their upper edges vary in size from $3\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{6}{16}$ in. to 6 in. $\times$ 4 in. $\times$ $\frac{10}{16}$ in.

Caps to iron and steel lower masts are now usually made of wrought iron, and are forged to their proper form. A variety of methods have been adopted at different times in the production of lower mast caps. Forged caps were doubtless the earliest form, and then for a time some builders made them of plates and angle irons riveted together, with the requisite "eyes" forged to plates and riveted to the sides of the cap. This method is even still very common in the Royal Navy. With the improvement in the manufacture of steel castings, there was manifested a desire to substitute cast steel for wrought iron forgings, and among other things cast steel caps were produced. Tests made upon these caps gave very satisfactory results, and for some time their use was found to be unattended with any disadvantage or risk; but either through the use of inferior material, or the neglect of the necessary precautions in casting and cooling, cast steel caps have not, during recent years, been found uniformly trustworthy, and consequently to avoid delays through their rejection, those of wrought iron are now almost invariably used. Air holes and brittleness are the chief faults which have been discovered in cast steel caps, and the latter defect has sometimes been so considerable that one or two blows with a heavy hammer have been sufficient to break off an "eye" from the side of a cap. Considering the heavy and sudden stresses which these "eyes" are often called upon to withstand in sailing vessels, it is necessary that very careful and trying tests should be applied to cast steel caps before they are allowed to be used. Forged caps made by careful and competent smiths have been found generally safe and satisfactory.

Caps are heated sufficiently to slightly expand them before being driven over the head of an iron or steel mast. The contraction in cooling tightens them over the mast head, and the connection is completed by the aid of a few stout rivets.

175. Method of making Iron Masts and Bowsprits.—Iron and steel masts, etc., are made in accordance with sketches previously prepared, showing the dimensions, shifts of butts, and the positions of the principal smith's work, and other large fittings. The plates are usually from ten to twelve feet in length, and the angle bars are often as much as forty feet long.

An expansion drawing is prepared, showing in figured dimensions the circumference of the mast at each of the plate butts, and the sizes of the plates are ordered therefrom, leaving a small margin for planing at the shipyard. As lower masts are larger at the wedging than at the ends, the plates composing a mast are necessarily of tapered breadths, and the thicknesses of the plates are likewise variable according to the diameters at the several parts. Care should be taken in arranging these thicknesses to increase and diminish them gradually, so as to avoid, as much as possible, all discontinuity of substance and strength.

In proceeding to make an iron mast, the workmen are provided with a board, upon which are drawn as many concentric circles as there are butts in the plating of the mast; the diameter of each circle being that of the mast at the corresponding butt. Both edges of the plate laps are drawn upon this series of circles, and thus the breadths of each plate at its extremities can be accurately determined.

The plates for the mast are then arranged upon a plank platform in strakes—as many strakes as there are plates in the round—the strakes being side by side, and the plates in each strake arranged in due consecutive order as shown upon the expansion drawing.

A middle line is struck along each strake upon the inside surface, and the correct breadths set off at each butt. The lines of the edges and butts are then drawn upon the plates, and the edge rivets are set off by means of a long template prepared for the purpose, and from a fixed starting point. so that those in adjacent strakes may agree

at their lap joint. The holes for the butt rivets are arranged according to the circumference of the mast and, therefore, breadth of the plate at the butt. If there are any stiffening angle bars to the masts, the lines of their rivets are struck in, and the positions of all doubling plates are marked, as well as the rivet holes connecting them together. The plates are then numbered and removed, in order that their butts and edges may be planed, and the rivet holes punched. This having been done, they are heated in a furnace to a bright redness, and taken to the bending rolls, through which they are passed until each plate is to the proper circular curvature for the part of the mast to which it belongs. These curvatures are given by the several concentric circles already referred to, which are copied by means of "set irons" to which the plates are bent, a separate "set" being made for each butt.

Tapering curvature is given to the plates by elevating one end of the rolls more than the other.

The plates, having been bent, are fitted together upon blocks laid for the purpose, whereupon they are tightly screwed up and their butt straps fitted, care being taken to keep the axis of the mast quite straight. It is usual to rivet the edges and butts before fitting and riveting the stiffening angle bars. Small holes are cut in the masts during construction through which to pass the hot rivets to the boy on the inside of the mast who acts as "holder up."

176. Chain Plates and Rigging Screws.—In the early iron ships chain plates were made very similar in form to those which had for a long time previously been fitted in wooden vessels. A wide spread was also at times given to the base of the rigging by means of the well known and long adopted device of channels. The narrow straps of iron forming the chain plates were riveted to the topside plating and passed through the wooden bulwarks and the main rail, the deadeyes for the rope lanyards being shackled in the usual way to their inside extremities.

With the introduction of iron bulwarks and gutter watercourses, this method of fitting chain plates gave way to that which is still in use. The chain plates are now almost invariably attached to the inside of the sheer strake above the gunwale angle bar, as shown by figs. 1 and 2 of Plate XXXI. Fig. 1 is a sectional, and fig. 2 a profile view of the bulwark, etc., showing an ordinary chain plate as fitted to an iron or steel sailing ship. The sheer strake, as already stated, usually projects about twelve inches above the stringer plate, and this allows a breadth of from six to seven inches, to which the "palms" of the chain plates may be riveted. At the upper extremity of the chain plate is an eye, and to this eye the rigging is attached, in several different ways, by the intervention of rigging screws, which, during recent years, have wholly superseded the wood deadeyes and rope lanyards that were so long used for setting up the rigging, and connecting it with the chain plates.

Rigging screws or screw lanyards are now made in most cases, as shown by Plate XXXI., with a wrought iron tube, into both ends of which eye bolts are screwed. The tube and the screw eyes at each end are made of such a size that they may each be fully as strong at a screw thread as the wire rope of the rigging. It should here be remarked that iron and steel wire has now practically superseded hempen rope for the rigging of iron and steel ships, and, indeed, of all classes of British built vessels, except the smallest.

There are several modes of connecting the rigging screw to the chain plate, but that shown on Plate XXXI. is one of the best. Sometimes the intermediate shackle is dispensed with, and the eye of the lower screw of the lanyard is directly linked with the eye of the chain plate, but this is disadvantageous in the event of the screw being broken, so as to necessitate renewal, for in that case the chain plate must be taken off.

In some of the earliest instances of the employment of rigging screws, the inner extremity of the chain plate was formed as a shackle, to which the rigging screw was connected by means of a pin, but this did not permit the free play at the junction of the two which is possible with the other methods described, especially that shown on Plate XXXI.

The tube of the rigging screw is in length rather more

than the combined lengths of the two screws which it receives, so that it may be effectual in tightening the rigging to the extent allowed by those screws. Each of these screws should be about nine inches long in vessels of 1000 tons and above, and consequently the tubes should be not less than eighteen inches in length. The tubes for topmast and topgallant backstays may indeed, with advantage, be somewhat longer, in order that the screws may take up all the stretch in the rigging which occurs on a long voyage, especially in a new ship.

The hole in the side of the tube is to receive the rod whereby it may be turned and the screw tightened; and ordinarily these holes are filled with tallow to prevent corrosion from taking place on the inside of the tube. For a like purpose tallow is applied to both the screws. Sometimes the tube is made of hexagonal section, and is, in that case, turned by means of a spanner.

The diameter of the chain plate is proportioned to that of the rigging, both being governed by the size of the vessel. By Lloyd's Rules the chain plates should be $1\frac{1}{4}$ in. in diameter for a vessel of 300 tons, increasing to $1\frac{7}{8}$ in. in a vessel of 1000 tons, and to $2\frac{1}{4}$ in. for one of 2000 tons.

The positions and directions of the several chain plates for the shrouds, capstays, and backstays, are determined from the rigging plan of the vessel, and the particulars measured from the profile drawing are supplied to the officials in the shipyard, by whom they are set off on the sheer strake and bulwarks. It is most important that the chain plates should stand in the direction of the rigging to which they are attached, in order that the stress upon them may be a direct one, developing the resistance of all the rivets in the palm, and not tending to bend the bar.

The number of shrouds, backstays, etc., of a sailing vessel is governed by her size and rig. In the largest ships there are six shrouds and a cap shroud, also three topmast backstays, and two topgallant backstays on each side. Vessels from 800 to 1000 tons have five shrouds and a cap shroud, two topmast and two topgallant backstays on each side, while those of 300 tons have four shrouds, and the same number of topmast backstays as vessels of 1000 tons.

When double topgallant yards are fitted there should be an additional topmast cap backstay, in consequence of the greater weight borne by the topmast.

The rigging of four-masted ships is in general rather lighter than that of ships with three masts of the same tonnage, as the individual masts are smaller, and carry lighter yards and less canvas. Four-masted ships of 2000 tons are rigged generally with the same number and sizes of shrouds, backstays, etc., as three-masted ships of about 1500 to 1600 tons; but no rule can be laid down in this matter, so much depending upon the height of the masts and the length of the yards. Plate XXXIV. shows a rigging plan for a vessel with four masts, which has been found to be efficient, and to give satisfactory results.

In concluding these remarks upon the rigging of sailing ships, it is desirable to call attention to the importance of using trustworthy wire for the standing rigging. The material at present employed is generally galvanised steel wire, but the qualities manufactured for the purpose are very variable. In addition to possessing a high tenacity, it is necessary that the rope should not readily stretch, and to conduce to this end the several strands of which the rope is formed should have a wire core, the strands being twisted round a central core of hemp.

CHAPTER XVII.

177. Rudders.—The rudder of an iron or steel vessel consists of a wrought iron or cast steel frame, which is plated on both sides; and as the safety and efficiency of the vessel is so much dependent upon the rudder, it is necessary that every care should be taken to make it strong and durable. The diameters of the heads, heels, and pintles of rudders are regulated by the same scantling numbers that determine the thicknesses of bottom plating, and those of steamers are somewhat greater than for sailing vessels of the same size, because of the greater strains which have to be endured in the former case, both by reason of the disturbed water from the propeller, and the usually greater speed of the vessel. The rudder frame should be carefully forged, and the stays joining the fore and after parts of the frame be spaced sufficiently close to stiffen the whole. Plate XI. shows a rudder for a screw steamer, with the arrangement of stays, pintles, and rivets in the plating. In this case the pintles are not forged with the frame, but are independent, being secured with a nut through which a small pin is passed; and this course is recommended chiefly because of the readiness with which the pintles may be renewed when worn or broken.

The pintles should not be more than four to five and a half feet apart, and the upper one should be placed as near as practicable to the rudder trunk, so as to steady the rudder at its head. The lowest pintle usually rests upon a convex steel bearing, placed in a gudgeon or socket at the heel of the stern post, and in order to minimise the friction, no other part of the rudder frame should rest upon the gudgeons or braces.

The rudder plating is riveted to the frame with through rivets of the same size as those in the upper edge of the garboard strake amidships, and they should have full snap heads; for, when flush riveted, it is found that the rivets soon become corroded and loose. It is very usual to fill the space between the plates with wood, to assist in supporting the plating and prevent water from getting there and corroding the iron. The plates, when there is more than one on each side, are often butted upon the stays, or upon solid bars between the stays; for, when this is done, the removal of the plate becomes easier than when they are butted upon thin straps. In the latter case, it need scarcely be said, the whole of the plating to each side of the rudder must be riveted together before it can be placed against and riveted to the rudder frame.

The rudder is so hung that it may be readily unshipped afloat by the removal of a small plate which closes the bottom of the rudder trunk at the after side; and the parallel portion of the rudder head extends sufficiently below the counter of the vessel to allow the rudder to be lifted high enough for getting the pintles clear of the holes in the braces. The diameter of the rudder trunk must, further, be large enough to permit the heel of the rudder being moved aft sufficiently to disengage it entirely from the stern post when lifted to the proper height. To prevent the rudder from being accidently unshipped at sea, a locking plate is fitted and riveted under one of the pintles, which keeps the rudder from being lifted until the locking plate is removed (see Plate XXXII.).

Stop cleats are riveted, as shown on the Plate, on each side of the rudder frame or stern post, preferably the latter, to prevent the rudder from being turned beyond the angle necessary for developing its full efficiency, having regard to the power applied. This angle is about 40 degrees.*

In the rudder shown by Plate XXXII., the pintles are forged with the frame, and this course is usually adopted, although, as already stated, that shown by Plate XI. is preferable. Figs. 1 and 2 of Plate XLI. show two views of what is termed a "centre plate rudder"—a form of construction which has recently found favour with many builders and shipowners. The frame is either of forged iron or cast steel—and has a series of arms or stays which, in consecutive order, are on alternate sides of a thick centre plate, to which they are riveted. (See Appendix.)

* See Thearle's *Theoretical Naval Architecture*, page 365. William Collins, Sons, & Co., Limited.

On the inside of the vessel the rudder head passes through a stuffing box which is usually placed upon a plate riveted to the upper sides of the reverse frame bars of the transom and radiating stern frames. The rudder trunk stops against the under side of the stuffing box, and should the trunk extend to a poop, awning, or spar deck, the stuffing box will be placed at the level of that deck. The stuffing box is fitted with packing glands, and it serves both to steady the rudder head and prevent water from coming through the trunk to the deck of the vessel.

The tiller fits over the rudder head either in the form of a single lever or a double yoke, and the vessel is steered thereby with the aid of a tackle which is worked by means of a wheel, or indirectly by a wheel acting upon a steering machine. In steamers it is not unusual to employ a steam steering machine instead of manual labour for turning the rudder. The movements of the steam steering engine are guided by the steersman, with the aid of a small steering wheel, which admits or cuts off steam and reverses the action of the machinery as may be required.

The power applied to the steering apparatus when fitted amidships is conveyed to the rudder by means of steering chains, wire ropes, or jointed rods, and sometimes with all in combination. Care should be taken to make the communication as direct as possible by avoiding sudden bends, in order to minimise the resistance due to friction; and the guides for the ropes, rods, or chains should be fitted with rollers or sheaves for the same purpose.

Relieving tackles and facilities for working the same should be provided in the neighbourhood of the rudder head for use, in event of injury being sustained by the ordinary steering gear.

Rudder pendants are fitted, in most cases, around the sterns of vessels, and connected with the back of the rudder at its upper part (see Plate XXXII.), in order to secure it in the event of accident. These pendants have sometimes been usefully employed for steering a vessel when the rudder head has been broken.

178. Corrosion of Iron and Steel.—When a ship has been built of iron or steel it becomes a matter of importance to preserve the material from wasting in substance by corrosion. Oxidation is, indeed, the only source of decay to which such structures are liable, and on that account alone, if for no other reason, the substitution of iron for wood was a great economical advantage. If properly looked after, there seems to be no reason why the substance of an iron sailing ship should at all diminish, except perhaps in the vicinity of the water line. Frequent painting upon a surface entirely free from rust must inevitably prevent wasting by corrosion, and that this is the case may be seen by examining the hulls of certain well kept vessels which are as much as thirty years of age. With steamers the difficulty of avoiding this source of wear is much greater, especially in the machinery compartments and bunkers; but even the lifetime of steamers might be prolonged by careful attention, as is evidenced by the case of H.M. steam troopship *Himalaya*, which is still reported to be in good condition after thirty-seven years of hard work.

The importance of taking all possible precautions for preventing corrosions in iron and steel vessels will be seen from the fact that for every 100 parts by weight of common iron rust there are no less than 60 of metallic iron. Corrosion in these vessels, therefore, results in serious diminution of the substance of the materials of which they are built, and corresponding loss of strength.

When iron or steel leaves the rolling mills, its surface is covered with a black oxide scale, and as soon as this scale is broken at any part of the surface, a galvanic action is set up between the iron or steel and the scale. As it is impossible to prevent the scale from being scratched or broken somewhere in the plate, it is, therefore, necessary for the preservation of the material from corrosion that the black oxide should be entirely removed before the plates are coated with paint. If this be not done, both the scale and the coating upon it will be thrown off, and the surface

beneath will be found considerably oxidised. This phenomenon occurs to a more serious extent in the case of steel than in that of iron, probably because of the greater purity of the former material. For it is found that the higher qualities of iron display a greater affinity for oxygen than the lower, and steel more than either. The tendency of steel to rapid corrosion is further increased by the presence of carbon and manganese, which set up local galvanic action.

It has not been usual to take any steps for the removal of the mill scale from iron plates, although the pitting sometimes seen upon the bottoms of iron vessels is doubtless due to the presence of the black oxide which was originally rolled into the surface of the plate and has never been thrown off.

With steel, however, it is found necessary to take special measures for the removal of the scale before any paint or composition is placed upon its surface. Unless this be done paint will not remain upon it, but will be continually thrown off, so that it has been found necessary to paint the inside of a steel vessel twice in the course of a year.

To expedite and ensure the removal of the oxide scale from the surface of the steel and render it fit to be advantageonsly painted before the ship is completed, it is now usual to employ certain corrosive solutions. On the Clyde a portable fire extinguisher is sometimes used for the purpose, and this is charged with a weak solution of sal-ammoniac which is pumped upon the plating in the early morning, so that the sun and air may together act upon it during the day. If this be repeated about three times in the course of a fortnight, the scale will readily be thrown off.

To obviate the retention of scale where marks are made for counting rivets, etc., the paint for these marks should be made with whiting, sal-ammoniac, and water.

179. Paint and Compositions.—Red and white lead, and the oxide of zinc, are the principal substances used for painting the surfaces of iron and steel ships. The paint is reduced to the required consistency by the use of oil or naphtha, especially the latter, which serves as a drier as well as a solvent. Oxide of iron paint is sometimes employed, but lead and zinc are more frequently used.

On the inside of a vessel, and above the water line on the outside, the paint is intended as an anti-corrosive, and to serve that purpose by keeping the atmosphere from coming in contact with the surface of the iron. When paint is laid upon a surface already corroded, the corrosion under such circumstances will still go on; it follows, therefore, that the painting of the insides of ships to be effectual should be carefully attended to, and, further, that all traces of oxidation should be removed by scraping before new paint is laid on.

Upon the outside of a vessel, below the water line, the paint or composition is intended generally to act not only as an anti-corrosive, but also to prevent "fouling," or, in other words, to check the adhesion and growth of marine plants and animals upon the bottom of the vessel. Two or three coatings are usually placed upon the bottom each time it is painted, the last being anti-fouling, and the others anti-corrosive.

Many compositions have been invented for the purpose of protecting the bottom of iron and steel ships from corrosion and fouling, but it is not our purpose, here, to discuss their respective merits. It is well, however, to remark that among anti-corrosive paints which are not protected by patents, the white oxide of zinc has been found very effectual for voyages of twelve months' duration when thickly applied and placed upon a well scraped, dry surface; also that tallow is an anti-fouling material which is easily applied, and generally found to serve the purpose for which it was used.

APPENDIX.

180. Bulb Angle Frames.—Until recent years the frame girders of steel vessels were formed either with a frame angle bar and a reversed angle bar, riveted together back to back, or with equivalent rolled sections of "zed" or "channel" form, either of which gave a flanged stiffener to the inner edge of the frame girder similar to that afforded by a reversed frame angle bar. It has been found, however, that in the bunkers of steamers, and in the cargo holds of coal-carrying vessels, this inner flange becomes wasted by corrosion at a more rapid rate than the remainder of the frame girder. To avoid this form of deterioration the frame girders of coal-carrying steamers, and sometimes the bunker frames of other vessels, have been formed of bulb angle bars (see G, fig. 12) having a section of equivalent strength to the combined frame and reverse angle or to the corresponding zed and channel sections.

Excellent results have followed the use of this section of material, but certain precautions have to be adopted in working with it, and special arrangements carried out for properly uniting the frames with keelsons and side stringers.

In setting the bulb angle frames to their desired form when hot, it will be evident, from the depth necessary to be given to the section, that more than ordinary extension will occur on one edge of the bar and correspondingly great compression on the opposite edge. In consequence of this, it is necessary to defer the punching of most of the frame rivet holes until after the bars are set to their curvature, as otherwise a serious distortion will take place in the form of the rivet hole, so as to prevent sound riveting. A similar result is experienced in the case of bars of channel and zed section at the curved portions of the vessel's side, and indeed in the case of large angle bars also.

When bulb angle frames are used, reverse angle lug attachments for the side stringers can only be made on the flat side of the bar, and consequently the angle lugs are made of increased size, so as to receive four rivets in each flange. Plate XLIII. shows the midship section of a vessel having bulb angle frames. This vessel has the usual cellular double bottom, to which the bulb angle frame is connected by means of the usual bracket floor. The side stringers are of double bulb angles in this vessel, that being a very common arrangement, more especially when compensation is afforded for the omission of a tier of hold beams, as in the case in question. The compensation consists in using larger bulb angles for the frames than would otherwise be required, and in fitting the additionally strong side stringers which are shown.

181. Deep Framing.—Reference has just been made to one form of compensation which is now commonly adopted in steel vessels for the absence of decks and tiers of beams. In the vessel with bulb angle frames, the bulb angles are made of larger section than would be required in cases where all the decks and tiers of beams suitable for the vessel's depth are fitted. Similarly, in vessels of ordinary frame and reverse frame section, it has now become a very usual practice to omit one or more decks, and, instead of fitting a web frame compensation, to obtain the necessary transverse strength by means of what is known as "deep framing."

A brief reference to deep framing has already been made at page 101; but during recent years the application of this system has become very general, and has largely displaced the web frame arrangement, which was formerly the usual compensation for the omission of decks and tiers of hold beams.

Deep frames are associated with side stringers of several different forms, but in every case they are worked intercostally, and attached to the shell plating. Plate XLII. shows the midship section of a vessel with deep framing, the manner of overlapping the frame and reverse angle bars in this case being indicated at A. This is the usual method now adopted, but sometimes they are fitted back to back, as shown at fig. 3, Plate XLI. The arrangement at A is found to be the preferable of the two, as it affords superior

facilities for the efficient attachment of the bracket knees to deck beams and to margin plates. In Plate XLII. one of the most usual forms of side stringer is shown, and A, fig. 32, is another arrangement very often employed. The methods shown at B and C, fig. 32, are not unusual. The stringer shown at D on the same figure is a flanged arrangement associated with web frames.

The overlap of the frame and reverse frame is usually 3 inches when connected with $\frac{7}{8}$ inch rivets, and $3\frac{1}{2}$ inch when

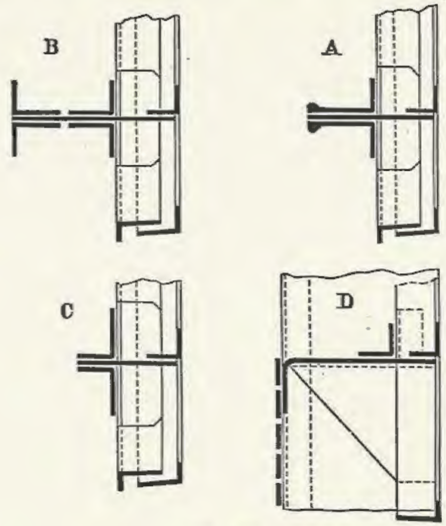


Fig. 32.

1 inch rivets are required. Hence the depth of girder formed by frame and reverse bars is the sum of the deep flanges of the angles, less 3 inches or $3\frac{1}{2}$ inches, as the case may be. The connection is usually made with machine compressed riveting, which yields better results than ordinary hand riveting, and is easily applied to this class of work.

Deep framing is rather heavier than the equivalent web frame arrangement, but being less costly to produce and more quickly performed, besides being of at least equal strength, and attended with less broken stowage, it is now commonly preferred to the web frame system. The

Scantling Tables of Lloyd's Rules now provide for deep framing in vessels of very large size, and permit of alternative arrangements of side stringers as already described.

When deep frames are fitted in vessels with double bottoms, the bracket floors connecting their heels to the margin plates are required to extend up the bilges to a height of not less than two and a half times the depth of an ordinary floor amidships in a vessel of the same size.

The side stringers in deep frame vessels need not pass through transverse watertight bulkheads and thereby interfere with their watertightness, but should preferably stop at the bulkheads, and be joined to them by means of substantial brackets secured with double angles. A very good bracket arrangement is obtained by widening the end intercostal plates of the side stringers in each hold. It is desirable, if possible, to arrange the horizontal stiffeners of transverse watertight bulkheads so that each may come in line with a side stringer and admit of being connected to it by means of bracket plates. In this way the brackets required at the extremities of the horizontal stiffeners will serve a two-fold purpose. Very effective resistance against racking stresses is afforded by this arrangement.

182. Bulkhead Subdivision.—More extensive bulkhead subdivision than formerly is now required in large steam vessels. The collision bulkhead is definitely fixed by Lloyd's Rules at not less than one-twentieth of the vessel's length abaft the stem at the lower deck. In steamers of 400 feet and under 470 feet in length, seven watertight bulkheads are required to be fitted; in steamers 470 feet and under 540 feet in length, eight watertight bulkheads are to be fitted; and in steamers 540 feet and under 600 feet in length, nine watertight bulkheads are required. These are all extended to the uppermost deck, except in awning and shelter-deck vessels, in which cases they should extend at least to the height of the main deck, and the collision bulkhead must extend to the height of the awning-deck also in vessels of that type.

183. Bulkhead Stiffening.—The increase in the extent of bulkhead subdivision beyond that which was formerly considered sufficient has been accompanied with important

additions to the stiffening afforded to the bulkheads. It is clearly of no use fitting bulkheads in a vessel for purposes of safety unless they are made capable of resisting the fluid pressure which may be brought upon them in the event of either of the adjacent compartments of the hold being full of water to the load line. The vertical stiffeners are now, as formerly, of frame angle size; but the horizontal stiffeners, except for comparatively small vessels, are usually of bulb angles. Lloyd's Rules require that, upon all collision bulkheads and all other bulkheads of 40 feet and upwards in breadth, the horizontal stiffeners shall be of bulb angles 6 inches deeper than would be required for bulb angle frames in the same vessel. All bulkheads of 36 feet and under 45 feet in breadth are further stiffened with a vertical web at the middle line, extending from the keelson to the hold or lower deck beams. Bulkheads of 45 feet and under 55 feet in breadth have two vertical webs, and bulkheads of 55 feet and under 60 feet in breadth have three vertical webs.

It will be evident that laid decks afford valuable stiffening to transverse watertight bulkheads, and hence, when these are omitted and compensated for by means of web frames or deep frames, some addition to the bulkhead stiffening is required where the decks would otherwise be. Semi-box beam stiffeners are provided for this purpose, to form which a beam is extended across the vessel at a frame space from the bulkhead, and at the level of the omitted deck. Plating is extended across the vessel, riveted to the top of this beam, and attached to the bulkhead by means of an angle bar. The vertical webs are sometimes connected to this plating, and effective horizontal and vertical stiffening is afforded in this way. Plate XLIV. shows the construction and stiffening of such a bulkhead as has just been described.

A is the semi-box beam, and B, B, B, are three vertical webs extending from the top of double bottom to the main deck. As will be seen, the semi-box beam and a horizontal bulb angle stiffener in this instance are in line with the side stringers in hold, to which they are bracketed. The other horizontal stiffeners are bracketed to the shell plating of the vessel. The vertical stiffeners are similarly bracketed to the inner bottom plating.

Plate XLV. shows other methods of stiffening transverse watertight bulkheads which are sometimes adopted. In this Plate the elevation, longitudinal vertical section, and the plan A refer to one bulkhead, while the arrangements B and C relate to other methods of stiffening of a somewhat similar character. In these three arrangements, the feature common to all is that of arranging the plates vertically in the bulkhead, and stiffening the latter by flanging the plate edges.

In the method shown by the elevation and vertical section sketches, each plate below the lower deck is flanged twice, as shown at D, the flange being sufficiently deep to render no vertical webs nor semi-box beam stiffeners to be necessary. The only horizontal stiffening is in the form of an intercostal stringer, A, formed with a channel bar fitted against the reverse flange, with a flanged intercostal plate riveted both to the channel bar and the bulkhead plating. This intercostal serves the two-fold purpose of a horizontal stiffener and a means of keeping the flanges from changing form under the stress of water pressure against the bulkhead.

The stiffening at the upper and lower 'tween decks is obtained by flanging broader plates to a lesser extent, as indicated in the vertical section, and by riveting intermediate vertical angle bar stiffeners, as shown at plan B, and indicated at E in the elevation. The dotted lines at F are short bulb angle stiffeners between the brackets, as also shown in plan at A.

Bulkheads are sometimes stiffened vertically throughout, as shown at B, and sometimes as shown at C; but in these cases the vertical stiffeners merely take the place of the stiffening bars of frame angle size; and, to complete the stiffening, horizontal stiffeners, webs, and semi-box beams are also fitted, as shown by Plate XLIV.

In the vertical stiffening shown at A and B, only one edge of each plate is flanged, and the plain edge of the adjacent plate is overlapped, as shown at D; but in the arrangement illustrated at C, alternate plates are flanged on both edges, and the intermediate plates are plain on both edges, as will be seen by reference to the sketch.

Experiments made to ascertain the relative values of angle and flange stiffening show the latter to be inferior to the former, by reason of the greater readiness with which a flange will alter its form under stress, as compared with the square-rooted angle bar. On that account it is usual to make the flanges somewhat deeper than the corresponding angle bar stiffeners would be. Bulkhead plates, when fitted as at A, are usually of sufficient breadth to give a distance of 30 inches between consecutive flanges, and, in the cases B and C, a distance of 60 inches. It is on account of this larger breadth that the intermediate angle bar stiffeners are required.

184. Midship Deep Water Ballast Tank.—Steamers have now so frequently to make long voyages in ballast trim that it has become necessary to provide greater capacity for carrying water ballast than is afforded by the double bottom and the fore and after peak spaces. Also, in order that vessels may not be unduly stable in ballast trim, the additional spaces for carrying water ballast are carried as high in them as possible. Midship deep water ballast tanks have, therefore, now become a very usual fitting in larger steamers and, in view of their depth, considerable stiffening must be given to the bulkheads, etc., in order to enable them to endure the stress due to the great head of water, more especially when the vessel is labouring in a heavy sea. The large experience now obtained with deep tanks of this description has resulted in very trustworthy data in regard to the nature and amount of stiffening required to render them efficient.

Plate XLVI. shows, in plan and section, the construction and stiffening of a deep midship tank. Scantlings are omitted, because these must be determined by the special conditions in any particular case. Being drawn to scale, the sketches clearly indicate the relative sizes of the different parts of the tank.

In designing a deep water ballast tank, it is necessary to provide a margin of strength, and make structural provision for the contingency of the vessel being pitching and rolling at sea with the tank not wholly full of water. Such a condition is, of course, an improper one and unnecessary, yet it sometimes occurs through accident or neglect. It is with a view to ensuring that the tank is really pumped up full of water, and to provide for any small loss which may occur, that the hatch coamings are made from 12 to 18 inches deep. The centre line longitudinal bulkhead is intended to break the wash of water if the tank is not quite full, and to afford structural strength. It is not usual to make this partition watertight, but rather to afford communication by means of a few manholes between the two divisions of the tank, and thus, while breaking any wash of water, to keep the two sides at the same level, and thus lessen the risk of the vessel getting a list.

As will be seen, the details of the stiffening to the end bulkheads of deep tanks, is of the same character as that of ordinary transverse watertight bulkheads, but greater in amount. The vertical webs are much more closely spaced, and the vertical stiffeners are of bulb angles much larger in size than the frames. The semi-box beams are connected to the side stringers with large gusset plates, and all stiffeners are well bracketed at their extremities. A complete row of quarter pillars is fitted on each side, secured at their heads to a longitudinal intercostal girder, and at their heels to tee bar lugs on the inner bottom. One or two web frames are fitted at the sides of the vessel, according to the length of the tank, and these web frames are extended to the deck above.

It is most desirable to cut the frames and reverse frames at the top of the deep tank, so that the top plating may be connected to the side of the vessel by a continuous angle bar, and so be the more readily made watertight. The web frames above the deep tank top serve to complete the connection afforded by the large brackets and double angles at each upper length of frame, as shown in the transverse section and the plan.

The bulkhead plating of deep water ballast tanks should be somewhat thicker than in the corresponding transverse bulkheads, and their edges and butts should be double riveted.

The covers to the hatches of deep tanks are stiffened and made watertight, and, when completed, the tank should be carefully tested by a head of water extending as high as the load line.

Plate 47 **185. Pillaring.**—In the earlier iron vessels it was usual to fit decks and tiers of beams in cases wherein at the present day they are omitted in order to obtain larger hold spaces, and, as previously stated, these are now compensated for by the use of materials otherwise arranged as in the form of web frames, deep frames, and strong side stringers. When the hold spaces are comparatively shallow, the diameters of the solid pillars formerly used were not generally disproportionate to their length; but with the omission of ranges of decks the solid pillars in hold, if not of much increased diameter, are of slender proportions and unsuitable for the service they should perform.

Short beams may evidently be of smaller section than long ones in the same deck, and beams supported by two or three rows of pillars need not be of such strong section as those of the same length, and in the same position in the vessel, when supported by only one row. The cargo carried in a 9 feet 'tween decks will be heavier than the corresponding cargo carried in a 'tween decks of 7 feet high, and consequently will require stronger beams to support it. Long beams require a greater number of rows of pillars to support them and the cargo upon them than do shorter beams.

These facts are now more fully recognised in steel ship construction than they were a few years ago, and, as a consequence, the Rules of Lloyd's Register associate beam and pillar requirements, and consider them in relation the one to the other. The tables of sizes for beams and pillars now applied in the construction of the greater part of the mercantile marine is based upon calculations made regarding the strains actually brought to bear upon these portions of the vessel, and, as already stated, the two are considered in their relation the one to the other. The tables are perhaps not so simple in their application as the elementary rules formerly in force, but they have the great merit of being scientifically founded, and of being both reasonable and trustworthy.

* When the length of the midship beam exceeds 43 feet, not less than two rows of pillars are fitted, and, when the length exceeds 55 feet, three rows are fitted. When beams are

fitted at alternate frames, each beam is pillared, unless the massed system of pillaring, hereafter to be described, is adopted. But if beams are at every frame, pillars should be fitted at alternate beams, and attached to continuous fore and aft girders under the beams. These girders are formed of double angles of the reverse frame size or other equivalent section, and they are attached to each ordinary beam, and to all deep beams and bulkheads at which they may abut, by means of short angle lugs.

It is very important that pillars to 'tween decks and in holds should be arranged so as to form continuous ties from the uppermost beams to the floors. The number and sizes of the rivets securing the heads and heels of the pillars should be proportionate to the diameters of the pillars, and these diameters, as already pointed out, should be regulated by the length of the pillars, the length of the beam, and the position of the deck which is supported in relation to those above it. All these considerations have to be taken into account in fixing the sizes of the pillars at different parts of a vessel, and in determining the attachments at their heads and heels. When the heels come upon inner bottoms, they should be riveted to short tee or angle bars, which are riveted to the plating of inner bottom before its watertightness is tested.

In a case of a 'tween decks being used exclusively for passenger accommodation, the pillars beneath might, of course, be of reduced size.

Cases often occur in which, for the purpose of fitting shifting boards, it is preferred to have three rows of pillars instead of two, where two rows would otherwise be admissable, the quarter pillars being in that case fitted in two incomplete rows. This is quite allowable, provided support be given to the intermediate beams, between the widely spaced quarter pillars, by means of continuous girders at the heads of the pillars, worked intercostally and attached to the deck plating. It is usual in such cases to fit the quarter pillars opposite every fourth frame, and to have beams fitted at every frame, of the reduced size suitable for that spacing. If the middle line pillars are "reeled" for receiving shifting boards they are of full size; but, should

double pillars be fitted for the purpose, they should be of not less than three-fourths the diameter of corresponding single pillars. Longitudual middle line bulkheads are sometimes adopted, as a permanent fitting, in lieu of portable shifting boards, and in such cases the bulkheads may be effectively stiffened to serve the purpose of pillars. Such bulkheads should be strongly secured at top and bottom, and to the deck beams, Similarly, the bulkheads of engine and boiler casings, and of coal bunkers, when disposed vertically, may be effectively stiffened to serve the purpose of quarter pillars.

186. Hollow and Sectional Pillars.—The solid pillar of circular section is a most wasteful mode of employing materials in a vessel, for purposes of support. Equal efficiency may be obtained from a much smaller weight of material made of a hollow form or of an ⊢⊣ or some other rolled section. Hollow pillars with solid heads and heels have long since been used at times in lieu of the unduly heavy solid pillars, and Lloyd's Rules have furnished the sizes of corresponding hollow sections which may be adopted. Of late, other sections have largely come into use, the chief of these being a rolled ⊢⊣ section or a similar form composed of two channel bars riveted back to back. The last named arrangement is of special value, inasmuch as it readily admits of bracket attachments at the heads and heels, instead of the comparatively less satisfactory arrangement which alone is possible with either the solid or hollow pillar of circular section. The double channel arrangement in larger sizes is also frequently adopted in the massed system of pillaring to be presently described.

187. Massed Pillaring.—The demand for roomy cargo holds affording unbroken stowage is rapidly on the increase, and to meet that demand shipbuilders have to devise arrangements whereby the number of pillar supports may be reduced to a minimum. In some small vessels, pillars have, indeed, been dispensed with altogether without loss of efficiency. To dispense with a great many comparatively small pillars, by substituting a few very strong ones, requires, in the first place, a closer bulkhead subdivision in the vessel than is normally adopted. In this way, longitudinal girders of reasonable depth can be fitted from bulkhead to bulkhead, sufficiently strong to support the deck beams when supported, themselves, at only one or two points by means of very strong pillars. The girders are, necessarily, strongly connected at their extremities to the bulkheads, and they are generally associated with several additionally strong beams, more especially at the extremities of the cargo hatchways.

There are very many forms in which these general principles may be, and are, carried out in practice, but the underlying principles in all are the same; these being strong longitudinal girders to efficiently distribute over all the deck beams, hatch coamings, and other components of the deck framing, the support obtained from a few very strong pillars. Sometimes the pillars are built up of rolled sectional material, such as channels, etc., riveted together, and in other cases they are of columnal structure —built in the same way as a steel mast. In every instance, however the pillar may be formed, provision is made whereby it can be connected both at the top and bottom to an extent commensurate with its strength.

Plate XLVII. shows an arrangement of massed pillaring which has given excellent results.

In this case there are only four pillars in the hold shown by the Plate, two of the pillars being hollow cylinders, built like masts, about 18 inches in diameter, and the other two being formed with double channel bars riveted back to back and strengthened with face plates. The pillars in the deck spaces above are formed of double channel bars arranged as shown. The bracket connections at the heads and heels of all the pillars are shown in the sketch, also the connections of the longitudinal girders, below the several decks, with the bounding bulkheads of the hold in question.

It will be noticed that in this arrangement the strong hatchway beams are removed one frame space from the ends of the hatchways. in order that room may be found for the heads of the large pillars, and for efficient diamond plate connections of the strong beam to the longitudinal girders having the same depth. The hatchway coamings are supported by means of short carlings joining the bulb

angle beams to the strong beams These strong end beams and corresponding strong half beams are attached to web frames marked W at the sides of the vessel.

The various sketches shown on Plate XLVII. will otherwise sufficiently explain this excellent arrangement of massed pillaring. Upon viewing the hold in plan, it will be seen how little the stowage is broken by these four pillars, and how well the latter are arranged in association with the girders for supporting the deck.

188. Joggled Plate Laps.—The use of mild steel in shipbuilding has led to the adoption of modes of combining the materials which are possible only with such a highly ductile material. As already seen in connection with the question of bulkhead stiffening, it is now very usual to flange steel plates in lieu of riveting angle bars to them. This is done in double bottoms at the upper, and sometimes at the lower, edges of floors, at the edges of intercostal plates, on the inner edges of side stringers (see D, fig. 32), and at other parts of the vessel. In such cases it is usual to increase the thickness of the flanged plate as compensation for the loss of stiffness which would otherwise occur through the substitution of a flange for an angle bar.

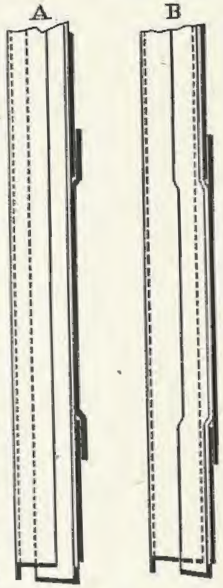


Fig. 33.

During recent years, advantage has been taken in other ways of the ductility of the material, and the chief of these is seen in the flanging of plate edges and the joggling of frame angles. The object sought in each of these devices is the omission of plate liners and the saving of weight resulting therefrom. Special machines and appliances have been invented for the purpose of producing both these results (see fig. 33).

Considering first the joggling of the plate landings, as shown at A in the figure, it may be remarked that not only has this device been applied to the shell plating but to inner bottom plating and deck plating also. When the shell plating is treated in this way, care must be taken in previously spacing the rivet holes in the frames, so that rivets may not occur at the joggled corners. To do this and avoid any widely spaced rivets, it is necessary to place two rivets in each frame bar at the lap, instead of one only as is done in the ordinary method of plating. Care also has to be taken in the joggling, as also in the fitting and screwing up of the landings previous to riveting, so as to ensure that the work shall be sound and tight when completed. The practice of joggling plate landings is a growing one, and has the advantage of not only saving weight but also of diminishing the number of thicknesses to be fitted and riveted together. It has, however, the disadvantage of not being suitable for ready repairs at parts of the world where joggling machines are not used.

The joggled frame system, shown at B, fig 33, has so far been chiefly adopted by Messrs. Russell, of Port-Glasgow, but it is not suitable for the parts of the vessel having much curvature of form. Very satisfactory work is, however, performed by the system, but care has to be taken that the joggle is, in every case, of the right depth for the particular plate to fit into it, and that it is correctly situated in the frame to properly receive that plate.

189. Centre Plate Rudders.—Centre plate or single plate rudders have now almost wholly displaced the earlier form, and during recent years, some improvements have been made in them which are worthy of record.

A form of forged single plate rudder, since slightly modified to the arrangement shown by Plate XLVIII., was first made by Messrs. D. & W. Henderson & Company, of Glasgow, and fitted in the steamers of the Anchor Line, where, although exposed to the heavy work of the North Atlantic trade, they were found to be very satisfactory. The firm in question have improved upon the first form of the type, and, for many years past, rudders such as is shown in the Plate have been adopted by them, and, more recently, by many other shipbuilders. One great advantage of this rudder is its reliability, as it is constructed without any welds. The main spindle may be hammered out of a steel ingot or a forged bar, and the arms are shrunk on and keyed as shown. The heads, as in other forms of rudders, are usually coupled.

Plate XLVIII. shows a plan of the rudder, and alongside of this plan sections are given at the lettered positions, A, B, C, etc., showing the form of the coupling and of the several arms of the rudder. The plate of the rudder varies in thickness from $\frac{15}{20}$ of an inch in vessels of small size with a 3 inch rudder head, to $\frac{22}{20}$ of an inch in large vessels requiring rudder heads 11 inches in diameter. The distance from centre to centre of the arms varies, in the two cases just mentioned, from 45 inches to 66 inches. The arms of the rudder are arranged alternately on opposite sides, and the plate is fitted into a groove formed in the main piece to receive it. As already mentioned, the arms are shrunken on the main piece, and further secured by keys fitted in the groove, as shown in the Plate, which further indicates the riveting connecting the single plate to the arms. Other forms of coupling at the rudder head are sometimes adopted, some of which permit of the rudder being unshipped without the head being lifted or its connections to the after steering gear being disturbed. Portable pintles are shown, which are now commonly adopted, and prove a very desirable arrangement.

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