the other butt being driven home closely against its neighbour.

When the plank is nearly in place, bend a slight batten and measure the girth against the timbers, from the last point where the plank touches them, to the butt of the adjacent plank of the strake against which the butt, about to be cut, must fit, and mark the latter point on the batten. Then, still keeping the first end of the batten fixed, let it spring along the inner surface of the plank, and mark the point upon the latter. Cut the butt at this point to the two bevellings obtained by holding a bevel against one of the edges of the planks and the butt to be fitted against; also, against the timber surface and that butt.

PART IV.—IRON SHIPBUILDING.

CHAPTER XVII.

249. Differences between Mercantile and War Ships.—While there are differences in the details of the hulls of wooden ships intended for mercantile as compared with those for war purposes, there is a much greater dissimilarity in the elements of iron ships intended for these respective services. The difference is more marked in armoured than in unarmoured war ships; but even the latter are in many respects very differently constructed to iron ships of the same size intended for commerce.

It must be observed that these differences are chiefly due to the adoption of the longitudinal system of construction in the Royal Navy, a system which has been but little applied to the mercantile marine. Besides this, the provision which has to be made for carrying such heavy weights of armour, etc., and the general adoption of a double bottom, have caused war shipbuilding to become a more distinct branch of the profession than formerly. We, therefore, propose to consider each of the principal elements of an iron ship, under two divisions, viz :—*firstly*, as applied to merchant, and *secondly*, as applied to war ships.

250. Scantlings of Merchant Ships.—So common is the practice of insuring ships engaged in commerce, that the scantlings, etc., of by far the greater proportion of the iron vessels built at the present day for the merchant service are regulated by the rules of the several associations of underwriters; and so well do those rules agree with the experiences of our best shipbuilders, that the majority of the ships not intended to be insured, are built according to the rules laid down by one or other of these associations. Hence the practice of iron shipbuilding is very uniform, and a detailed statement of the dimensions and modes of connecting the several parts of a ship for the mercantile navy would consist of little other than a copy of the rules of the three principal underwriters' societies, viz:—Lloyd's, The Liverpool Registry, and the Bureau Veritas. As a statement in detail of the niceties of difference between the rules of these societies would occupy a much greater space than the limits of this work will allow, it is not intended to enter fully into particulars of scantlings, but rather to state the functions and requirements of the several parts of the ship, and the methods of performing the work in connection therewith. It may further be remarked, that the rules referred to are continually being changed in accordance with the experience which is being acquired with regard to iron ships.

251. The Keel and Keelson of Mercantile Ships.—There are three principal forms of keel in vogue, viz:—*bar*, *flat plate*, and *centre plate* or *side bar* keels. Of these the former is the commonest, being associated with the frames and keelson in several different ways, of which those shown by Plates LXXXIX. and XC. are very usual.

252. The Bar Keel (Plates LXXXIX., XC., and XCI.) is generally of hammered iron, made in pieces as long as can be conveniently forged. The butts are usually scarphed and riveted (see Plate XCI.); but sometimes, though rarely, they are welded. The latter operation must necessarily be performed near the keel blocks, and by means of a temporary hearth. The difficulty of securing a good weld, and the expense of the process, have considerably limited its adoption.

The scarphs are always vertical, similar to the French system for wood keels; they are plain, and in length about eight or nine times the thickness of the keel.

The holes in the keel bars for securing the garboard plates are arranged in accordance with a sketch or template; they are drilled, usually by the contractor who forges the bars.

The holes in the scarphs are not usually drilled until after the latter have been fitted, although, sometimes, only those at the lip ends of the scarphs are left; they include some intermediate holes, smaller than the others, for joining the

pieces of keel previous to the garboard plates being riveted, the latter operation completing the connection. (See Plate XCI.).

The holes in bar keels are set off in different ways, the double chain arrangement shown by fig. 3, Plate XCI., being one of the most usual; the double zigzag system, shown by fig. 2 on the same Plate, is also very common, and is recommended by Lloyd's rules. Fig. 1 on that Plate shows an arrangement which has been adopted in the Royal Mail Company's vessels; however, it does not appear to be so satisfactory as the others, in consequence of the way in which the bar is riddled with holes for the sake of rivets which are quite unnecessary. Fig. 2, Plate XCI., is adopted by the Netherlands Steam Ship Co., while fig. 3, on that plate, is found in the vessels of the Pacific Steam Navigation Co. It should be remembered that Lloyd's and the Liverpool Underwriters' rules allow nothing less than double riveting in keels.

The diameter of the rivet used in bar keels is $\frac{1}{4}$ inch greater than is required for plates of the same thickness as the garboard plates (see Art. 328), and the spacing is about five diameters from centre to centre, in order that the joint between the plates and the bar may be caulked.

The garboard strakes form the only connection of this kind of keel to the remainder of the hull (see Plates LXXXIX. and XC.), except in such cases (which are very rare) when intercostal keel plates between the floors are riveted to the bar, with either a rabbet, groove, or plain joint.

253. The Side Bar Keel.—The next kind of keel in order of frequency of adoption is the *centre plate* or *side bar keel*. See Plate XCII., which shows two forms of this kind of keel. The *side bar* system is much superior to that which we have just been considering, but as it is more expensive, and requires more careful workmanship, it is not so common as the bar keel. It consists of a vertical plate, extending from the underside of the keel to the top of the floors, as in fig. 2, Plate XCII., or to the top of the keelson as shown in fig. 1 on the same Plate. On each of the lower edges of this plate another plate is riveted to it, so as to form an external keel of the same depth and thickness as a bar keel for the same class of ship.

The plates are as long as can be procured, and their butts are carefully shifted. The side plates, or bars, are connected to the vertical plate by an openly spaced series of small rivets, termed "tack rivets," marked T in fig. 1, Plate XCII., which are arranged with reference to the holes for riveting the garboard plates in some such a manner as there shown, the latter being spaced about four and a half diameters apart. The Liverpool rules require that the butts of the centre plate shall be "secured by double butt straps, each of a thickness equal to two thirds that of the centre plate, and to be treble riveted."

Great nicety of workmanship is required in riveting the centre, side, and garboard plates together, in order to obtain an accurate correspondence of the holes, the rivets having to pass through five thicknesses, and sometimes, when double side bars are fitted, through seven thicknesses of plating.

254. The Flat Plate Keel is not generally adopted in the merchant service. The early iron shipbuilders used wood keels bolted to the lowest strake of plating. Finding that the wood was very liable to decay, they discontinued its use, and bent plates to a dish form instead. The inadequacy of such a form to bear the weight of the ship when grounding, led to their being substituted by the bar and side bar keels now in use. In a highly efficient form, however, being associated with an internal vertical keel, the flat plate keel is now adopted in iron-clad ships of war. (See Plate XCIV.)

The *hollow* or *dish keel* is a variety of the *flat keel* system, of which examples are given by figs. 1 and 2, Plate XCIII.

Lloyds' rules state that, "when hollow or flat keel plates are adopted, their breadth must be the same as given for the garboard strakes, and their thickness not less than once and a third that prescribed for those strakes, for three-fifths the vessel's length amidships. The butt straps of flat keel plates are to be one-sixteenth of an inch thicker than the plates they connect, and treble riveted."

255. Summary.—In the earlier specimens of bar keels the garboard plates were rabbeted into the former, thereby considerably relieving the riveting when the work was carefully executed; but the expense involved by so doing led to the

rabbeting being discontinued, and the garboards are now riveted against the sides of the bars. As already stated (Art. 252), the vertical plates, when fitted between the floors, were sometimes grooved or rabbeted into the bars and riveted. At the present day, it is generally considered sufficient to simply rest the lower edges of these plates upon the bar, and connect the former to the floors only; although when vessels built for the government service have bar keels, a tongue is left on the upper part of the bar to which the vertical intercostal plates are riveted.

The greatest variety of combination, however, has been found in the case of the side-bar system. In some cases the centre plate extends only to the top of the floors (fig. 2, Plate XCII.), at others to a sufficient height above to form a keelson, as in fig. 1 on that Plate; while, again, at others it has been carried high enough to form such a keelson as is shown by fig. 2, Plate XC. In another variety the centre plate projects just high enough to allow a piece of *bulb plate* to be riveted to it, and thus form a keelson.

256. Internal Keels.—This leads us to a more detailed consideration of that portion of the keel which is on the inside of the ship. Judging by the extent of its application, it has only been during late years that the importance of a vertical plate between the floors has been fully recognised.

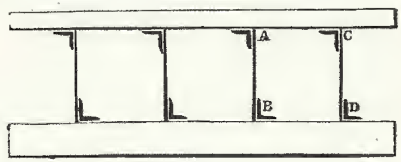

Fig. 28.

It has been a common practice to place no longitudinal tie between the outer keel and the longitudinal combination of plates and angle-irons on the top of the floors, known as the *gutter plate* and *keelson*. Certain accidents to iron ships have called attention to the fact, that the hogging strains peculiar to long, narrow ships tend to produce a tripping of the floors; or an alteration in the form of the space A B C D in fig. 28, enclosed by keel, keelson, and floors (see also

Plate XC., fig. 1) shown by fig. 29. The remedy evidently consists in placing a vertical plate between the floors, and this is usually done. (See Plate LXXXIX.)

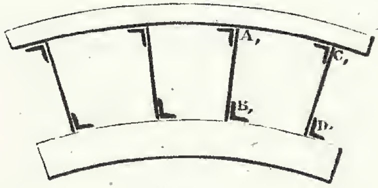

Fig. 29.

It will be seen that by fitting a series of intercostal plates in this way, no more longitudinal strength can be obtained than is given by the rivets connecting the plates to the floors; except such a case as in Plate LXXXIX., where a little additional strength is gained by continuing the plate above the floors to form a keelson. Hence in some cases, especially those of very long ships, a continuous vertical plate has been fitted, the floor-plates on each side being butted against it. A loss of transverse strength results from such an arrangement, which strength is not required to such an extent in long, narrow ships. Generally, the frame or reverse frame angle-iron (usually the former) has been scored through the edge of the keel plate, and thus a portion of the transverse strength has been retained. When the continuous vertical plate has extended above the floors, a scarphing angle-iron two to three feet long is usually passed through a hole in the former and riveted to floor plates, reverse frame and gutter plate on each side; this being required by the Liverpool rules.

The keel shown by Plate LXXXIX. is a very usual form, and although the longitudinal connection is not all that could be desired, yet as it sufficiently provides against the floors tripping, and affords a means for direct communication of the thrust from the keel bars to the pillars; and as the side keelsons contribute considerable resistance to a deflection of this, the lowest part of the girder, the arrangement on the whole cannot be considered unsatisfactory. A great advantage of this mode of combination is the cheapness and facility

with which the work of framing can be performed, by crossing the frames over the keel in one piece, and then erecting them, compared with the piecemeal process of building when the transverse frames are not continuous.

257. Box Keelsons.—It is not necessary to do more than just allude to the complex and varied systems of box-girder keels and keelsons which have been adopted from time to time; against the difficulties in the construction of which, their weight, cost, and the impossibility of access to their interiors, to check corrosion, there is scarcely any set off whatever.

258. Keels and Keelsons of Iron-clad Ships.—There has been a marked uniformity in the construction of the keels of iron-clad ships for the Royal Navy; the style adopted in the *Warrior* being very little different to that in vogue at the present day. As will be seen by reference to Plate XCIV., no external keel is fitted, the material which would otherwise be so disposed being employed to greater advantage in the form of a plate and angle-iron girder at this, the lowest part of the ship. Besides this view of the case, it is apparent that the flat keel plates, supported by the internal keel and framing, affords a better bearing surface than a bar keel for such heavy weights to ground upon.

The keel of an iron-clad ship consists of the following parts:—

First—A flat keel plate, which is a continuation of the bottom plating, the latter being so arranged that the flat keel plate is an outer strake. This strake is usually rather thicker than the remainder of the bottom plating; in this respect coinciding with Lloyd's rules for keels of that construction (see Art. 254). This is very necessary for local as well as structural strength, as these plates are more liable to injury from touching the ground, etc., than the remainder of the bottom.

An inner strake of flat keel plate is worked in conjunction with this outer strake, being fitted between the inner edges of the garboard strakes, or strakes next to the keel plates. The edges of the inner strakes are secured to the outer by means of a single row of rivets, the edge of the outer being secured to the garboard strakes by a double row (see Plate

XCV., fig. 1). The butt straps of both strakes are on the inside of the plating; they are generally treble chain riveted, and are in width equal to the width of the plates they connect, minus the space occupied by the keel angle-irons; while their length, in the case of treble chain riveting, is about sixteen diameters of the rivet.

The lengths of these flat keel plates, bear the same ratio to the room and space as those of the bottom generally, being about three or four times.

Second—A vertical keel plate, extending from the inner surface of the flat keel plates to the inner bottom plates, being usually of the same length as the garboard plates, or about three or four times the room and space. Sometimes, however, they are in alternate lengths of four and five times the room and space, so that two plates of these dimensions will give good shift to three plates, each three times the room and space in length.

Plates XCV. and CII. show a rather unusual case, in which the bottom plates are four times the room and space, or 16 feet in length, while the vertical keel plates, which are of steel, are double the lengths of the bottom plates.

The butts are always carefully shifted with regard to those of the continuous work in the neighbourhood, and are connected by double butt straps, treble chain riveted; each of the butt straps being a little more than half the thickness of the plates they connect.

The vertical keel plates are connected to those of the flat keel by angle-irons on each side, in lengths about double those of the vertical plates, except in such an exceptional case as that just mentioned, when they are of the same length. Their butt straps are usually shifted clear of each other, but sometimes they have been placed opposite to each other in the same frame space. They are very carefully fitted, and are sufficiently long to receive two rivets in each flange, on each side of the butt. The rivets in the keel angle-irons are spaced about five to six diameters apart, so as to make a watertight division of the double bottom space. It will be observed that these rivets serve also to connect the outer and inner flat keel plates.

This completes the continuous portion of the keel, the

remainder of which consists of an intercostal staple-shaped angle-iron, on each side of the vertical keel at its upper edge, serving to connect the inner bottom (when fitted), also the bracket or floor plates to the vertical keel. The riveting in these angle-irons is also spaced so as to make a watertight division between the two sides of the double bottom space. The angle-irons are often so arranged as to extend down the sides of the vertical keel, and butt against the frame angle-irons alternately, at two different heights above the flat keel plate, as shown by Plate XCIV., thus breaking joint with each other; the difference in the lengths of the arms of the angle-irons being sufficient to receive one rivet.

A consideration of the keel of an iron-clad ship is not complete without a reference to the gutter plate, or the middle strake of inner bottom, in the event of the latter being fitted. This strake forms the upper flange of the I girder, the lower flange of which is represented by the flat keel, and the web by the vertical keel plate. In order to obtain a watertight division of the double bottom space, it is necessary to fit these plates with great care, when they form a part of an inner bottom. The angle-irons along the upper edge of the vertical keel, and the continuous angle-irons (to be referred to presently), must be fitted very accurately, so as to form a fair surface upon which to fit the gutter plates, and obtain a watertight joint when riveted and caulked. The rivets are spaced for watertight work, the butt straps are fitted on the under side, and, like those of the flat keel plates, they are in two lengths.

A keelson is not often fitted above the gutter plate of an iron-clad ship; or, if so placed, its primary use is as a support to a boiler flat, or some other purpose not directly connected with the hull. Of course, the structural value of such girders as boiler and engine bearers, especially when disposed in a longitudinal direction, must not be overlooked; nevertheless they cannot be said to constitute a portion of the keel, keelson, or any of the other elements of the hull proper.

259. Keels and Keelsons of Unarmoured War Ships.—The keels of unarmoured iron war ships are differently constructed to those just described. In these ships the flat keel is composed of two thicknesses, as before, unless the bottom is sheathed with wood, in which case it is usually of one thickness only (see Plate XCVI.).

The vertical keel is composed of a continuous plate (in lengths the same as before), and is riveted with a single row of rivets to intercostal pieces of vertical keel, which are the width of the lap deeper than the frames. As the inner angle-irons of the frames do not cross the keel similar to those in armoured ships, the inner angle-irons of the vertical keel are consequently continuous. The vertical keel is connected to the flat keel plate by a single angle-iron, generally on the same side of the plate as the continuous keel plate is riveted. This angle-iron is intercostal, and turns up against the side of the floor plate and vertical keel, until it butts against the inner angle-iron of the frame, or reverse angle-iron, which turns down against the keel. The butts are sometimes extended, alternately, to two different heights, so as to break joint with each other.

As double bottoms are not usually fitted to unarmoured ships, the precautions necessary to obtain watertightness, already referred to, are not needed. Holes are usually cut in the intercostal portions of the vertical keel to serve as water courses.

As in the case of armoured ships, it often becomes necessary to fit longitudinal combinations of plates and angle-irons to serve as boiler and engine bearers, in which case it is usual, when practicable, to connect these bearers to the vertical keel and longitudinal frames; or rather to deepen these to the extent necessary to serve the purpose in question.

260. Stems and Stern Posts of Merchant Ships.—The stems of iron merchant ships are merely continuations of their keels, and preserve the characteristics of the latter throughout, the pitch of rivets and connection to the frames being uniform.

The great curvature in the pieces of stem rendering it very difficult to transport them from place to place, it is usual to supply the stem from the forge in a straight piece, and then to bend it, after being heated in a furnace, on the bending slab, in the same way as angle-irons are bent for the frames (see Art. 271). When so bent the stem is erected by means of tackles, then shored and proved to its proper position, in a similar manner to a wood stem (see Art. 173).

The stern post of a paddle, twin screw, or sailing ship, consists simply of a bar similar to those composing the keel, being bent to the angle between the stern post and keel, then carried along for a short length and scarphed to the latter in the same manner as the pieces of keel are joined together. Sometimes the braces or gudgeons for the rudder are forged to the post, while at others they consist of straps passed through holes in the fore edge of the rudder, and riveted to the post in such a way that the rudder cannot be unshipped without taking off the braces. In any case, the rudder post of a sailing, twin screw, or paddle wheel ship, is much simpler than that of a single screw ship; and, in the latter case, there is necessarily a difference between the stern posts of ships having lifting, and those with non-lifting, screw propellers.

Plate XCVII. shows the stern post of a screw ship of the latter class. If it were intended to raise the propeller, the portion between *D* and *E* would be omitted, and the fore post *BE* would be extended to about the same height as the rudder post *CD*. As will be seen, provision is made for housing the screw shaft by giving a swell to the post, as in a wood ship (Art. 25).

The hole is drilled within about half an inch of the finished diameter before the stern post is erected, so as to leave ample margin for boring out the shaft hole correctly after the ship is built. The stern post is erected by similar means, and with similar precautions to the stem; and the plating of bottom is connected by riveting similar to that in the keel bars.

261. Stems and Stern Posts of Iron-clad Ships.—The stem and stern posts are very formidable items in an iron-clad ship. This is true not only of their size and, therefore, weight, but also of the elaborate, difficult, and therefore expensive character of these forgings.

The provision for ramming, which has become an important feature in modern naval tactics, renders the stem far heavier, and more difficult to forge, than would otherwise be required; but with regard to the stern post of a ship with a single screw, the great massiveness is necessary, not only to give the required form for the large screw shaft to pass through, but also to act, as it were, like an anvil block, and so protect the hull from the great vibratory strains which the application of enormous engine power to screw propulsion must necessarily bring upon the after part of the ship. Twin screws have been fitted to some of our recent ironclads, and in these the stern post is similar to that of an iron sailing ship, as before described.

262. **The Stems of Ironclads.**—Plate XCVIII. shows the stem of an iron-clad ram, sections being given at different places to explain the form of this elaborate and expensive forging. The stem is usually forged in two or three pieces, which are carefully scarphed, keyed, and riveted together, but sometimes, when practicable, it is forged in one piece (Plate XCIX.). The scarph is arranged so as to simplify the forging, by reducing the curvature of the pieces as much as possible, at the same time keeping the scarph clear of that portion of the stem which would receive the principal portion of the shock, in the case of collision by ramming.

The stem of an iron-clad ship is differently shaped at different positions in its length. From the upper part of the stem to the upper part of armour belt it is formed as shown by the elevation and sections between *A* and *B* (Plate XCVIII). Only one rabbet is cut on each side of this portion, these being to receive the fore butts of the topside plating, which are connected to it by a double row of *tap* or screw rivets. Sometimes the stem is wider at this place than is merely required for riveting the butts of the side plating, in order to secure to it a continuation of the vertical keel, similar to that shown by Plate XCIX.

The portion of the stem in the wake of the armour belt, between *B* and *C*, has rabbets cut in it to receive the fore ends of the plating behind armour, the teak backing, and the armour plates. (See sections at main and lower decks, Plate XCVIII.) A separate stop was prepared for the ends of the teak backing in the stem of the Monitor, represented by Plate XCIX., which was not done in the case shown by Plate XCVIII. The armour shelf is riveted at the lower part of this portion of the stem (Plate XCIX.).

The remainder, to where it joins with the keel at *D*, is the most variable portion of the stem. The bottom plating is

rabbeted into this part, the rabbit being of uniform depth; and, in order to obtain a flush surface when the plating is fitted, the laps are chipped thinner to a little abaft the portion which butts on the stem. The plates are secured to the stem by a double or treble row of tap rivets.

At the lower extremity, as shown by the plan at *D*, the several sections and the elevation, the two flat keel plates terminate at different places, so that their butts may give shift to each other. The extremity of the stem is forked, in order to receive, between the forks, the vertical flanges of the lower angle-irons (see *E* in the Plate) of the vertical keel, the horizontal flanges being fitted into a rabbet cut in the underside of the stem.

These angle-irons stop at such a position that their ends shall be well shifted with regard to the ends of the flat keel plates. They are through riveted to the fork, and tap riveted on the underside through the flat keel plates. The vertical keel is continued over the inside of the stem, sometimes to the top of the latter, and at others stopping at a bulkhead, breasthook, or deck flat. In every case it is connected to the stem, either by angle-irons on each side, through riveted, and tap riveted to the stem, or else by riveting the plate to a projecting piece on the stem, as shown in Plates XCVIII. and XCIX.

The preceding remarks describe the general characteristics of the stem of an ironclad; but with regard to further details it may be remarked that these vary in almost every ship.

263. **The Stern Posts of Ironclads.**—As in the case of merchant ships, the form of the stern post is regulated to a considerable extent by the conditions of a lifting propeller, or otherwise. In the former case the body and rudder posts are not connected above the propeller; but both of them are carried as high as one of the decks, to the beams and plating of which they are firmly united. If the propeller is not intended to be lifted, then the two posts are joined, both above and below the propeller; below by a shoe riveted to the lower part of the body post, the latter being formed so as to be a continuation of the keel; and above by a keyed and riveted scarph, joining two arms, which, when united, form the upper boundary of the screw aperture.

As shown by Plate XCVII., the stern posts of merchant ships, of which the propellers do not lift, are forged in one piece, but the great sizes of such forgings in large war vessels renders it almost necessary to scarph them. It should be observed that in the *Northumberland* the rudder post was not riveted to the body post by a shoe at the foot, but the two parts were welded together while in place on the blocks, by means of a temporary hearth; a V scarph being formed and welded just above the heel of the post. The manner of scarphing and riveting the two pieces composing a body post is shown by Plate C. Four of the rivets in this case are through, and four are tapped.

The adoption of a balanced rudder considerably modifies the stern post arrangements, as no rudder post is then required. This form of rudder is not so much in use now as it was a few years ago, in consequence of its unsuitability to evolutions under sail. The stern post shown by Plate C. is of the kind fitted in ships having balanced rudders; but the portion of the post marked *D* has been usually made much wider and thinner, in order to provide for a greater amount of lateral strain than in the case shown. In the *Penelope*, the shoes* are formed of plates and angle-irons, and in the *Bellerophon*, the construction was very similar. It should be stated that in the *Northumberland* the after spur of the body post was also flanged, but in that case the thickness was maintained, as a portion of the weight of the rudder post and rudder was borne thereby, whereas the weight of the balanced rudder is entirely borne by the upper part of the stern; the flange of the post at the bottom offering resistance to the lateral strains upon the rudder in steering. When a balanced rudder is fitted, there is, necessarily, no after support to the propeller, the shaft of which must therefore have a good bearing provided for it in the body post.

264. Forging Stems and Stern Posts.—The information supplied from the mould loft floor for making a stem or stern post, consists of a batten mould with the shapes of sections of the forging at different parts marked upon it, very similar to Plate XCVIII. The forging is made of slabs of hammered

* This vessel had two rudder posts, rudders, and screw propellers.

iron, carefully "piled" and worked by a "porter bar" in the ordinary manner. In this way, a hammered stem, stern post, or piece of the same is formed as nearly as practicable to the required size, leaving sufficient material for the exact dimensions to be obtained under the planing machine. Sometimes the stem, or each piece of a stem, is forged and planed straight, and then bent to the required shape. This is a very cheap and easy way of doing the work when the stem is not so thick as to make the bending impracticable. The most common plan, however, is to forge the stem or its pieces to something like the required form and shape, and then plane it either by a machine having rectilinear motion only, or else by one the tool of which works to the required curvature by means of a guide. This latter process has been carried out with great success at Chatham yard. The rectilinear machine, however, is most commonly employed, and consequently a great deal of chipping is necessary, both in cutting clearances for the planing tool, and in finishing.

The scarphs are carefully planed and fitted, but sometimes it is considered preferable to join them by welding. Allusion has already been made to the case of the rudder post of the *Northumberland*, which was welded to the body post when in place on the blocks. The welding together of two pieces of finished forging is a very delicate operation, as, in addition to the careful correspondence which is essential to a satisfactory joint, provision must also be made in preparing the two pieces for the stretching or "drawing out of the fibre," as it is termed, which is necessary in order to get a good weld. Besides this, a further allowance must be made for the contraction which takes place in cooling. These precautions are particularly necessary with regard to the rudder post when it is intended to support the after end of the propeller shaft. In that case, a small margin of material must be allowed at the boss, and afterwards a line representing the centre of shaft must be drawn, the correct size set off therefrom, and the surplus iron removed.

265. Rivets in Large Forgings.—A great many of the rivets which are used in the work connected with the stem and stern post, are necessarily much longer than elsewhere in the ship; and it may not be out of place to refer to the precautions which are necessary in clenching these rivets.

In consequence of their length, the contraction in cooling is much greater than in the case of ordinary rivets; hence, if the rivet is heated throughout the whole of its length, a very great strain is brought upon the head and point; so much so, that these latter frequently break off in cooling. The heads and points do not always fall off, owing to the fracture in the rivet taking place within the surface of the forging; hence, the defect is not at all times detected until the vibration of the machinery, or the working of the ship causes the pieces to fall out. Such a defect causes undue strains to be brought to bear upon other rivets, some of which are already in a state of extreme tension; and although sound, yet having been cooled very rapidly by contact with such a large mass as a forging, are often very brittle.

In this way fractures have occurred, which can be and are avoided by adopting the following precautions. Cut a piece of rivet bar, of the required diameter, to the length sufficient for the necessary size of head, and point when hammered down. Heat one end, place the other in the hole for the rivet, and knock a head at the heated end, a "dolly" being held against the other. Then remove the rivet from the hole, heat the other end, taper it slightly, and drive it through the hole from the side opposite to that from which it was first driven, and then beat up the point. In this way, by not raising the body of the rivet to a high temperature, the contraction which ensues upon cooling is not greater than in an ordinary rivet; that being quite sufficient for closing up the work.

CHAPTER XVIII.

266. Framing.—With the exception of a few vessels built on the *longitudinal system* (see Art. 278), and one or two others with frames placed diagonally, iron merchant ships have been, and still continue to be, framed in almost exactly the same way. But while this uniformity has existed in the mercantile navy, a great many modifications and changes have occurred in the framing of Her Majesty's ships.

At the present time there are three distinct modes of framing, only two of which, however, are carried out to any great extent.

1. *The transverse system*, generally adopted in the mercantile marine.

2. *The longitudinal system*, so ably advocated by Mr. Scott Russell.

Very few ships have been built on this principle; but of these the *Great Eastern* is a noble specimen.

3. *The above systems combined*, in two principal forms—viz.:—the *bracket system* in iron-clad ships, and the *solid-floor system* in unarmoured war ships.

267. The Transverse System owes its origin to the early iron shipbuilders combining the new material in the same manner as they had been accustomed to do with wood. The frames cross the keel transversely, being generally evenly spaced, and the skin plating is riveted to them in a manner analogous to the mode of securing the plank of a wooden ship. Indeed, the transverse system, as a whole, bears a far greater similarity to wood shipbuilding than our present knowledge of the relative properties of the two materials, iron and wood, would prepare us for.

268. Its Components.—A frame of an iron ship built on the transverse system is composed of three parts, viz.:—

1. *The frame angle-iron* or outer angle-iron, to which the

bottom plating is riveted (see *A* and *B*, Plate LXXXIX.). This angle-iron rarely crosses the keel, but generally extends from the keel to the topside on each side of the ship.

2. *The reverse frame* or inner angle-iron, the longitudinal flange of which stands in an opposite direction to that of the *frame* angle-iron; the ceiling, foot-waling, lining, etc., being secured thereto (see *A* and *B*, Plate LXXXIX.). From about the turn of the bilge to the topsides these two angle-irons are riveted back to back. The reverse angle-iron is either carried across the keel and stopped at a short distance on the other side at alternate sides of the keel—or else it is butted at the keel, and a connecting strap carried across so as to join the two pieces. In small ships it is sometimes possible to carry the angle-iron across the ship continuously from side to side.

3. *The floor plate*, which extends from the turn of the bilge on one side of the ship to the same height on the opposite side, serving to deepen, and, therefore, strengthen, the frame at that part. The reverse angle-iron is riveted to its upper, and the frame angle-iron to its lower, side. It is connected to the intercostal keel plate by short angle-irons, as shown in Plate LXXXIX. When the keel plate is continuous, as in the side-bar arrangement, the floor plate is in two pieces; but when, as in the above-mentioned Plate, the keel is worked intercostally, the floor plate extends from side to side. For large ships it is difficult to obtain the floor plate in one length; in that case they are supplied in two pieces, which are welded or butt-strapped together at alternate sides of the middle line; welding being the usual method.

Lloyd's rules require that the butts of the frame angle-irons shall be connected by angle-iron straps not less than three feet long; while, by the Liverpool rules, the lengths of these angle-irons vary from four feet to six feet. The reverse angle-irons are not carried to the full height of the frame angle-iron, but stop at different positions according to the proportions and classification of the ship. Lloyd's and the Liverpool rules require double reverse angle-irons to be fitted in the way of all keelsons, hold and beam stringers (see Plate LXXXIX.). It is perhaps hardly necessary to call attention to the circular hole cut in every floor plate on each side of the keel, just above the frame angle-iron, for the purpose of a watercourse, cement being laid upon the bottom plating to that height.

269. Modes of Building the Frame.—It is not easy to describe the methods of framing an iron ship on the transverse system, inasmuch as each of the principal iron shipbuilding centres has a system of its own. We will, however, endeavour to give a brief summary of the chief features of these methods; at the same time it may be stated that if the importance of any system can be measured by the extent of its application, then that practised on the Clyde would undoubtedly carry off the palm.

270. Rivet Holes in Frames.—On the Clyde it is the practice to punch all the holes in the frame angle-iron, except those for the rivets in the plate edges and at the turn of the bilge, before bending them; also, sometimes, the holes in the reverse frames for fastening the ceiling, foot-waling, etc. On the other iron shipbuilding rivers all the angle-irons are punched after being bent. The rivet holes in the floor-plates and reverse bars, by which they are connected to the frames, are always marked from the holes in the latter by laying one upon another after the reverse bars are bent.

In setting off the rivet holes in the frame angle-irons, when building by the Clyde system, a batten is bent to the curvature of the frame on the scrive board (see Art. 144), and the positions of the plate laps, etc., are set off upon it; after this the distances between the laps are divided so as to have a spacing of rivets about eight diameters apart. The holes are always punched from the outer surface of the angle-iron; *i.e.*, the surface against which the plating will ultimately fay. In setting off the rivet holes for securing the frame to the reverse angle-iron and floor plate, care should be taken to avoid placing two rivets in the same section of the angle-iron, so as not to unduly weaken it.

271. Bending Frame Angle Irons. — The frame and reverse angle-irons are bent to their required form upon a large slab of iron, which is cast with a number of square holes in it, disposed like the squares on a chess-board. This is technically called the "bending slab." Adjoining this slab are the angle-iron and plate furnaces, and (in the north of England and Scotland) the scrive board (see Art. 144); while in the south of England the frame moulds are kept conveniently near.

The angle-irons are placed in a reverberatory furnace, and while they are being raised to a bright red heat, the workman transfers the curve of the frame which is to be bent upon the bending slab. When the scrive board is used, a flat rod of soft iron termed the "set iron" is bent to the curvature, the bevelling spots are set off upon it, a line is drawn with chalk upon the slab to the shape of the bar, and the points where bevellings are to be applied are also marked upon the line. Strong iron pins are next driven and wedged tightly into the holes in the slab which are nearest to the chalk line. The angle-iron, when sufficiently hot, is removed from the furnace, laid upon the bending slab close to the iron pins, and one end being fixed at a certain point, the other is bent round, and the whole length wedged and driven tightly against the bars. A "set" or pressure is obtained by means of other pins driven and wedged into holes on the opposite side of the angle-iron.

The flange of the angle-iron to be riveted to the floor plate or reverse angle-iron, is that which is laid upon the slab, and the other flange bears against the pins first placed in position. In applying the bevellings the bevel is held upon the slab, and against the back of the angle-iron, in a position square to the curvature. Great care should be taken in opening or closing the angle-irons being bevelled, in order that their strength may not be deteriorated in the process, or their b become so bulged or bruised that the plates will not well against them.

When the angle-irons are bent to the curves, and before they are cool, their curvatures are proved by laying them upon the scrive board and trying them to the lines there shown, the board being preserved from burning by strips of half-round iron which are nailed upon its surface.

It should be observed that an allowance for the stretching of the angle-iron in punching and bending should be made when working by either of the processes. The final operation at the bending slab is to mark upon the angle-iron the

positions of plate edges, harpins, and other important points, and nick them with a cold chisel.

272. **Bending Reverse Angle-Irons.**—The lines of the insides of reverse angle-irons are drawn upon the scrive board as far from the middle line on each side as the ends of the floor plates, the lines being also the edges of those plates. The reverse angle-iron is bent just after the corresponding frame angle-iron, the line of its curvature being obtained by setting off the depth of the frame, above the floor ends, on the inside of the curves of the frame angle-irons, the said depth being given by the midship section. When the line is set off, the reverse angle-iron is bent and bevelled in a similar manner to that already described. When cold, the frame angle-iron is laid upon it, and the rivet holes set off; the holes for the rivets which connect it with the floor plates are also spaced, and the holes in the floor plate are afterwards copied by placing the reverse angle-iron upon the plate.

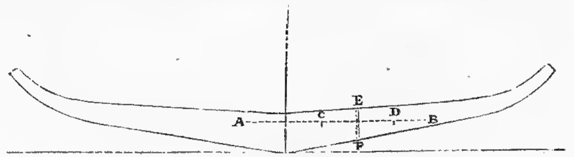

Fig. 30.

273. **The Floor Plates** are provided by the iron manufacturer with straight edges, and, as already stated, sometimes in two or three lengths. On the Clyde, when the floors are supplied in two pieces, they are bent nearly to their required shape, as given by the scrive board, separately, and then sheared or cut to the exact form. The two pieces are then laid upon the scrive board in their correct positions, overlapping each other about $\frac{3}{4}$ inch, and a straight line is struck upon them (see A C D B, fig. 30); also two marks as C and D with a centre punch, these being about 3 feet apart. When the plates are welded, then A C D B must be a straight line, and C and D the fixed distance of 3 feet apart. The rivet holes are set off very carefully by placing the frame and reverse angle-irons upon the plate.

274. **Erecting the Frames.**—By the Clyde and Tyne

systems the frames, reverse frames, and floor plates, are riveted together either by the side of the blocks or across the keel upon a stage level with the latter, and there they, with the beams of one or more of the decks (according to the size of the ship), are riveted together. It is usual to rivet up a great number of frames in this way before commencing to erect them, the latter operation being commenced aft, and proceeded with towards the bow. The pieces are first "cottered" together, and then a number of frames are riveted up in succession. The rivets usually have *pan* heads, and their points are finished with a *snap tool* (see Art. 326).

By the Mersey system the frames are erected before riveting any beams to them, the two sides being connected by cross spalls and harpins. By this process a great number of harpins and ribbands are required, and the work must be carefully set off and shored, as there is very little rigidity in each of the pieces to keep the structure to the required form without such precautions being adopted. It will be admitted that by the Scotch system, where each of the frames is of itself sufficiently rigid to maintain its form, much less trouble is required, in order to ensure an accurate result. The erection of the frames is generally entrusted to wood shipwrights, who adopt the same or very similar means of proving the accuracy of their positions as in wood shipbuilding (see Art. 178).

275. Stern Frames.—In proceeding to erect the frames, it is usual to commence aft at the last transverse frame that rests upon the keel, and then proceed forward. As the stern post includes a portion of the keel, if that forging is not ready to be erected, several of the aftermost frames are temporarily grouped closely together until the stern post is in place, and then these frames are correctly spaced. Plate CI. shows a very usual method of framing the after part. By this sketch it will be seen that the stern frames are canted, and heel against a deep transverse frame, termed a "transom frame," situated at the fore ends of the rudder post, and connected thereto.

276. Bow Frames.—The iron ships of the merchant navy are not usually sufficiently bluff to render it necessary to cant the bow frames, so that whether the stem is upright or

raking, the foremost frames are square to the middle line, and cross the stem the same as if it were the keel.

277. Side Keelsons are the chief source of longitudinal strength in the lower portion of the framing of an iron merchant ship on the transverse system. They are of various forms; but in all the varieties the portion of the keelson from the outer bottom to a little above the inner side of the reverse frames, is worked intercostally (see *C* and *D*, Plate LXXXIX.). Sometimes, however, the keelson is altogether inside the reverse frames (see *E*, Plate LXXXIX). The intercostal portion is connected to the bottom and floor plates by short pieces of angle-iron, as shown. The continuous portion of the keelson consists either of two angle-irons back to back, as at *D*, a piece of plate bulb, an **I** girder, as at *C*, or some other such form. The positions of the side keelsons are nicked upon the angle-irons of the frames when the latter are being finally proved on the scrive board, or by the moulds.

278. The Longitudinal System.—By this system, instead of the frames being arranged in continuous transverse "bends," as in wood shipbuilding, they are disposed fore and aft, and thus better adapted to withstand longitudinal strains. The propriety of building short wide ships on the transverse system is obvious, but for ships of the extreme proportions built for commerce at the present day (often with a ratio of length to breadth of 10 or 11 to 1), it seems very inconsistent to dispose so much of the material in such a manner as to render but scanty assistance in resisting the longitudinal bending forces, which must be considerable in such long ships.

The longitudinal system of Mr. Scott Russell, whose name has been long associated with the subject of longitudinal framing in iron ships, has been thus enunciated by that gentleman:—

"1. To divide the ship by as many transverse bulkheads as the practical use of the ship will admit. I like to have at least one bulkhead for every breadth of the ship in her length. In a ship eight breadths her length, I wish to have at least eight transverse bulkheads.

"2. I have between these bulkheads what I call partial bulkheads, or the outer rim of a complete bulkhead, with the centre part omitted, so as to form a continuous girder running transversely all round the ship, and not interfering with stowage.

"3. I run from bulkhead to bulkhead, longitudinal iron beams or stringers, one along the centre of every plate of the skin, so giving each strake of plates the continuous strength of an iron beam, one portion placed at right angles to another. This longitudinal forms one continuous scarph across all the butt joints of the plates, hitherto their weakest part, and adds, also, to the strength of the rivets of the joint, the help of a line of rivets and angle-irons along the centre of the plate. These longitudinals and the skin are therefore one.

"4. What remains over, after this is done, of the superfluous iron used in the ribs, I make into a continuous iron deck, mainly carried by the bulkheads, and by longitudinals under it; and I believe this iron is infinitely better applied in a deck than in ribs fastened to the skin."

The *Great Eastern*, a part transverse section of the framing of which is shown by fig. 3, Plate XCIII., was constructed by Mr. Scott Russell on this system. Both Mr. Russell and Mr. E. J. Reed claim, with reason, that the framing at the bow and stern is much more readily executed than by the transverse system, chiefly owing to the work being more accessible.

The experience which has been gathered in working by the longitudinal system is so slight that we are unable to state any particular method of carrying out the work which shall have the merit of economy, or any other form of superiority. Indeed, it would appear that it is the lack of knowledge of this kind which has hitherto stood in the way of the adoption of the longitudinal system by many intelligent shipbuilders, who, while fully aware of its great structural advantages, are yet deterred from applying it by the fact that the experience gained by our workmen in the transverse system, and the consequent facility and cheapness with which they perform the work, render competition by a new system comparatively hopeless. We understand that Mr. E. J. Reed, C.B. (late Chief Constructor of the Navy), to whom the profession and country are indebted for the many valuable improvements and developments in iron shipbuilding, which his enlightened foresight has induced him to recognise and adopt, has recently laid down some iron ships at the Earle Company's shipyard at Hull, which are being constructed on the longitudinal system. It remains to be seen whether, by so doing, an impetus will be given to that system. Mr. Russell has admitted that greater skill, intelligence, and accuracy are required in building upon this principle. We fear that these difficulties are more formidable than is generally imagined. Whoever has had any experience regarding the class of workmen into whose hands iron shipbuilding has fallen, will, we believe, share with us the opinion that any deviation from the groove into which the practices of iron shipworkers have been running during so many years, will not meet with pecuniary success for, at least, some considerable time.

279. **The Bracket System** is the development under the auspices of Mr. Reed of the transverse and longitudinal systems combined, by which iron-clad ships have been built since their introduction.

The framework of iron-clad ships consists of two sets of frames—transverse and longitudinal. These cross each other at right angles, or nearly so; the plates of the longitudinals being continuous, and those of the transverse frames in short pieces between the longitudinals. The plates in the transverse frames, when on the bracket system, consist of a bracket-plate on each side of the longitudinal (see Plate XCIV.).

280. **Longitudinal Frames.**—These are constructed very similarly to the vertical keel (Art. 258), and consist of—

1. A plate extending from inner to outer bottom plates, in the wake of the double bottom, and a somewhat reduced and tapering breadth before and abaft it. These plates are sometimes disposed in alternate lengths of four and five times the room and space, and at others they are all in either three, four, or even six room and space lengths. The butts are carefully shifted with regard to each other, and to the butts of the outer and inner bottom plates (see Plates CII. and CVIII.). They are connected by double butt straps (similar to the vertical keel), which are double-chain riveted, except in the case of those longitudinals which make a water-

tight division in the double bottom space, the butts of which are generally treble chain riveted. Longitudinals, and the vertical keel, have frequently been made of mild steel plates, carefully annealed, so as to break at about 32 tons to the square inch.

The inner or continuous angle-irons of the transverse frames inside the double bottom, pass through slots cut in the upper edges of the longitudinal plates, thus reducing the effective breadth of these plates to the same as those immediately outside the double bottom space, where the inner angle-irons of the transverse frames pass above the inner edge of the longitudinal plate. The plates are lightened and rendered more uniformly strong by holes, these being of such a size as to leave at least the same effective sectional strength across the hole, as in the line of rivets through the angle-iron joining the longitudinal to a watertight transverse frame. At intervals holes are cut sufficiently large to allow a man to pass through. These holes, in consecutive longitudinals, are placed in alternate frame spaces, so that complete access can be had to all parts of the framing beneath the ceiling, and in the double bottom. Holes are not cut in the frame spaces where the longitudinal butts occur. The man-holes are oval-shaped, the sizes varying between 18 × 12 inches, and 22 × 18 inches. Small circular holes are also cut, si[illegible] to those in the transverse frames, to form watercourses. [illegible]hese are, of course, omitted in watertight longitudinals.

2. A continuous angle-iron riveted to the lower edge of the plate, generally on the side farthest from the middle line. The lengths of these angle-irons are generally double those of the plates; their butts are shifted with regard to each other, and to those of the bottom and longitudinal plates (see Plate CII.); they are also carefully strapped with two rivets on each side of the butt.

Generally one of the longitudinals on each side is watertight throughout the length of the double bottom, in order to divide that space into watertight cells. In such case the rivets in the inner and outer angle-irons are spaced about four to five diameters apart so as to get a caulk; elsewhere, about eight diameters is the usual spacing.

It may be noticed in passing that in the *Warrior* class there are two outer angle-irons to each longitudinal, instead of one, as now fitted in such ships.

3. An inner angle-iron which in the wake of the double bottom is in short lengths between the transverse frames; but outside that space it is continuous, in lengths about the same as the outer angle-irons, to the butts of which they give shift. In this case, as before stated, the inner angle-irons of the transverse frames pass over the inside of the inner longitudinal angle-iron.

The longitudinals are always connected with outside strakes of plating, and are placed, if possible, square to the ship's surface, so that the angle-irons do not require bevelling when this end is attained.

Formerly, it was the practice to score the longitudinal plate, and joggle the angle-iron over the butts of the bottom plating; but as it is inconvenient to defer fitting the longitudinal until the bottom plates are brought on, and as it is difficult to butt the bottom plates so as exactly to fit the score, this practice is discontinued, and the butt strap of the plate is now fitted in two pieces, one of which is sometimes made to lap over and is riveted through the outer angle-iron of the longitudinal.

The girth of the ship's bottom being considerably less at the extremities than at amidships, it is impossible to extend all the longitudinals right fore and aft without unduly crowding them together, and thus making the bow and stern framing inaccessible, and unnecessarily heavy. It is usual to stop one of the longitudinals at the extremities of the double bottom, and another at an intermediate position between these points, and the stem and stuffing-box bulkhead; two or three longitudinals generally extending from the former to the latter. At the bow, especially in ships constructed for ramming, the longitudinals on each side meet and form breast hooks, one or more of these being plated across from side to side as far aft as a transverse bulkhead; and so the space before that bulkhead is thus divided into two or more watertight cells. The advantages of this arrangement in a ship intended for ramming are obvious. The modes of framing the bow are very various; that shown by Plate XCIX. being the bow-framing of the Bombay Monitor

Magdala. The same style is carried out aft as forward, but not nearly to the same extent, framing of that kind not being so much needed as at the bow.

281 The Armour Shelf.—Although the armour shelf or recess plate is a part of the longitudinal framing of the ship, it has also other functions which we will briefly consider. Forming the upper boundary of the bottom plating, and making a watertight connection between the latter and the plating behind armour, it at the same time offers a suitable lodgment for the backing and armour.

There have been several modes of constructing the shelf, and of uniting it with the bottom plating. In the earlier iron armour-clads the shelf was formed of a bent plate, which was rolled to one of the shapes shown by fig. 31, and then bent, the point A forming the angle of the shelf. This was connected to the plating behind armour by an angle-iron above and another below the shelf. It also lapped outside the upper strake of bottom plating, thus taking the place of an outer strake the surface being flush with that of the armour.

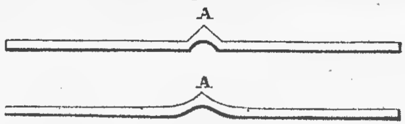

Fig. 31.

The great expense attending this method, and the injury done to the plates by bending, led to others being devised. The first deviation from the preceding was in the case of the *Hercules*, the shelf of which was formed in the manner shown by Plate XCIV. This style has since been retained for ships having *wing passages*, except in the case of the *Captain*, where the outer angle of the armour shelf was wider than in the *Hercules*, and instead of being tap riveted against the shelf plate, it was connected by an edge strip to a narrower plate than in that ship; in other respects the shelf was very similar to that shown by Plate XCIV.

The preceding remarks apply to ships having wing-passage bulkheads, as shown in Plate XCIV. In the *Invincible*, *Cyclops*, and some other recent ships, the wing-passage bulkhead is dispensed with, and the inner bottom is continued to the same height as the armour shelf, the latter being considerably widened in the wake of the inner bottom, in order to form a wide, watertight compartment between the shelf and the next longitudinal below it. The longitudinal referred to is, necessarily, made watertight, and the compartment is divided into a number of cells by watertight transverse frames spaced about sixteen feet apart. The armour shelf of a large ship, when made in this way, is very wide in the wake of the double bottom (see Plate CIII.); elsewhere it is formed similarly to that shown by Plate XCIV. If possible, the whole width is made of one plate, but when this cannot be done, two plates are riveted to each other with a lap-joint, the latter being situated immediately below the angle-iron connecting the shelf to the plating behind armour, so as to receive the same rivets. On the inner edge the shelf plate is connected to the inner bottom by a continuous angle-iron, of much smaller size than that on the outer edge. The riveting of both edges is spaced for watertight work.

In the *Devastation* class of ships the armour shelf differs from those in their predecessors, inasmuch as, owing to the overhang of the armour, the shelf is in two pieces, the outer of which is connected on the outside of the ship to the bottom plating, and is tap-riveted underneath the armour.

The butts of both the plates and continuous angle-irons composing the shelf are shifted with regard to those of the remainder of the longitudinal framing, and the plating in the vicinity. The butt straps are on the underside, being generally double riveted, as also are those of the angle-irons. The points of the rivets in the outer angle-irons are countersunk, so that there may be a flush surface for the armour to rest upon. The armour shelf tapers in width forward and aft to suit the tapering thickness of the armour and backing.

282. The Transverse Frames.—The transverse frames in an iron-clad ship consist of the following components:—

1. The outer or frame angle-iron; in short lengths between the longitudinals, except in the case of watertight frames, where they are made *staple-shaped*, so as to fit against the longitudinals.

2. The inner or continuous angle-iron, termed the reverse angle-iron, which in small ships extends from shelf to shelf,

but is generally in two lengths, butted and strapped at a short distance from, and on alternate sides of, the keel.

3. The bracket plates, fitted in pairs, one on each side of each longitudinal, being riveted to the frame and reverse angle-iron, and connected to the longitudinal plate by a short piece of angle-iron on each side of the longitudinal, but on one side of the frame only. The earliest iron-clad ships, such as the *Warrior*, *Northumberland*, etc., had solid floor plates, pierced with holes fitted between the longitudinals, instead of bracket plates; the latter were first used in the *Bellerophon*.

It is, perhaps, impossible to better describe the advantage of the bracket system than in the words of the gentleman under whose auspices it was first introduced. In his *Shipbuilding in Iron and Steel*, Mr. Reed says:—"The objects of the invention and introduction of this system were to save weight, to simplify workmanship, and to add both to the strength and safety of the ship. The characteristic features of the system are the adoption of an inner bottom, and of short angle-irons connected by bracket plates, in place of staple and other forged angle-iron work. A great increase of longitudinal strength is gained by the use of much deeper longitudinal frames than those of the *Warrior* and other of the earlier ironclads. Another important feature resulting from the employment of deep longitudinals is, that the space between the two bottoms is roomy and easy of access for cleaning and painting operations, which are essential to the preservation of an iron structure. Facilities are also offered by these arrangements for letting in water between the bottoms to serve as ballast, the space being so divided into watertight compartments as to enable the officer to regulate the trim of the vessel by filling the fore or the aft spaces. Provision is, of course, made to pump out any compartment when required."

Allusion has already been made to the difference in the depths of the frames within and without the double-bottom space; a difference is also frequently made in the spacing and construction of the bracket framing. The frames within the double bottom are almost invariably spaced four feet apart, outside those limits they are sometimes four feet and at others two feet apart; although occasionally a three-

feet spacing has been adopted. Again, the decrease in the depths of the frames at the extremities often render it impossible to have spaces between the brackets sufficiently large for man-holes, consequently it is found cheaper and just as light to substitute for the bracket plates, solid plates pierced with holes at that part, in a somewhat similar manner to the portion of the frame immediately below the armour shelf in Plate XCIV. The framing before and abaft the double bottom, when the latter is constructed as shown by Plate CIII., is constructed similarly to the corresponding frames of ships of which the double bottom is framed in the manner shown by Plate XCIV. Care is taken to stop the reverse frames, and the frames behind armour, so that they may scarph over each other alternately at different distances from the armour shelf. For instance, in the *Hercules* type of ships, the frames behind armour in the same transverse sections as those of the bottom,* stopped alternately at the second longitudinal below the armour shelf, and three feet below that point; the reverse angle-irons of the same frame extending as high as three feet above the same longitudinal, and to the longitudinal, alternately; thus causing the scarphs of consecutive frames to be shifted three feet clear of each other, the scarphs themselves being three feet long.

A modified form of the bracket system has been adopted in some foreign iron-clad frigates recently designed by Mr. E. J. Reed. Both the frame and reverse angle-irons of these ships are continuous, slots being cut at both the upper and lower parts of the vertical keel and longitudinals for these angle-irons to pass through. The longitudinal plates are continuous, as before, but the angle-irons are intercostal, being in some cases worked staple-shaped, instead of using short angle-irons to connect the bracket plates to the longitudinals; this is often done in ordinary bracket framing in the case of the frames beneath the engines, and always in watertight frames.

The reasons for framing in this manner appear to be two-

* The frames in the double bottom are spaced four feet apart, but those behind armour are two feet apart; hence alternate frames behind armour are connected to the frames of the bottom. The others stopping at the first longitudinal below the armour shelf.

fold. *First*, in order to get increased transverse strength, the ships being very wide in proportion to their length; and *second*, for the facilities offered in erecting this kind of frame (see Art. 285).

283. Transverse Framing of Unarmoured War Ships.—Reference was made in Art. 259 to the framing of unarmoured ships of H.M. Navy, which is differently constructed to that of iron-clad ships.

In the midship part of these ships, for rather more than half their length, the transverse frames are of two kinds, placed alternately (see Plates XCVI., CIV., and CV.). In the one case (Plate XCVI.), the frame is composed of a frame and reverse angle-iron, which extend from upper deck to upper deck (the angle-irons being necessarily in two or three lengths), the butts of which give shift to each other (see Plate CV.), and are carefully strapped. There are no floor plates in these frames, consequently they are of uniform depth throughout.

In the other case, the frame is composed similarly to that just described, as low down as about the turn of the bilge (see *A*, Plate CIV.); but below that the frame deepens by stopping the reverse angle-iron and introducing a floor plate, extending to the inner edges of the longitudinal frames, the junction being made by scarphing the floor plate upon the upper reverse angle-iron, and continuing the lower reverse angle-iron as shown.

At the extremities of the ship, throughout the remainder of the length, all the frames are formed as in Plate XCVI.

The floor plates of the frames shown by Plate CIV., are worked in intercostal pieces between the longitudinals and the vertical keel; being pierced with holes to lighten the framing, produce uniformity of strength, and allow ready access through the frames under engines, boilers, bunkers, ceiling, etc. A double angle-iron is riveted to the inner edge of the floor plates, being in short lengths like the latter.

284. Longitudinal Framing of Unarmoured War Ships.—The longitudinal frames below the turn of the bilge are in two portions, one of which, the lower, is worked intercostally between alternate transverse frames, *i. e.*, the frames shown by Plate XCVI., while the upper portion is continuous. Thus the intercostal portions are twice the room and space in length. The longitudinals are consequently formed of the two sets of plates lapped and riveted together, and three angle-irons—viz., two on the upper and one on the lower edge. It will thus be seen that the longitudinal is constructed very similarly to the vertical keel as described at Art. 259.

The outer angle-iron is intercostal, like the outer plates of the longitudinal. The latter extend to a sufficient height above the shallow frames (Plate XCVI.), to receive a row of rivets connecting them to the continuous plates of the longitudinal. The shift of butts of the latter, and their continuous angle-irons, follow the same rule as already stated (see Art. 280, and Plate CII.). The longitudinal plates are lightened with holes similarly to the floor plates.

By reference to Plate XCVI., it will be seen that two longitudinals are fitted above the turn of the bilge, where the floor plates do not extend. Each of these is worked intercostally between all the frames, a portion projecting sufficiently far on the inside to receive the rivets connecting to it two continuous angle-irons, back to back, running across the insides of the reverse frames, and riveted to the fore and aft flanges of the latter. The longitudinals are connected to the transverse frames of both kinds by short pieces of angle-iron as shown in the Plates.

285. Systems of Building Bracket Framing.—There are several methods of putting together and erecting the frames of iron-clad ships. In describing one or two of the principal of these, we will assume that the angle-irons and bracket plates have been prepared, fit to go into place.

The blocks having been laid and duly sighted, the two thicknesses of flat keel plates are prepared by means of the keel staffs and templates, the butts fitted, the holes punched or drilled, and the whole temporarily secured to the blocks in a correct position. The lower angle-irons of the vertical keel are next laid in place, the holes marked upon them from the flat keel plates, and those to connect it to the vertical keel set off. The holes in these angle-irons are then punched or drilled, and the angle-irons temporarily secured in place. Next, the vertical keel plates are placed in position, their butts fitted, the holes marked on them from the keel angle-irons, and then punched or drilled. The stations are already set off, and the holes for connecting the frame angle-irons to the flat keel plates set off and punched. Next, the lines of holes for connecting these frames to the vertical keel are squared up, the holes set off, also those for the angle-irons on its upper side. Then the slots in the upper side are cut for the continuous or reverse angle-irons to pass through. The angle-irons at the upper edge of the vertical keel are not fitted until the reverse frames are crossed. The pieces of frame angle-iron between the vertical keel and the first longitudinal on each side are now temporarily secured, having first been punched for the riveting.

When this stage is reached, there are at least two modes of procedure. In the Royal dockyards, and on the Thames and Clyde, the reverse angle-irons are next crossed, and are supported by means of ribbands at their upper ends on the inside surface, and then shored. On the Mersey, the first longitudinal and the lower tiers of bracket plates are next put into place, and temporarily secured; after which, the next row of frame angle-irons and their bracket plates; then the second longitudinal, and so on, to the armour shelf; the whole being supported by ribbands and harpins, which are fixed and shored as the work proceeds. After this, the continuous angle-irons are crossed and connected. In some cases the bracket plates and angle-irons have been connected on the ground, and then erected.

The first-mentioned system seems to be the more preferable, as by securing a continuous angle-iron of each frame by ribbands and shores, the whole of the outer frame angle-irons and bracket plates can be hung to it, even if the longitudinals are not quite ready to go into place. Of course, when these portions of the frame are hung to the continuous angle-iron, the latter is quickly relieved of its weight by placing shores under the frames, and then the reverse angle-iron acts as a ribband to keep the frame to its shape.

The framing recently adopted by Mr. Reed, referred to at Art. 282, is very readily erected. The outer angle-irons are first crossed in place before the vertical keel is laid upon the flat keel plates; these are connected by ribbands and shored.

Next, the bracket plates and longitudinals are placed upon the frame angle-irons and temporarily secured, and then the inner angle-irons are crossed. The short angle-irons (if any) connecting the longitudinals and bracket plates being next fitted, the whole is riveted together.

In every case it is usual to frame the midship portion of the ship first, as high as the armour shelf, or even above; so that the armour plating may be proceeded with amidships, while the more difficult framing at the bow and stern is being erected.

286. Building Frames of Unarmoured War Ships.—The following was the mode of procedure in building the *Active*, the framing of which is shown by Plates XCVI. and CIV. After the flat keel plates were bent, the edges and butts were lined off and sheared. Lines were also struck upon them, for the centres of the rivet holes at the edges and butts, and along the centre for the angle-iron connecting it to the vertical keel. The rivet holes were then set off and punched. The plates were fitted together upon the blocks, temporarily united, and butt straps fitted, the holes being marked upon them from the plates, and then punched.

The outer angle-irons were next erected, and temporarily secured to ribbands prepared for that purpose; the reverse angle-irons were then crossed and secured to the flat keel plates. The intercostal floor plates were also got into place and temporarily fastened to the outer angle-irons until the longitudinals were ready, when some of them were removed to facilitate the fixing of the longitudinal plates. All the frames were inclined slightly forward of their true position at their upper extremities, but were kept well to their correct stations on the keel plates. This was done to allow for the usual tendency to set aft as the work proceeds. The whole of the plates forming the keel, both continuous and intercostal, were put in place singly after the frames and reverse frames were in position. At each intermediate frame one of the floor plates adjacent to the keel was removed, being taken from each side alternately, for greater convenience when getting the continuous plates of the keel into place, and were replaced as soon as possible after these plates were got up. The butts of the latter were then fitted, their holes set off and punched. The longitudinals were next fitted, similar means being adopted as when fitting the vertical keel.

287. Frames behind Armour.—In the earlier ironclads the frames behind armour consisted of a $\frac{5}{8}$-inch plate, 10 inches wide, connected to the plating behind armour with two angle-irons, a single angle-iron being riveted on the inner edge. The plate was reduced in width to 7 inches at the framing of the bottom, and, with the angle-iron on the inner edge, was continuous from gunwale to gunwale.

In the *Bellerophon*, and succeeding ships, the frames behind armour consist of a reverse angle-iron 10 inches wide, which is connected with two angle-irons to the plating behind armour. When a wing passage bulkhead is fitted, this reverse frame extends down as far as about the second longitudinal from the armour shelf, being reduced in breadth to about 5 inches, and scarphing with the continuous angle-iron of the bracket framing. The two outer angle-irons of the frames behind armour extend to about midway between the shelf and the adjacent longitudinal; both are riveted to the solid plate, and stop at about 18 inches from each other.

When the armour shelf is constructed as shown by Plate CIII., then the frames behind armour in the wake of the double bottom are connected in the manner shown. In this case, the union is aided by means of the bracket at *B*; sometimes, however, when the lower deck beam is above the level of the shelf, a bracket plate is fitted so as to connect the beam, shelf, and frame behind armour.

288. Frames above Armour.—At the present day, when the armour plating is being concentrated in a belt at the water line, and the ship's side above that belt is left unprotected, except from bullet fire, a great proportion of the framing above the water line is included under the above heading. These frames are necessarily very slight, being made sufficiently strong that, with the side plating and pillars, they may efficiently support the weight of the decks above, together with their armaments, and altogether give the necessary structural strength. They are usually of two kinds, placed alternately, about two feet apart. The larger size consists of an angle-iron about $7 \times 3\frac{1}{2} \times \frac{7}{16}$ in., with a reverse angle-iron about $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}$ in., while the other

is an angle-iron about $4 \times 3\frac{1}{2} \times \frac{7}{16}$ in. The feet of both are bent down and connected to the plating of the deck immediately above the armour belt (generally the main deck), the junction being effected similarly to that shown by *B*, Plate CIII. In the wake of the explosion of the heavy guns, as at the embrasures, etc., the whole of the frames are of the larger size.

CHAPTER XIX.

289. Outer Bottom Plating.—Independent of its primary purpose to keep the ship afloat, this is perhaps the most important part of the structure, especially so in merchant ships. By far the greater portion of the material worked into the hulls of the latter is in the form of bottom plates. Indeed, a merchant ship is little other than a shell of iron plates stiffened by transverse ribs. The bottom plating being, then, such an important item in the construction of the ship, so much of the weight put into the hull being necessarily required in order to obtain a watertight and comparatively impenetrable bottom, it becomes a matter of considerable moment to so arrange and secure these plates, as to obtain their maximum efficiency.

The bottom plates are always arranged in longitudinal strakes, like the planks in wooden ships. The plates in all cases are riveted to the frames, and connected to each other by straps at their butts, and by either lap joints or strips at their edges, lap jointing being by far the more common method.

There is scarcely any variety in the connection of the plates to the frames, this being done with a single row of rivets in the frame angle-irons, spaced seven to nine diameters apart by Lloyd's, and eight diameters by the Liverpool, rules.

290. Flush Plating. — In the early days of iron shipbuilding, several systems of combining the bottom plates were adopted before builders were agreed, as it were by common consent, to the form now in vogue. Among these early systems was that of *flush* or *jump* joints and butts connected by edge strips and butt straps on the inside surface. These edge strips were themselves, in some cases, connected at their butts by straps. In some instances the butt straps were fitted between the edge strips, and in others were

made the full width of the plate, by joggling them over the strips so as to receive some of the rivets in the edge fastening. Liners, the width of the frame angle-irons, were fitted between the strips behind the frames, the strips being continuous behind the angle-irons.

291. The Clinker System.—Again another, termed the *clinker*, arrangement was sometimes adopted, the connection in this case being by lapping the edges one upon another, after the fashion of boat planks. In this case tapered liners were required, thus rendering the system rather expensive, notwithstanding that less riveting and material were required than by the preceding method.

292. Lamb's System.—A system just the reverse of that in Art. 289, was patented by Mr. Lamb in 1856. This consists in fitting the edge strips on the outside surface, and thus rendering liners unnecessary. Like the first-named system, this has the advantage of the resistance to vertical shearing forces offered by adjacent edges which rest upon each other. It has a disadvantage as regards cost of riveting compared with the system now practised (Art. 293). Lamb's system has been adopted in the ship *Inconstant* of H.M. Navy, the strips being made thick in order to receive the screw fastenings of the plank with which that ship is sheathed, in order that the bottom may be coppered, to prevent fouling (see fig. 38).

293. The Raised and Sunken Plate System is that at present practised; and we will now proceed to consider the differences in the arrangement of butts, riveting, etc., which are adopted in plating the bottoms of ships in this way.

294. Shifts of Butts.—The bottom plates being butted either at the middles of the frame spaces or at some other constant distance from the frames, generally the former, it consequently follows that the lengths of the plates are multiples of the room and space. In order to get an even and simple arrangement of butts, the bottom plates extend over the same number of frame spaces throughout, with the exception of those at the extremities of the ship. By both Lloyd's and the Liverpool rules, the bottom plates are never less than five frame spaces in length, and as these spaces range between 21 and 24 inches, it follows that the minimum limits range between 8 feet 9 inches and 10 feet in length. As a matter of fact the lengths usually employed in large ships are between 10 feet 6 inches and 12 feet, although it is not at all unusual, especially in H.M. ships, to find lengths of 16 feet and upwards employed.

Lloyd's rules further require that butts in adjoining strakes shall not be nearer to each other than two frame spaces, and the butts of alternate strakes are not to be under each other, but shifted not less than one frame space. These restrictions are not very exacting, as it is neither difficult nor expensive to provide even a superior arrangement to that demanded. Plate CVI. shows the *diagonal arrangement*, such as is now commonly adopted at the principal iron shipbuilding establishments, including the Royal dockyards; also Plate CVIII. shows the shift of butts of one of H.M. ships arranged by this system. In the former disposition it will be seen that there are no butts in alternate frame spaces, and in both the Plates consecutive butts in the same frame space are alternately on outer and inner (or *raised* and *sunken*) strakes.

Before the improvements in the manufacture of iron had enabled the makers to supply plates of such lengths as have just been named, the iron shipbuilder was considerably limited in the disposition of the butts of bottom plating. The *brick* arrangement was very common, and even now is sometimes adopted, although never in classified ships. By this system the butts of alternate strakes are in vertical lines, each butt being placed at the middle of the lengths of the plates immediately above and below it. Consequently, one line of butts are all those of outer strakes, and the next those of inner strakes. When the plates are arranged so as to have the same apparent breadth, and therefore the inner are wider than the outer strakes by twice the width of the edge lap, then on the supposition that the butt, even when strapped, is a place of weakness, it necessarily follows that a ship plated on this system is weaker across a line of butts of inner than of outer strakes. This can be, and is, sometimes prevented, both when plating by this and other systems having the same defect, by making all the strakes of the same width. By the *diagonal* system, shown on Plate CVI., the relative widths of the strakes is almost immaterial. It should be remarked that the garboard strakes are shifted clear of the keel scarphs, and are never nearer each other on opposite sides of the ship than two spaces of frames, as shown by Plate CVI.

Plate XCV. shows the disposition of butts in the bottom plating of an iron-clad ship, where the plates are 16 feet long, and the room and space 4 feet.

The butts are disposed on a half block model, from which also the edges are transferred to the scrive board or mould loft floor. In ordering the plates from the manufacturer, the lengths are measured from the model and the breadth from the scrive board or mould loft floor. After the frame angle-irons are bent and adjusted, the positions of the plate edges are nicked upon them with a centre punch or cold chisel, so that the plates can be "pitched" in the positions indicated by these marks; care being taken that the edges are in fair lines, got in by the aid of shearing battens.

295. Fitting the Plates.—The ship being framed, and the beams and stringers riveted in place, the plating is proceeded with; the plates received from the manufacturer, when for high class ships, having been first tested and proved sound, and of good quality. The stations of the several plates are sometimes indicated to the foreman in charge of the work, by a duplicate of the model, or by a sketch showing an expansion of the bottom plating; but on the Clyde, a copy of the book by which the iron is ordered, is all the information afforded. It being usual to mark the strakes alphabetically, and to number the plates in each strake, the workman is thus guided in pitching them.

296. The Inner Strakes (or sunken strakes) are, necessarily, the first to be fitted; generally commencing with those next to the garboards, the latter being outer strakes (see Plate LXXXIX., and fig. 2, Plate XCII.). Sometimes the fitting of the outer strakes is commenced directly two inner strakes are fitted, but very frequently the whole of the inner strakes are fitted in place before commencing the outer.

Templates are used for taking account of the rivet holes in the inside strakes corresponding to those in the frames, when the plates are too heavy to be held in place, and there marked. Some builders use templates very sparingly, preferring rather to fix a plate, weighing as much as half a ton, temporarily in place, in order to mark the rivet holes. These templates are of several kinds, but that most commonly in use consists of two battens, of ¼-inch fir (see fig. 32), representing the edges of the plate, with a cross batten nailed at every frame space corresponding with the frame angle-irons.

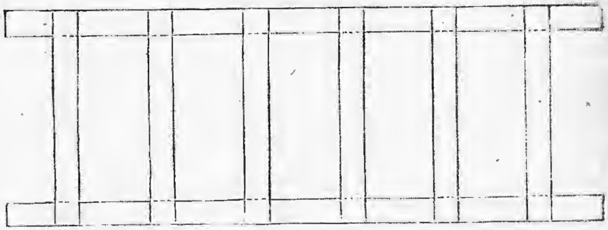

Fig. 32.

This template or batten mould is fixed by means of "hutch hooks" against the frames, at the place where the plate is to be fitted, and the lines of the butts and edges are marked upon it. At the same time the positions of the rivet holes in the frames are copied upon the template, by dipping a hollow cylinder of wood or iron in whiting, and putting it through the holes in the angle-irons. The template is then laid upon the plate, and the lines of edges and butts, also the frame rivets, are copied upon it, the latter being performed by means of a "marker" or reversing tool (see Plate CVII.). This is done by dipping the projection *A* in whiting, and then holding the reversing tool as shown by the Plate; the hole *B* being immediately over the whiting mark for the rivet in the template. Then by pressing the lower fork down upon the plate, a circular mark is made, which, when punched out, gives the rivet hole in the correct position.

The edges and butts of the plates are lined off, the edges being sheared when for inside strakes, while both the edges of outside strakes and all the butts are generally planed to the lines. Sometimes the butts are also sheared, in which case they are fitted by chipping and "jumping" them; that is, by hammering the butt of the plate until it fits against the butt of the next plate. "Jumped" butts, now dis-

allowed by Lloyd's rules, are obviously inferior in quality of workmanship to those which are prepared under the planing machine. Indeed, the jumping system is now rarely adopted, and only in small yards where there is a lack of planing machines. When the butts are jumped, the Liverpool rules require that "the ridge formed by jumping shall be chiselled off the inside, in order that the butt straps shall fit closely; the ridge outside to be hammered into the seam."

The edges and butts of a plate of an inside strake having been cut, and the holes for the frame rivets transferred from the template, the centres of the holes in the edges and butts have next to be lined off. The holes are usually set off by means of patterns or templates, a pair of which serve for the edges of that portion of the bottom in which the plating is of the same thickness. One of these templates is made to suit the rivets of the portion of an edge in a frame space where there is no butt on either of the adjacent plates, and the other for the case where a butt occurs. The reason for this will be seen by reference to Plate XCV. When the plates are of the same breadth, a single butt strap template will suffice; but, in any case, a template suited for the butt of a wide plate can generally be utilized for setting off the rivets in the butts of all plates of the same thickness. The rivet holes marked on these templates are bored out, and thus the holes are easily transferred to the plate by means of the hollow cylinder and whiting.

Should it be necessary to give great curvature to the plate, the latter is bent between iron rolls, the exact shape of the plate being obtained by the aid of section moulds having straight edges, which are out of winding when the plate is to the required form, the moulds being held in their proper positions. There are various kinds of plate-bending machines; a sectional view of one variety is shown by fig. 33. It con-

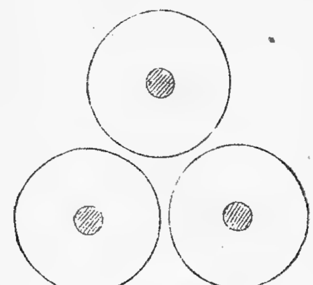

Fig. 33.

sists of three iron rollers, each about 16 feet long and 20 inches in diameter. The upper roller rests in bearings, being free to revolve, but not turned by the machinery which causes the two lower rollers to revolve. It can be raised or lowered to suit the circumstances of the case, this being done by the aid of a lever. When being bent, the plate is lifted by a number of men, under the direction of the "plater" in charge, who hold the plate in the necessary position for obtaining the required curvature and twist. The plates are bent cold, unless very considerable curvature is required, as at the boss. Generally, when the plate is forged to its shape, a skeleton mould is made for it, constructed of small iron rods bent and welded together. In this way the inner strakes are cut, bent, punched, and fitted, after which they are temporarily secured in place by means of nut and screw bolts, "cotters," etc., until the outer strakes are brought on.

297. The Outer Strakes (or raised strakes).—The garboard strakes are the most difficult to prepare of the outer strakes of bottom plating, when either the bar or side bar system of keel is adopted. The difficulty referred to arises from the furnacing which these plates must undergo, before they can be bent to the angle between the bottom of the ship and the side of the keel (see *A*, fig. 2, Plate XCII.). This bending is very carefully performed, the plate being usually bent on a cast-iron slab, and then proved by section moulds. In order to get a satisfactory set of rivet holes for connecting the garboard strakes to the keel and adjacent plating, it is advisable to shore the plate in place, and mark the rivets in that position.

Templates are generally used in taking account of the rivets in the edges of the inner strakes, above and below the outer strake to be fitted, for the purpose of setting them off upon the latter; except in the case of light plates, which are held up or shored in place, and the holes marked upon them. As already mentioned, some builders prefer holding up or shoring, and then marking the holes on heavy plates in this way. The template employed for outside strakes is similar to that shown by fig. 32, and the holes are transferred from them to the surface of the plate by means of the reverser, shown by Plate CVII.

A patented template has been used on the Thames, having a number of revolving tongues of zinc working on its edges, with holes in them. These tongues can be set in any direction, so as to indicate the position of the rivet holes in the inner strake of plating. No reverser is required with this template. The template commonly in use on the Thames is similar to that shown by fig. 32, except that the two extreme cross battens are connected to the upper and lower battens with working joints, and the remaining cross battens are of thin iron, which can be set to the positions of the frames. The holes for the butt straps of the outer strakes are set off similarly to those of the inner strakes; also the butts are fitted and the edges sheared as before stated.

298. Sheer Strakes.—As every precaution should be taken in building a ship to have the material most efficiently disposed, it necessarily follows that the greatest longitudinal strength should be given at the upper and lower parts; being where the greatest tendency to extension and compression occur. The vertical keel, side keelsons, and the other longitudinal connections in their vicinity, when properly arranged, afford the required strength at the lower part: we have now to consider one of the principal modes of providing corresponding resistance at the upper part of the ship.

Sheer strakes are the strakes of the plating (generally *outer*) which are adjacent to the principal decks; the strake in the wake of the main deck being that to which attention is chiefly given. In vessels of extreme length this strake is doubled for a considerable distance amidships, and in all cases it is thicker than the adjacent strakes (see Plate LXXXIX.), and should be connected to the deck-stringer plate. No holes should be cut in these strakes without compensation, this being effected either by doubling the plates above and below, or by strengthening the stringers; the former being the most effectual method.

It may be remarked that the plates at the bilges are thickened, and frequently doubled, for a considerable length amidships in very long ships; the extent to which either of these is done being laid down by Lloyd's and the Liverpool rules. In the latter case the butts of both thicknesses are carefully strapped, and the two thicknesses riveted together between the frames.

299. Riveting in Bottom Plating.—Reference has already been made to the riveting of the bottom plating; we will now consider this subject somewhat more in detail. It will be obvious that since the bottom plating occupies such an important position in the structure, the riveting upon which the efficiency of the plating entirely depends must be deserving of careful attention.

There are three sets of rivets in the bottom plates of a ship, viz., those in the edges, butts, and frames (whether transverse or longitudinal). Unless the frame is watertight, the rivets connecting the bottom plating to it are openly spaced, generally from seven to nine diameters of the rivet from centre to centre; but at the watertight transverse and bulkhead frames the rivets are spaced about six diameters apart, while in the watertight longitudinals the spacing is about five diameters.

The rivets in the edges are sometimes in a single, and at other times in a double, row. Lloyd's rules require, that "in all vessels the edges of the garboard strakes and the lower edges of sheer strakes are to be double riveted. When the remaining outside plating is $\frac{6}{16}$ of an inch in thickness, or less, the edges may be single riveted; when the plating is above that thickness, the edges must be double riveted, from the keel to the height of the upper part of the bilges, all fore and aft. In all vessels the edges of the plating above this height (excepting the lower edges of sheer strakes) may be single riveted if the plating is $\frac{8}{16}$ of an inch, or less, in thickness; but if above that thickness they must be double riveted." The Liverpool rules also require the same conditions. In the Royal Navy double riveting is always adopted in edges, except in cases of ships sheathed with wood, which are single riveted at the edges, the plates being thinner than those in ships of the same size which are not sheathed. The narrow lap for a single row is shown by Plate XCVI.

Double riveting is of two kinds, viz., *chain* and *zig-zag*. The former is shown in Plate XCV., and fig. 3, Plate XCI.; while the latter is shown by fig. 2 on the same Plate. The Liverpool rules require chain riveting for all double and treble riveted joints and butts, but Lloyd's rules merely recommend its use, without enforcing the same.

Again, the Liverpool rules permit the rivets in the edges of the sheer and garboard strakes to be of the size corresponding to the thickness of the adjacent strakes (Art. 327), but that the rivets in the butts shall be the size required for plates of equal thickness.

By both the rules it is required that the widths of the laps of the plate edges shall not be less than six diameters of the rivet, when double chain riveting is adopted; and three and a half diameters when single riveting is worked. The Admiralty practice is rather less than the above.

As a general rule rivets should never be nearer the butt or edge of any plate, angle-iron, edge strip, or butt strap, than a space equal to its own diameter, a little more being preferable; and in edge or butt riveting the space between two consecutive rows of rivets must not be less than one and a half times their diameter, one and two-third times being preferable.

Butt straps of bottom plating are always, at least, double riveted, and sometimes treble riveted. The butt straps are the same thickness as the plates they unite, and the strap is cut with the grain of the iron in the same direction as in these plates. Lloyd's rules require a length equal to thirteen diameters of the rivet for double-riveted straps, and nineteen diameters for treble. The requirements of the Liverpool rules vary from thirteen to fourteen diameters for double, and demand eighteen diameters for treble, riveted straps. In both these rules the lengths of the straps have been increased by one or two diameters during recent years. The Admiralty practice is about twelve diameters for double, and sixteen and a half diameters for treble, riveted butts.

Lloyd's further stipulate that the rivets in both edges and butts shall be spaced not more than four and a half times their diameter from centre to centre; and this is the Admiralty practice. By the Liverpool rules, however, the spacing is four diameters apart. In treble-riveted butts both the rules permit alternate rivets to be omitted on the farthest rows from the butt; this practice is not observed in plating the bottoms of iron ships.

The rivets in edges, butts, and angle-irons should be punched *from the faying surfaces;* that is, the faying surfaces are to be uppermost when the plates are held to the punching machine; as by this means the conical form given to the hole by the punching tool is such that when the plates are in place and the holes coincident, the latter are the shape of two frustrums of cones joined at their small ends. The extra binding effect of the rivet by this arrangement need hardly be pointed out. The holes for the frames, and those in the edges of the raised strakes, also those in the butt straps, are countersunk on the outer surface; the countersink generally extending through the thickness of the plate. The outside or point of the rivet is chipped flush, or nearly so, after it is hammered up; the usual practice being to chip the rivet points slightly convex beneath the water line, but flush above. The rivets should be of a conical shape under the head, in order to fill up the conically-shaped holes in the angle-irons and inside strakes of plating.

300. Liners.—The raised and sunken system of bottom plating requires *liners* to be fitted between the outer or raised strakes, and the frames. Except in the watertight frames these liners are about the same width as the frame angle-irons, and the rivets connecting the frames to the plating necessarily pass through the liners.

In the preceding article it was remarked that, while the rivets connecting ordinary frames and bottom plates are seven to nine diameters apart, those in the watertight frames are only six diameters. Although this is a wider spacing than is adopted in watertight joints at other parts of the ship, yet it will be observed that a row of rivet holes so arranged reduces the strength of the ship at a line passing through them by one-sixth, and even more than this if we take into account the deterioration in the quality of the iron in the remainder of the section caused by punching these holes. In order to bring up the strength of the ship at this section to the same as at an ordinary frame, the liners at these watertight frames in H. M. ships are made wide enough to take two additional rows of rivets on each side of the frame, and thus serve as butt straps to join the portions of the plate on both sides of the line of rivets. (See the watertight frame in

Plate XCV.) Lloyd's and the Liverpool rules require that the liners shall extend from the fore side of the frame before the watertight frame or bulkhead, to the aft side of the frame abaft it. It should be remarked that in the ships of the Royal Navy the longitudinal frames afford a connection between the portions of the plates on both sides of a line of rivet holes, which is altogether wanting in ships built on the transverse system (see Art. 278). Besides this, the frame space is so small in merchant ships, compared with the length of the butt strap, that a double row of rivets on each side of the angle-iron is nearly tantamount to the requirements of the rules alluded to.

301. Stealers.—As already stated (Art. 138), the great difference between the girth of the ship at amidships and the extremities renders it necessary to end some of the strakes of bottom plating before reaching the bow and stern, particularly the former. Plate CVIII. shows an expansion of the forward portion of the bottom plating of an ironclad. It will be seen by reference thereto that the two uppermost strakes terminate before reaching the bow at the points *S, S;* two strakes in each case blending together so as to form one. This union is effected in different ways, that shown by Plate CIX. being very satisfactory. It will be seen that *X* strake is a stealer finishing at its fore end flush with *IX* strake. The manner in which this is done is shown by the section at *A*, *B*, and *C*. The edges of the plates are rabbeted together, the rabbet being 7 feet long. The edges of the plates are strengthened at the joint by an edge strip, as shown; the latter being formed to serve also as a butt strap at the end of the stealer. *E E E* represent tapered liners in the wake of the frames.

302. Frame Spacing in Relation to Butt Fastening.—Uniformity of strength in the connection of the bottom plates at their butts and edges is of the highest importance; and, as we have already seen, the butts should be carefully shifted and strapped in order to insure this result.

The weakness at a section passing through a line of frame rivets in the bottom plating is evidently unavoidable; and the best practice has been to take the tensile strength of such a section as a standard in calculations for regulating the fastenings at the butts. Mr. W. H. White, Professional Secretary to the Admiralty Council of Construction, in an interesting and instructive paper read by him at the last (1873) annual meeting of the Institution of Naval Architects, has shown that the frame spacing is an important element in such a calculation; and that the advantages of long plates and a careful shift of butts have frequently been neutralized by the close spacing of frames now adopted in the merchant navy, and required by Lloyd's and the Liverpool rules.

The author in his paper says:—

"Supposing the butt of any particular strake to be that under consideration, it would be proper, according to the ordinary method, to consider this butted strake to be associated with and helped by two out of the four passing strakes which on either side intervene between this butt and the next butt falling in the same frame space with it. If the shift gave only two passing strakes between consecutive butts, then the butted strake would be supposed to be helped only by one strake on either side, and so on. Having settled this important condition, the strength of the strakes associated together is calculated for the weakened section adjacent to the butt; and this strength is made the standard of comparison for breaking strengths corresponding to other less direct, but not improbable, modes of fracture, which would lead to the rupture of the passing strakes, and the tearing asunder either of the butt, or of the butted strake, at some section near the butt. The plan, however, is principally useful as a mode of analysing cases when the frame space and shift of butts are both determined upon; and for our present purpose some further assumptions are necessary. These will be briefly summarised, and then applied.

"First, it will be taken for granted that the maximum amount of succour which a *butted* strake can receive from the adjacent *passing* strakes, is determined by the shearing strength of the edge rivets lying between the necessarily weakened section of the plating nearest to the butt, and some line across the butted plate, or the butt strap, made unusually weak by being pierced to receive the butt fastenings. This is really only equivalent to saying that the passing strakes are far more likely to yield at their weakened sections in wake of the frames than at their practically unpierced sections intermediate between the frames; and that the question whether the butted strake will yield at the same section, or have its edge fastenings sheared and its butt torn asunder, depends mainly upon the strength of the edge fastenings between the butt and the weakened section at the frame.

"Secondly, since the utmost help which can be given to the butted strake by any shift of butts is limited by the shearing strength of

these edge rivets, it follows that when the number of passing strakes between consecutive butts lying in the same frame space has been made sufficiently great to secure the fracture of those passing strakes at their weakened section, all further additions to the number of passing strakes are comparatively useless.

"It will be obvious that the number and shearing strength of the afore-mentioned edge rivets is practically governed by the frame space; and it is on this account that frame space has such an important influence on the arrangement of the butt fastenings.

"This departure from the ordinary method of calculation will be seen to lead to a considerable saving of labour; besides enabling the effects of frame space and shift of butts to be considered separately, and determining the shift of butts that should be made use of in association with a certain frame space and edge riveting. The butted strake is, in fact, treated far more independently, although not dissociated from the passing strakes."

Having given some specimen calculations to illustrate his arguments, Mr. White further states in his paper:—

"Apart from quantitative results, however, it must be admitted that the easiest and best way of securing proper strength for the butts is to increase the spacing of the transverse frames, and thus to succour the butt fastenings by the edge riveting to a greater degree than is now possible. This conclusion, supported as it is by numerous calculations, furnishes another argument against the ordinary system of framing iron ships; and although not worthy to be named in comparison with the more weighty arguments based upon a consideration of the strength of the ship as a whole, it is not without force. There can be little question but that a considerable loss of strength in the skin plating, at present resulting from the close spacing of the transverse frames, would be avoided if these frames were spaced more widely; and it is to be hoped that before long some change of the kind will be initiated. With a frame space of say 3½ or 4 ft., and with plates from 10 to 12 ft. long, the present defective butt fastenings might easily be made all that could be wished, without incurring any additional cost or involving any additional weight on the skin itself."

Further calculations made by the author,

"Show that *one* passing strake between consecutive butts would suffice (with the experimental data employed) to secure all that is needed; and that, with the 22 or 24-inch frame spaces, all other shifts of butts, giving a greater number of passing strakes between consecutive butts in the same frame space, are of practically no greater use in succouring the butted plates than the common *brick* shift. With the transverse frames placed further apart, say from 3 to 3½ feet, the number of edge rivets to be sheared is of course greater, and it would undoutedly be desirable to have *two* passing strakes between consecutive butts, just as has been the practice for many years past in the iron ships of the Royal Navy, where the frame space is from 3½ to 4 feet. With a still greater frame space three or four passing strakes might be advantageously employed; but extremely long plates would then be required, if the assumed conditions of the previous cases were made to hold, and the arrangements would really resemble very closely those of a longitudinally-framed ship—a case to which we shall refer hereafter."

The conclusions at which Mr. White arrives are as follow:—

"*1st*, For longitudinal-framed ships.

"I. In such special vessels it is most advantageous to make use of long plates, and to adopt a shift of butts enabling one to associate a good number of passing strakes with a good 'step' between the nearest butts of adjacent strakes.

"II. Necessarily weakened sections must exist near the butts in order to receive the closely-spaced rivets required for caulking the joints; and the utmost efficiency of the edge-riveting with any particular shift of butts is reached, when the shear of the rivets in the 'steps' brings up the breaking strength for indirect fracture to that for fracture along a line passing directly across the plating through a series of the weakened sections of the butted strakes.

"III. The shearing strength of the rivets on one side of the butts should never fall below the breaking strength of the butted plate along its necessarily weakened section. Consequently, with the ordinary pitch of rivets for watertight work, single riveting ought never to be adopted for the butts.

"IV. Single-riveted edges need not be sources of weakness, if associated with certain shifts of butts and lengths of 'step.'

"*2nd*, For ships in which the ordinary conditions are fulfilled, and the transverse frames occupy a prominent position, it would appear that very different conclusions must be drawn respecting the arrangement and the fastenings of the skin plating.

"I. So far as strength under tensile strains is concerned, the use of long plates is not specially advantageous, except when the frame space is unusually great—say from 5 or 6 feet upwards. Some saving of weight in butt straps would, of course, result from the use of such plates.

"II. The frame space, regulating as it does the amount of succour which passing strakes can give to butted strakes, practically governs the arrangement of the butt fastenings and affords a means of determining upon a suitable shift of butts.

"III. Double edge riveting is always a source of strength in such vessels, as compared with single edge riveting; but its adoption may, in some cases, necessitate a modification of the shift of butts. Single riveting for the butts is objectionable in these vessels for the reasons given above for longitudinally-framed ships.

"IV. It appears that an increase in the spacing of the transverse frames favours the more satisfactory development of the strength of the skin plating, without any increase in cost of workmanship or weight of material. A change in this direction has been repeatedly enforced on weightier grounds than the above, but has been long postponed. There can be little doubt, however, that nothing but advantage, so far as strength in proportion to weight of hull is concerned, would result from modifying the present system of framing, widening the frame space, and combining with the reduced transverse framing some well-considered system of longitudinal framing."

These statements and conclusions require no comment, but show clearly that notwithstanding the great experience and skill which have been brought to bear upon this important subject, both in framing underwriters' rules and in building up the practice of our best shipyards, there is still very considerable scope for progress in the art of iron shipbuilding.

303. Plating behind Armour.—The armour and backing of iron built armour-clad ships are secured to a skin of iron plating, which is riveted to a system of frames as referred to at Art. 287. This plating is generally very thick, varying from 1 to 2 inches, and both for facility of workmanship and strength of combination, as well as economy of cost, it is usually worked in two equal thicknesses, the edges and butts of which give shift to each other. The plates are butted upon the frames, being single riveted through the frame angle-irons. A stronger butt connection than this is unnecessary, as each thickness of plating is a butt strap to the other. The edges are also single riveted, and, in order to reduce the number of perforations in the plates, and leave as much flush surface as possible on the inside for heaving up the nuts and washers of the armour bolts, one of these rows of rivets sometimes serves to connect an angle-iron girder to stiffen the plates (see Art. 304, and Plate CX.). The outer edges and butts are made watertight, and consequently the rows of rivets in them are spaced sufficiently close for caulking. Such precautions are not necessary for those of the inner strakes.

The points of the rivets are usually countersunk, in order to give a flush surface against which to fit the backing. Great care should be taken in fitting these plates, and templating the holes, to insure that the latter may correspond in the two thicknesses. For this reason the holes in the outer thickness should be marked from those in the inner, although they are sometimes both marked from one template, and punched and fitted almost simultaneously.

304. Girders behind Armour.—The girders are formed of angle-irons, the deep flanges of which are about an inch less in width than the thickness of the backing, the flange riveted to the plating being about $3\frac{1}{2}$ inches wide. They are in lengths as great as can be procured, and their butts are carefully shifted and strapped. If the girder is near the water line of the ship, the edge of the angle-iron upon the plating is chipped and the joint caulked, although the riveting is not more closely spaced than usual for this purpose. This is done in order to keep any water between the backing and plating from getting under the angle-iron, and then by means of a rivet hole, not properly filled, circulating between the two thicknesses of plating. These girders are disposed so that they may be clear of the armour bolts, and generally placed so that there are two girders behind each strake of armour plates. In the case shown by Plate CX. there is only one girder behind each strake.

305. Side Plating above Armour.—The plating on the sides of war ships above the armour is usually flush, being connected by single riveted edge strips and double riveted butt straps, the former being in short pieces between the frames. The spacings of the rivets in edges, butts, and frames, are similar to those in the bottom plates (see Art. 299); also the butts are disposed by similar rules (see Art. 294).

CHAPTER XX.

306. Beams.—Of the many sectional forms of beams that have been adopted in iron ships, there are five principal varieties still in use. In fig. 34, A represents the section of a T bulb beam, a very usual form, as it combines lightness with the necessary shape to afford good security for the deck fastening, and resisting vertical and lateral bending forces.

Fig. 34.

B is a variety which is more in use than any other, especially for deep beams, as the T bulb, when rolled to a large size in one piece, is very expensive. This beam consists of plate bulb, with an angle-iron riveted to it on each side, and is therefore heavier than the beam at A when of the same depth and width of flange. It should be stated that the beam at A was, until recently, rolled in two pieces, viz., a T piece and a piece of plate bulb. These were welded together, the joint being situated along the line of the *neutral axis* of the beam, *i.e.*, the part of the beam which, when the latter is bent, is neither extended or contracted. The Butterly Company had the patent right to manufacture these beams, which were known as the "Butterly Patent Welded Beams." Recently, however, beams have been rolled, in one piece, to this section. C shows a form of section which has been strongly recommended and sometimes adopted; it cannot, however, be rolled in long pieces, consequently that shown at D is generally used in cases where a long, strong beam is required. In this latter form of section the upper angle-irons are larger than the lower, as the former have to receive the deck fastenings.

The section at E is that of a beam termed angle bulb, often used in the decks of small vessels, and for the light decks such as poop and forecastle in larger ships.

307. **Sizes of Beams.**—Lloyd's rule for beam plates requires that their depth shall be "one quarter of an inch for every foot in length, and to be in thickness one-sixteenth of an inch for every inch in depth." The Liverpool rule is almost identical with the preceding. Lloyd's rules further require that "the sizes of all beams which are not less than three-fourths of the length of the midship beam may be in proportion to their lengths, all other beams must not be less than three-fourths the depth and thickness of the midship beam, excepting at hatchways exceeding in length four spaces of frames, mast and pall bitt beams, and beams under the heel of bowsprit, which must not be less in size than the midship beam."

The Liverpool rules require greater uniformity in the dimensions of beams, as may be seen by the following extract:—"The full depth and thickness of the beams to be carried over three-fifths of vessel's length amidships; and may be reduced thence to ends as follows:—main deck beams one-sixteenth of an inch in thickness, and, at after end only (except in vessels having three tiers of beams), one-sixth of their depth. Lower and orlop deck beams one-sixth of their depth, and one-sixteenth of an inch in thickness at both ends when the thickness is nine-sixteenths, and two-sixteenths of an inch when the thickness is ten-sixteenths, and over. Beam knees to be the same depth all fore and aft."

In war ships, the sizes of the beams are governed by the weight of the armament, and sometimes a shallow beam is fitted in order to get as much space as possible between decks; in such a case the strength is made up by increasing the number of the beams, or some other such expedient.

The beams of merchant ships are usually rolled in one length; but for wide ships it is necessary to weld the plates and angle-irons; the butts of those in each beam being well shifted with relation to each other, and to those of the adjacent beams, so that the pieces of alternate beams are similarly arranged. The made beams for H.M. ships (see D, fig. 34), are generally formed in this way; sometimes as many as four plates and twelve lengths of angle-iron entering into the construction of each beam.

308. **Spacing of Beams.**—The spacing of beams in merchant ships is of a very variable character, depending upon the ratio of the length to the breadth, also upon the number of decks to the ship. In all cases the beams are fastened to frames, and placed immediately over each other. The usual spacing of beams in H.M. ships is 4 feet, being placed at alternate frames, which are generally 2 feet apart above the armour shelf.

309. **Beam Arms.**—These are very important parts of the beam, as the efficiency of the latter entirely depends upon its connection with the ship's side. There have been many forms of beam arm, but that shown by Plates LXXXIX., XCIV., and XCVI., is now almost universally adopted. The shape of this arm is obtained in two or three different ways. To make the arms of the Butterly beams, already referred to, the welding of the two portions of the beam is omitted for a short distance from each end of the beam as supplied from the maker, and the lower half is heated and bent down to the required curve of the arm, while the upper is left straight. The form of the arm is then completed by welding a piece so as to join the upper and lower parts, sometimes leaving a triangular hole rounded at the angles, for the purpose of reducing unnecessary weight. This method is also sometimes employed in forming the arms of plate bulb beams, but in this case, the end of the beam must be heated, cut, and the lower part bent. The arms of the I beams as shown at C, fig. 34, also of the angle bulb shown at E, are made in the same manner. On the Clyde, however, the arms of the section shown by B in that figure (which is the pattern usually employed), are often made by bending the whole of the end of the beam plate to the required shape of the arm as shown by ABC, fig. 35, and then welding a piece of plate at the upper corner of each end of the beam, as shown by D in the figure; the bottom of the arm being finished off as shown by the line DE. At Messrs. Elder's yard, Govan, the beam is cut to its length at A, fig. 36, the portion of the bulb between A and C is chipped off, and a short piece of bulb plate DE is welded on to form the arm,

its upper end being curved as at C. A piece G is welded on, and the arm cut to the line AF. This mode of forming the arm does not appear to be so satisfactory as that shown by fig. 35. The arms of made beams, such as shown by D, fig. 34, are made by cutting the plate to the required shape of the arm, and bending the lower angle-irons to the curve of the arm and riveting it thereto.

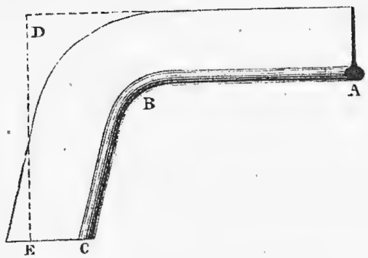

Fig. 35.

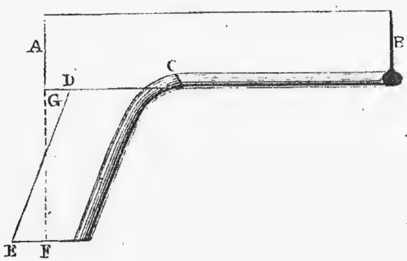

Fig. 36.

Among the many other modes of joining the beam with the ship's side, we may call attention to that shown on Plate CIII., where it will be seen that the upper deck beams and the frames behind armour are of one piece of bulb plate, or rather two lengths welded together, the welds of consecutive beams being situated on alternate sides, at about 6 feet from the middle line.

Both Lloyd's and the Liverpool rules require that the length of the arms shall not be less than two and a half

times the depth of the beam; in the Royal Navy, however, the arms are generally three and a half times that depth.

The riveting is generally arranged upon a template by which the holes in both the frame and beam arm are set off simultaneously; but sometimes the holes are set off in either of these, and from thence transferred to the other. The former is the practice adopted on the Clyde.

310. **Bending Beams.**—When the beams are set to their round up cold, the operation is performed by means of a screw press, or a beam-bending machine. They are, however, frequently bent hot; sometimes upon the bending slab similarly to the frames, and at others by resting the beam, when heated, upon blocks laid to the required curvature, and allowing it to settle down to its shape. The first named method is the most usual.

The plate bulb of beams, such as B, fig. 34, should be bent before the angle-irons are riveted to their upper edges, after which it is necessary to check and adjust the curvature, which alters slightly in the process of riveting. It may be remarked that the riveting of both beams and frames is now frequently performed by means of a riveting machine. The beams are proved by a beam mould, and are generally cut to the lengths given by the scrive board, or mould loft floor; by reference to which, also, the angles of the arms are determined. Sometimes, however, the beam arms are cut to the angles given by moulds which are themselves made from the floor, the lengths of the beams being given by a mould, as shown by fig. 1, Plate LXV. This latter is the practice of the Royal dockyards, while the former is peculiar to the northern shipyards. The processes of bending, adjusting, and cutting the beams, also riveting the angle-irons to the plate bulb, are usually carried out simultaneously with the riveting up of the frames. On the Clyde, all the beams of small vessels are riveted to the frames before the latter are erected; but in vessels of more than about 1000 tons burthen, the upper and main deck beams only are so riveted, and the remainder are fixed and secured afterward. The reason for this difference is, that the collective weight of the beams and frame of a large ship being so great, renders it very difficult to erect without straining and loosening the riveting. On the other principal shipbuilding rivers, the beams are not riveted until the frames are erected, the two sides of the latter being in the meantime connected by cross spalls.

311. **Half Beams and Carlings** have the same functions as when of wood. They are usually of smaller size than the beams, except when the carlings form the sides of long hatchways, when they are often of larger sectional form than the beams; and the half beams are then frequently made of light angle bulb, especially when the hatchway is also very wide. The connection of beams and carlings is by means of angle-iron corner pieces, when the beams are of a rolled section; and by turning down the upper angle-iron of the carling against the beam when it is of the section shown by B, fig. 34. Carlings made of the section shown by D on that figure, are made of a plate and two box-shaped angle-irons, the latter being riveted to the adjacent beams.

312. **Watertight Bulkheads** are a peculiar feature of iron ships, as the manner of framing the ship and the materials employed afford special facilities for the construction of such water-tight divisions.

Iron transverse watertight bulkheads are constructed in several ways. In H.M. service the plates are generally arranged horizontally, while in some private yards, especially on the Clyde, they are arranged in vertical strakes. In the Royal Navy the bulkheads at the extremities of the smaller compartments are connected by single-riveted lap joints and butts (see *A*, Plate CV.), the bulkhead being stiffened by angle-irons about 24 to 30 inches apart (see *B*). The bulkheads of larger compartments, such as the engine and boiler spaces, are generally built with flush joints connected by T bars, the edges of the plates being closely fitted upon the middle of the flange, which thus serves as an edge strip, while the web of the T bar stiffens the bulkhead; the butts are strapped and double riveted. In this case also, the bulkhead is stiffened with angle-irons on the opposite side to the T bars; the two sets of angle and T bars thus form a rectangular lattice work of stiffeners.

The bulkheads of large merchant ships often have single-riveted lap joints and butts, and are stiffened by horizontal angle-irons at the middles of the plates on one side, and by vertical angle-iron stiffeners about the same distance apart on the opposite side, the butts of the plates being brought to the middles of the spaces between the vertical stiffeners. The shift of butts is not very important, the *brick* arrangement being usually considered quite sufficient.

When both the edges and butts are lapped, the corners of the plates that come between two others are beaten down thin, so as to bring the thickness of the three plates to about the same as that of two plates elsewhere, and to allow the joints to be caulked. As will be supposed, liners are required behind the stiffeners by the lap-jointed system. The rivets in the butts and edges are spaced as for watertight work elsewhere, while those in the vertical stiffeners are spaced about ten to eleven diameters apart.

313. **Connection of Bulkhead to Ship's Side.**—Great difficulty has been experienced in connecting the transverse watertight bulkheads to the ship's side. This is due to the close spacing of rivets which is necessary in order to obtain a watertight joint between the frame angle-iron, which connects the bulkhead to the side, and the bottom plating, whereby the bottom plating is pierced by a line of holes, producing considerable local weakness. One of the earliest methods of connecting the bulkhead to the bottom plating was by a single frame angle-iron; the defect of this method has just been alluded to. At the present time there are two modes of performing this work adopted in the merchant navy, both of which are sanctioned by Lloyd's and the Liverpool rules. One of these consists in connecting the bulkhead with a double frame angle-iron, and by the other method the bulkhead is connected with a single frame angle-iron (sometimes with double zig-zag riveting), and with horizontal bracket or knee plates riveted to the bulkhead and outside plating. The brackets are placed on alternate sides of the bulkheads, and at or near the centres of the strakes of bottom plating upon which they come. It may be remarked that sometimes these brackets are fitted together with double frame angle-irons, although such is not required by either of the above rules. Wide liners are fitted between the bulkhead frames and bottom plating, as described at Art.

300, which serve also as straps to butts of bottom plating in the frame spaces adjacent to the bulkhead.

In ships with double bottoms, the bulkheads in the wake of the inner bottom are connected to the plating of the latter, generally by a single angle-iron. The watertight division is completed to the outer bottom by means of watertight frames, which have already been alluded to. Before and abaft the double bottom, the bulkheads are lapped upon and riveted to the floor plates, and continuous reverse angle-irons of the frames.

Great care is taken to preserve the continuity of strength of the longitudinal framing, such as keel and keelsons in ships as ordinarily framed, and the keel, longitudinals, armour shelf, inner bottom, etc., in armour-clad ships, where these pass through the transverse bulkheads; and at the same time to obtain watertight joints. Plate CV. shows a method of covering these joints, the particular form of the angle-iron being of course governed by that of the longitudinal frame or other longitudinal connection.

314. Longitudinal Bulkheads occupy a subordinate position compared with those just considered. Both the Underwriters' rules enforce the fitting transverse watertight bulkheads, in number according to the size and character of the ship; but no reference is made to longitudinal bulkheads. In steam ships the longitudinal bulkheads of the coal bunkers are sometimes made watertight, also the bulkheads of the shaft passages. Great prominence is given to longitudinal bulkheads in ships built by Mr. Scott Russell's longitudinal system, as in the *Great Eastern*. The engine and boiler spaces of several twin screw iron-clad ships of the Royal Navy, now in course of construction, are divided by longitudinal bulkheads, extending as high as the main decks. It is evident that the two sets of engines required for twin screw ships, afford opportunities for fitting these bulkheads in the engine room not found in single screw ships. The statical and structural advantages derived from them are of course considerable.

A great many small iron bulkheads are fitted in H.M. ships to enclose magazines, shell rooms, spirit rooms, chain lockers, etc., all of which, while essential to the internal

economy of the ship, are in most cases of service considered structurally and statically. The details of their construction are unimportant.

There are a great many fittings, such as water-tight doors, sluice valves, etc., inseparable from a detailed description of water-tight bulkheads, but which require more space for their due consideration than can be spared in this work.

315. Pillars.—The beams of iron ships being riveted to the frames, and thus arranged in vertical tiers, an efficient system of pillaring is easily obtained. This is very important, as the pillaring of a frame adds considerably to its strength, by acting both as a strut and a tie; consequently the strength of the whole structure is correspondingly augmented. A pillar at the middle line increases the strength of a beam by about one half; and the resistance to transverse bending is increased by connecting the beams with the floors.

Lloyd's rules require "all beams for at least one-half the length of the vessel amidships, the alternate beams before and abaft this length, and all hatchway carlings, to be pillared; the pillars to have not less than two rivets in each of their ends, so as to form a continuous tie from the keelson to the upper, spar, or awning deck."

The Liverpool rules require pillars on every beam for one-third the length, and agree with Lloyd's regarding the number of pillars before and abaft that space.

Formerly, in war ships, it was not considered necessary to secure the pillars at both the head and heel; but since the introduction of the present heavy guns into naval armaments, it has been found requisite to give due attention to the pillar as a tie, in consequence of the great tendency of the deck to lift, which is experienced when these heavy guns are fired over it. In addition to this, it is evident that the working of the ship must at times bring a similar strain upon the pillars, which should therefore be secured at the heels.

Solid wrought-iron bars are commonly used for pillars in the merchant navy (see Plates LXXXIX. and CXIX.), these being generally riveted by means of a palm to the side of the beam, and secured through the deck plank to the beam below by means of nut and screw bolts, which are made watertight by means of grommets. Similar pillars in H.M. ships are connected in the same way.

Tubular pillars are very commonly used in the Royal Navy in preference to the solid bars, as the former possess greater lateral rigidity with the same weight of material. The tubular pillars are welded or riveted to solid heads and heels, by means of which they are secured, similar to solid bar pillars. When pillars are fitted under an I beam, the heads are made and secured in the same way as the heels.

Around capstans, and in similar positions, it is necessary to fit portable pillars. These are sometimes made to revolve on a pin at their head, and to tighten by driving the heel over a wedge-shaped shoe, the same as described at Art. 229. A better method, however, is to tighten the pillar by means of a brass nut with a hemispherical bottom, screwed on its heel, the convex part of the nut resting in a hollow deck plate secured to the deck. The pillar is tightened by turning the nut with a spanner. It is hardly necessary to state that the hole in the head of the pillar, about which it revolves, is made oval, in order that the pillar may rise to the necessary extent, as the nut is hove up, in order to take its proportion of the weight of the deck.

316. Mast Holes.—The deck framing around the mast hole of an iron ship, consists of the beam adjacent to the mast, a carling on each side between the beams, and a plate riveted upon these beams and carlings, with sometimes another plate riveted underneath. In this way a cubical space is enclosed that is sometimes filled in solid with wood, through which a hole is cut for the mast, in the manner shown by Plate LXXVIII. The most usual mode is to fit and secure an iron tube, as shown by Plate CXI. In both cases the mast is kept firmly in place by wedges driven between it and the iron tube.

The Liverpool rules require "mast partners at decks, where wedged, to be plated over twice the width of the hole cut out of them, and to take three beams in length."

Lloyd's requirements are equivalent to the preceding, with the addition that the plating is not to be less in thickness than is required for stringer plates. Of course, these rules apply only to sailing ships, and are not strictly adhered to in steam vessels.

317. Stringers.—Stringers are of two kinds, viz., *hold* and *deck stringers.* The deck stringer consists of a strake of plating, fixed in a direction about square to the surface of the side plating; and it serves the double purpose of a longitudinal tie and to stiffen the bottom plating, while, at the same time, it tends to keep the frames and beams in their correct relative positions, giving rigidity to the structure in its vicinity.

Hold stringers sometimes consist of plates and angle-irons, and at others of angle-irons only; they are connected to the ship's bottom by brackets, which are riveted to alternate frames, the stringer being connected to both the bottom plating and bracket by pieces of angle-iron worked intercostally.

Deck stringers (see Plates LXXXIX., XCIV., and XCVI.) are the strakes of deck plating riveted upon the top of the beams against the ship's side, being generally connected by angle-irons to the outside plating. The longitudinal strength of the stringer is necessarily limited to the tensile strength of the plate and connecting angle-iron, consequently an ordinary stringer does not offer very considerable resistance to the strains due to bending moments. But it is in their connection with the beams and sheer strakes that the efficiency of the stringer is developed, for in this way a girder is formed at the sides of each of the decks, which resists longitudinal alteration in the ship's form, whether she be at rest upon an even keel or rolling in a seaway. It will also be noticed that when the ship is working at sea, great racking strains are set up, tending to alter the relative positions of the beams to each other and to the ship's side; to resist all of which the stringers, by their position and form, are eminently adapted.

Lloyd's rules require stringers of upper decks when the ship has two, and main deck when three, tiers of beams, to be "in width one inch for every seven feet of the vessel's length, for half her length amidships, and from thence to the ends of the vessel they may be reduced to three-fourths the width amidships; in no case, however, is the width to be less than eighteen inches." The same rules further require that "the stringer plates on all tiers of beams are to be fitted home and riveted to the outside plating fore and aft, with angle-irons." Also that "the objectionable practice of cutting through the stringer plates for the admission of wood roughtree stanchions will not be allowed."

The Liverpool rules require much wider stringers than Lloyd's for small, and rather narrower for large, vessels. For instance:—By Lloyd's rules the main deck stringer of a ship 100 feet long is 18 inches, and by the Liverpool rules it is 25 inches, whereas, for a ship of 500 feet in length the former require $71\frac{1}{2}$ inches wide, and the latter 65 inches. It will thus be seen that on the whole the Liverpool rules require the widest stringer plate.

The butts of stringer plates should be shifted clear of those of the sheer strakes, also cargo ports and all openings in the side adjacent to the decks. Wherever it is necessary to cut holes in the stringer for scuppers, etc., the strength should be made up by fitting straps around the hole, or by doubling the sheer strake on the inside in the vicinity. The butt straps of stringer plates are generally treble-chain riveted. As a water-tight joint is not required it is very usual to omit alternate rivets in the row next to the butt, thus increasing the strength of the connection.

318. Tie Plates, sometimes fore and aft, and at others fitted diagonally, are required by both Lloyd's and the Liverpool rules (see Plate LXXXIX.). They serve to connect the beams, and thus relieve the deck fastenings of the strains brought upon them when the ship is working. The deck fastenings are not so efficient in iron as in wood beams, and hence both stringer and tie plates are of service in opposing the first tendency of the deck to elongate.

However, Mr. E. J. Reed and other eminent authorities call attention to the fact that tie plates are not a satisfactory form in which to work iron into a ship, as they give but little aid to the vertical plating, such as sheer strakes, etc.; whereas, if the same amount of material were added to that already worked in the form of stringer plates, it would be much more advantageously disposed (see *F*, Plate LXXXIX). Even as at present worked, tie plates would be of much greater service if deck fastenings were placed through both

the deck planks and tie plates, between the beams, as by this means the longitudinal strength of the deck plank, an important item in the hull of a wood ship, could be utilized; whereas, when the fastenings are through the beams only, very little of the strength of the plank is developed.

Mr. Nathaniel Barnaby, the Admiralty Chief Naval Architect, in a paper read before the Institute of Naval Architects in 1866, on "Economy of Material in Iron Decks and Stringers," proposed a novel mode of lightening stringers and tie plates without reducing their strength; on the contrary, he stated that the tensile power of the plates will be increased when thus lightened. "The principle on which this arrangement rests is, that when strains are suddenly applied to the plates, it is necessary to consider not only the number of tons required to break the weakest sections, but the amount which it would stretch before breaking, in other words, the work done in producing rupture. In order, therefore, to make the amount of work done as great as possible, it is necessary to reduce the strength of the plate between the weak sections, at the butts and beams, to the strength at these sections, or even to less than this, in order to obtain long spaces of uniform strength to give elongation. If these long spaces of uniform strength are not provided, and the plate is consequently left with strong parts between the beams, no practical elongation will take place in these strong parts under the action of a sudden strain; but the stretching will be thrown almost entirely on the weak points, and if any one of these is weaker, in any sensible degree, than the rest, it will be confined to that point. The author states that the fact that the strains of greatest magnitude in a ship are sudden makes the principle above stated of no slight importance to naval architects, because by its application the time is increased during which a given force must be applied in order to produce rupture."*

319. Gutter Waterways associated with stringers are often fitted in ships of the Royal Navy (see *G*, *G*, Plates XCIV. and XCVI.). Their construction is simple, while, at the same time, they constitute a very efficient longitudinal tie, and serve the twofold purpose of conveying water from

* *Shipbuilding in Iron and Steel*, by E. J. Reed, C.B. Pp. 164 and 165.

the deck of the ship to the scuppers, and connecting the beams and stringer to the framing. Lloyd's rules recommend that these gutters be cemented, and that practice is always carried out in H.M. ships.

320. Deck Plating.—But although the importance of the stringer, especially when efficiently connected to the side plating and frames with angle-irons, cannot be doubted, yet something more than this is required on the upper or main decks of long ships. The practice of plating over the greater portion or the whole of the beams of the upper or main decks of merchant ships is becoming more common of late years than formerly, this being, no doubt, due to the great length which is given to the high-powered steamers required for the ocean traffic of the present day. It is not usual, however, to plate the whole of the surface, it being evident that there is very little, if anything, gained by laying plating near the middle line, where it is pierced with large holes for hatchways, etc. Hence, when decks are plated for structural purposes only, it is usual to do so in four strips, viz., two wide stringers and a belt on each side of the hatchways, the belt and stringer on each side being sometimes joined at their edges.

In this arrangement, when each strake is aided by those adjacent to it, it is usual to connect the butts by double-riveted straps, although the stringers sometimes have treble-riveted straps as in other ships. The edges of deck plates are usually connected by single-riveted edge strips, both these and the butt straps being usually fitted on the upper side, and consequently the deck planks are scored over them. The riveting is countersunk on the upper surface of the plating to simplify the fitting of the deck planks.

When no wood deck is laid, as, for instance, in steam colliers, where the constant loading and unloading of such a cargo would soon damage a wood deck, the beams are covered with iron plating, in order to form a deck flat. In this case the joints are made watertight, and the edge strips and butt straps are fitted on the under side.

The upper and main deck beams of iron-clad ships are often covered with thick plating, chiefly for the purpose of resisting explosive missiles (see Plate CIII.). The plates vary

in thickness from one to two inches, and sometimes as much as three inches. In order to reduce the weight and maintain a uniformity of resisting power, the thickness is made up with two or three thicknesses or layers of plates, generally two. The butts and edges of these give shift to each other, the former being brought upon beams and the latter on the middles of the other thicknesses of plates. Hence each thickness performs the function of butt strap and edge strip to the other. The riveting in the butts and edges of upper strakes is closely spaced, to enable the joints to be caulked; that in the other edges and butts is not spaced closer than about six to seven diameters apart. The holes are countersunk on the upper side of the upper strake, so as to give a flush surface.

In fitting this plating the holes in a plate should be marked from those already punched in the opposite plate, this method being preferable to marking both by the same template, as it is very difficult by the latter system to get the holes in the beams and the two thicknesses of plating to sufficiently agree for good riveting.

321. Deck Flats.—In Art. 223 reference was made to the mode of fitting deck flats to iron decks in wood ships, which description is equally applicable to those of iron ships. The shift of butts is the same as when secured to wood beams, except when an iron deck flat is laid, in which case the arrangement of the butts is not of so much importance.

When an iron deck is not fitted, the butts are brought upon the beams and fastened to the flanges with galvanized iron nut and screw bolts, except in the wake of the stringers or tie plates, where the fastenings should be off the beams, the flanges of the latter being already sufficiently cut by the riveting. As remarked at Art. 318 sufficient deck fastenings should be placed in the stringers and tie plates to enable the wood flat to communicate as much as possible of its longitudinal strength to the structure, besides keeping the plates from buckling.

When an iron deck is fitted, the butts of the deck plank are generally placed midway between the beams. It is not usual to fit an oak flat upon an iron deck, as the acids in that wood have a deteriorating influence upon the iron.

Teak has now, to a great extent, supplanted oak as a material for deck flats, especially for ships intended for service in hot climates, as, in addition to the absence of any such corrosive acid as is contained in oak, teak is very free from shakes, and shrinks but very little when exposed to heat.

In the Royal Navy, Dantzic crown deals, varying from $2\frac{1}{2}$ to $3\frac{1}{2}$ or 4 inches in thickness, are employed for the lighter decks; whereas teak is generally used when there is considerable wear, exposure to the sun, or when required to co-operate with a thick deck plating in forming a shell-proof flat.

In flush deck Monitors, as shown by Plate CIII., it is necessary to rivet thick pieces of iron plate upon the surface of the deck plating, near the edges of the deck, which, when let up into the plank, serve as dowels to keep the deck flat from sliding off the plating under the pressure of the caulking.

Yellow pine is generally used for deck flats of high class passenger ships, in consequence of its superior appearance. It does not, however, especially as fitted, contribute much to the strength of the ship.

Care is taken to make the fastenings of the decks of iron ships watertight, by fitting wooden end grain plugs over the heads of the bolts, these being likewise coated with lead paint.

It may be remarked in passing, that in war ships it is usual to fit heavy shell-proof gratings, composed of deep bars of iron, to the hatchways of decks which are elsewhere plated with thick iron, as described in Art. 320.

322. Coamings to Hatchways are sometimes of wood, and at others of iron. In the latter case the construction is very simple, and consists of a deep angle-iron riveted to the upper side of the beams, or of a plate connected to the beams by an angle-iron; short pieces of angle-iron being used to connect the corners of the hatchway. If a grating is fitted, a ledge is prepared for it to rest upon by riveting a narrow strip of plate against the inside of the coaming. Plate CXII. shows the method of fitting a hatchway to an iron deck. In the case of a watertight scuttle to a watertight iron deck flat, an angle-iron is riveted around the upper edge of the iron coaming, to which the hinges of the plate

cover are riveted, the cover being secured by wedged buttons worked with a spanner, or some other such artifice.

323. Topsides.—The topside of an iron ship admits of great variety of construction. In the early specimens of iron ships, the topsides consisted simply of wood stanchions lapped against the frames and bolted thereto, the frames being stopped at the height of the upper deck. Deals or thin plank were secured to the outside of these stanchions, and the whole was surmounted by a rail of some kind. As stringers were not usually fitted to these ships, the method was not at all objectionable. On the introduction of stringer plates, these stanchions were for some time retained, the connection being obtained by cutting holes in the stringers to allow the stanchions to pass through and scarph with the frames. The objection to this is evident, and hence the clause to that effect in Lloyd's rules, referred to in Art. 317.

A method nearly as objectionable is sometimes adopted. This consists in continuing the iron frame to the height of the topside, and then connecting a rail to them by means of an angle-iron running fore and aft upon the top of the frames. It is evident that, in order to continue the frames, it is necessary to cut slots in the stringers, and although only alternate frames are continued above the upper deck, yet the loss of strength due to cutting only one slot in the stringer is as great as if the whole of the stringer were reduced in breadth by the width of the frame. It should, however, be noticed that, as the size of the angle-iron frame is less than that of the wood stanchions required for a topside of equal strength, the stringer is not weakened so much as by the other method. In this case the topside is usually plated up with thin plates as high as the rail. The topside shown by Plate XCVI., is formed by continuing the frame above the upper deck stringer, first reducing it in depth by 3 inches, the breadth of the outer angle-iron. Pieces of teak, the breadth of the frame, are secured to these, and the inner and outer plank of the topside are fastened to them. In the wake of the ports and channels, extra strengthenings, in the form of internal stanchions or struts, are fitted; also plating connecting the frames, and thus distributing the strains. A very common form of topside is made by continuing the side plating to the rail, and supporting it by angle-iron or rod stanchions similar to those just referred to. The most approved method, however, consists in continuing the side plating to a short distance above the stringer, connecting it thereto by an angle-iron, and then fitting a thick piece of waterway in the angle so formed. Wood stanchions are then let down into the waterway, and the whole secured with horizontal bolts through the stanchions, waterway, and side plating; also, with up and down bolts through the stringer and waterway (see Plate CXIX.). There are several varieties of this style; in some cases, a gutter waterway is fitted on the inside of the stanchions, the wood waterway being between the side plating and gutter waterway; also, several other methods differing in detail only.

In H.M. ships, wood topside stanchions are sometimes fitted, these being let down into a thick waterway or covering board, and through bolted thereto. In several of the iron-clad ships the topside wood stanchions have been extended down behind the armour plating, thus partially taking the place of the backing; a strong connection is obtained in this way. A very usual method, however, is to fit light angle-iron frames, turned down and riveted to the deck plating, thin plating being riveted thereto to complete the topside.

A great advantage of wood framing over iron for a topside is found in the superior facilities for connecting the topside fittings, such as cleats, bolts, racks, etc.; hence, when the framing is of iron, it is frequently found necessary to secure wood stanchions thereto for that purpose.

In the merchant navy, it is a very common practice to carry up the topside and fit a light deck over what would otherwise be the upper deck of the ship. This light deck is then termed the "spar deck," and the deck beneath is termed the "main deck." The spar deck is nearly flush (see Plate LXXXIX.), a piece of waterway being around its boundary, to which iron guard stanchions are secured by palms at their feet. Either guard rods or chains are passed through holes in these stanchions; and in the former case, a rope netting is generally fitted outside all for the safety of the passengers and crew.

324. Rudders.—The rudders of iron merchant ships are

very simply and uniformly constructed, the only variety existing in the manner of fitting the gudgeons or braces. This statement does not include the steering apparatus, into the details of which it is not our intention to proceed. The rudder consists of an iron frame covered with thin plates, the spaces between the plates being usually filled up with fir or some other light material. The pintles are sometimes forged with the frame and filed to shape, or turned in a lathe, or else they are made independently and secured to the rudder by nuts. The rudder frame is forged similarly to the stern post, a mould being provided for the purpose, it is afterwards planed to size, and the head turned in a lathe. It is a very common practice to forge the rudder frame in two pieces, turn the main piece in the lathe; then weld the two together, and plane to the required thickness where necessary.

Plate CXIII. shows an ordinary rudder frame for an iron ship, in which the pintles *P* are forged with the frame. The space *A* is left to allow the engineers to remove and replace the packing around the after bearing of the screw shaft in the boss of the rudder post. The lower pintle, marked *B*, rests in a bearing prepared for it, marked *F* in Plate XCVII. Sometimes, however, the weight of the rudder is borne by the first or second pintle from the top.

The ordinary form of rudder frame for H.M. ships is similarly constructed to that shown by Plate CXIII., although usually differently shaped. The space *A* is never required in H.M. ships; nor are all but the lower pintle of the same length as shown. The weight of the rudder is taken by the first or second pintle from the top, which is shorter than the others, and has a hemispherical steel point that bears upon a corresponding hemisphere of steel fitted in the brace, thus reducing the friction considerably. The rudders of large ships have two such bearing pintles. The rudder is covered with thin iron plates, connected to each other with edge strips, and tap or through riveted to the frame. The plates composing each side are generally fitted, and then taken to pieces and riveted together on the ground; one side is then partially secured to the rudder, the spaces between the arms of the frame filled up with the wood or other material determined upon, after which the plating is laid upon the opposite side and the whole riveted together. It need hardly be stated that the outer surface of the plating is thus made flush.

A locking plate is fitted to the upper pintle, as in the case of a wood rudder. In the Breastwork Monitors, where all the pintles are underneath the surface of the water and always inaccessible except by diving, it is necessary to keep the rudder from lifting, either by causing its head to bear in a socket fitted beneath portable beams, or by fitting a piece of T bulb beneath the counter, just abaft the rudder, extending through an angle of forty-five degrees each way, and in this way the rudder must be turned through that angle before it can be lifted sufficiently to allow the pintles to clear the braces. A locking plate on the inside of the ship prevents the paul plate from revolving more than forty-five degrees, and so keeps the neck of the rudder immediately below the T bar until the locking plate is removed.

Balanced rudders have been occasionally fitted for many years in ships of the mercantile marine; and during the past eight or nine years the difficulty experienced in steering large ships of war has resulted in their adoption in ships of our own and several foreign navies. The balanced rudder revolves about an axis so situated that about two-thirds the area of the rudder is on the aft, and the remaining one-third on the fore side of the axis. The advantage of this form consists in the ease with which they can be put over to large angles; but the suddenness with which they stop the speed of the ship has caused them to be disused of late, chiefly in consequence of the difficulty of performing evolutions under sail with vessels so fitted. The weight of the balanced rudder is borne upon rollers on the inside of the ship, there being only one pintle, viz., at the bottom of the rudder, which revolves in a socket prepared for it on a projection from the stern post (see Art. 263). The limits of space preclude a more detailed description of this form of rudder, full particulars regarding which will be found in Mr. E. J. Reed's *Shipbuilding in Iron and Steel.*

325. **Bilge Keels** are made either of wood or iron; in both cases they are connected to the bottom plating by angle-

irons. The earliest form of bilge keel consisted of a plate connected by two angle-irons, and stiffened on the outer edge by two strips of half-round iron riveted thereto. This style of bilge keel is still frequently adopted, sometimes in the modified form of plate bulb connected by two angle-irons.

An ordinary form of wood bilge keel is shown on Plate XCIV.; the angle-irons being riveted to outer strakes, and the bilge keel fitted beneath longitudinals, to resist the thrust in the event of the ship grounding. The wood bilge keel is in two pieces, viz., a *main* and *false* piece, the former being secured to the bottom by bolts through the two angle-irons, and the latter by nails driven into the main piece.

In one or two of the Indian troop ships a peculiar form of bilge keel, having a V-shaped section, has been fitted. This has been made of two plates of iron riveted to the bottom, also riveted together at the lower part of the V, the triangular space between the two plates and the bottom being filled in with wood or other light material. A bilge keel of this form has been proposed for the sheathed ships of H.M. Navy, the bottoms of which are covered with zinc sheets (see Art. 337).

It is usual in the Royal Navy to connect the angle-irons of the bilge keels to the bottom plating with tap rivets, which have nuts hove upon them on the inside surface of the plating. A portion of the thread of the screw is in the angle-iron, so that upon grounding violently the tap rivets will break off outside the plating, and leakage is prevented by means of the screw in the plating and the nuts on the inside.

The advantages of bilge keels have probably been overrated; nevertheless, they no doubt offer some resistance to rolling and leeway, besides which their structural efficiency, especially when made wholly of iron, must not be lost sight of.

In fitting bilge keels, care must be taken to minimise the resistance offered by them to the speed of the vessel. To effect this the projection of the bilge keel upon a plane, perpendicular to the longitudinal vertical plane of the ship, should be of the smallest possible dimensions. In lining off the keel in the body plan, the same process is followed as in getting the sight edge of a longitudinal by the method at Art. 166, taking care that the line joining the two rabbets therein referred to is parallel to the load water line.

CHAPTER XXI.

326. Rivets and Riveting.—In the course of the preceding remarks on iron shipbuilding, frequent reference has been made to the character and spacing of the rivets at the several parts of the ship. It is now proposed to consider this important branch of the subject a little more in detail.

327. Forms of Rivets.—Rivets are of two kinds, *clenched* and *tapped*, the former being secured by beating up the point or "clenching," and the latter by screwing the rivet into a screw hole previously prepared for it by means of a "tap tool."

Considering first the clenched rivet, which is the great uniting agent in the ship: By referring to Plate CXIV., it will be seen that there are several different ways of forming both the head and point of this rivet. *A* on that Plate represents the *pan head* rivet, which is the commonest form in use. As will be seen, it is slightly conical under the head, in order that the rivet may fill the hole of that form made by the punching tool. There are three principal modes of forming the point of this rivet. *B* represents the *boiler point*, so named because it is the form used in boiler making when hand riveted. This is the most efficient form of rivet point, not so much in consequence of its shape as the nature of the hammering it receives in being beaten up. It is not usual in shipbuilding to give this rivet point the exact conical form which is customary in boiler making, as it is not often employed in riveting work exposed to view. The *boiler point* is chiefly used in riveting transverse and longitudinal frames. *C* represents the *snap point*, which is formed by first roughly beating down the point, and then finishing it by holding a snap tool thereon, and striking the latter. This snap tool consists of a hollow cup of steel welded to a punch head for striking upon. Snap points are chiefly employed for work in sight, as, for instance, bulkheads, beams, etc., and sometimes for frames. It cannot be depended upon like the boiler point, as, unless the rivet is carefully beaten down before applying the snap tool, it will probably be defective, either by not filling the hole or by looseness. This is caused by the snap tool finishing off the edge of the clench, while it does not press upon the rivet so as to squeeze it into the hole. It is a very common practice in private shipyards to let out the frame riveting by "piece work," allowing the rivets to be snap pointed; the result is, that when the frame is erected (especially if by the Scotch system), a tap with a small hammer upon each rivet reveals the fact that a large percentage is loose, and, therefore, inefficient. When carefully performed, however, snap riveting has a very neat appearance, and is found to give watertight work when tested by water pressure. *D* represents the *flush* or *countersunk point*, which is used for bottom and side plating, deck plating, plating behind armour, etc. Below the water line the point is generally chipped slightly convex, but above water it is generally made flush.

At *E* is shown the *snap head* rivet, used in machine riveting of beams, boilers, etc. It is not often employed for hand riveting. *F* shows a rivet which is only used on rare occasions, when both surfaces are required to be flush; as, for instance, in the case of the nut and washer of an armour bolt being in the wake of a rivet in the plating behind armour, it is found necessary to form the rivet as thus shown in order to give the washer, nut, etc., a fair bearing surface.

The last form which we will consider is the *tap rivet*, shown at *G* and *H*. This rivet is employed in cases where it is impossible to clench the point, either because it is put into solid iron, or because the point side of the rivet is at an inaccessible part of the ship.

The hole is first drilled, and then a steel "tap" is inserted and turned by a spanner until it cuts a thread in the side of the hole to fit the thread on the rivet which is to be placed therein. The rivet is hove up with a spanner by means of a projection on the head, as shown at *G;* when the rivet is screwed up tightly, the head is chipped off flush, or nearly so. Tap riveting is employed in securing plates to forgings, such as the stem, stern post, etc, and to armour plates. It should be stated that it is important that the whole of the screw thread should be beneath the surface of the forging, etc., as, if above, the rivet will readily break at the first turn of the screw thread above the forging. In riveting the angle-irons of bilge keels to the bottom plating tap rivets are used, and so placed as to readily break off in this way (see Art. 325).

328. Sizes of Rivets.—In connecting iron work with rivets the object is to get a uniformity of strength between the plates, or angle-irons and rivets, so that the former may not be so strong as to cause the latter to break first, nor *vice versâ*, but that the two may be on the point of yielding simultaneously; hence the sizes and spacing of the rivets must be regulated accordingly. Calculations made in order to determine the diameters of rivets which should be used in connecting different thicknesses of plates have shown that the former should never exceed twice the latter; while with thick plating it would appear that the rivet should be but slightly thicker than the plate. The requirements of Lloyd's and the Liverpool rules, also the practice of H.M. dockyards, are given by the following table, where the sizes are stated in sixteenths of an inch:—

TABLE OF DIAMETERS OF RIVETS OF DIFFERENT THICKNESSES.

Thickness of Plates.	Diameter of Rivets.		
	Lloyd's Rules.	Liverpool Rules.	H. M. Dockyards.
5	10	8	8
6	10	10	10
7	10	10	12
8	12	12	12
9	12	12	14
10	12	13	14
11	14	14	14
12	14	14	16
13	14	15	16
14	16	16	18
15	16	17	18
16	16	18	18

It will be seen from the above that unless for the thinnest plates, the Liverpool rules and the practice of H.M. dockyard (especially the latter), require larger rivets than Lloyd's rules. The sizes required by the Liverpool rules were larger a few years since. Where plates of more than one inch in thickness are used, the diameters of the rivets are from $\frac{1}{8}$ to $\frac{3}{16}$ inch greater than the thickness of the plates; and when two plates of unequal thicknesses are riveted together the diameter of the rivet is estimated from the lesser thickness. As already stated, the rivets connecting plating to stem, stern post, or keel, are $\frac{1}{4}$ inch larger in diameter than for the same thickness of plating elsewhere. Tap rivets are usually about $\frac{1}{8}$ inch greater in diameter than ordinary rivets for the same thickness of plating.

329. **Spacing of Rivets.**—The spacing or pitch of rivets required by Lloyd's rules is "four and a half diameters apart, from centre to centre, excepting in the keel, stem, and stern post, where they may be five times, and through the frames and outside plating, and in reversed angle-irons of frames, where they may be from seven to nine times, their diameter, from centre to centre." The Liverpool rules require "rivets to be four diameters apart, from centre to centre, longitudinally in seams and vertically in butts, except in the butts where treble riveting is required, when the rivets in the row farthest from the butt may be opened eight diameters apart, centre to centre. Rivets in framing to be eight times their diameter apart." The Admiralty practice is four and a half to five diameters in edges and butts of bottom plating, and five to six diameters in watertight work elsewhere. The rivets in the frames are spaced about eight diameters apart. Again, Lloyd's rules state that "in chain riveted butts, a space equal to twice the diameter of the rivet to be between each row; where treble riveting is adopted, a space equal to twice the diameter of the rivet to be between each row, with half the number of rivets in the back row. The overlaps of plating, where chain riveting is adopted, are not to be less than six times the diameter of the rivets, and where single riveting is admitted, to be not less than three and a half times the diameter of the rivets." The Liverpool requirements for breadths of overlap are almost tantamount to the preceding, while the Admiralty

practice is rather less. The breadth of butt strap for double riveting is about thirteen times the diameter of the rivet by Lloyd's rules, and from thirteen to fourteen and a half times by the Liverpool rules, while the practice of H.M. dockyards is eleven and a half to twelve diameters. For treble-riveted butt straps, nineteen diameters in breadth are required by Lloyd's, and about eighteen by the Liverpool rules, while sixteen to sixteen and a half diameters is the Admiralty practice.

330. **Testing Iron.**—The most carefully arranged combination of plates and angle-irons, and the most satisfactory spacing of rivets, are altogether useless unless the materials so combined are of good quality. Hence a very important branch of the iron ship-surveyor's duty, whether for Lloyd's Register, the Liverpool Underwriters, H.M. service, or private shipowners, consists in examining and testing the quality of the iron supplied for the ships.

The tests required for H.M. ships are of a very searching character, far more so, we believe, than for any other class of vessels. These tests are laid down in a code of rules which are too lengthy for insertion here. The tests are of two kinds, *tensile* and *forge*. The former are performed with the aid of a powerful machine; the latter, which are of two kinds, "hot" and "cold," are made by a smith. It may be remarked that in addition to these a preliminary test is made by striking the plate with a hammer and listening to its "ring;" blisters are also sought for in the same way.

331. **Tensile Tests** are made by means of a compound lever machine, sometimes worked with a hydraulic or oil pump. Strips are cut from the plate selected for testing, both *with* and *across* the grain of the iron, *i.e.*, with and across the direction in which the plate issued from the rolls in the process of manufacture. These strips are reduced in breadth towards the middle, as shown by *A*, Plate CXV.—a parallel breadth being left for a length of several inches. The area of a section of this strip at this part is generally about one square inch. The strip is placed in the machine in such a way that it is between the motive power and a balance in which weights are placed, representing the tension upon the piece being tested. The machine is often so con-

structed, by an arrangement of levers, that a one pound weight placed in the scale represents a ton pull upon the piece of iron. Weights are placed in the scale until the iron breaks, and then the strength of the latter is measured by the weights in the scale. Two marks, six inches apart, are made in the test piece with a centre punch before it is put into the machine, and, when broken, the two pieces are fitted together and the distance between the centre punch marks is measured; the excess of this above the six inches being a criterion of the ductility of the iron. The fractures are then examined, and by their appearance an experienced eye can judge the quality of the material.

Pieces of the flanges of angle and T irons, beams, etc., are planed or slotted off, and tested in a similar way, only that no cross test can be made of these pieces.

The Admiralty regulations require for B.B., or first-class iron, a tensile strength of 22 tons per square inch, lengthways, and 18 tons crossways. Second class, or B. iron, is required to stand 20 and 17 tons respectively. Bar iron is tested in a similar way to the plate strips, except that it is not usual to reduce the diameter unless the bar is too stout to be broken by the machine.

332. Forge Tests are of two kinds, "hot" and "cold;" the iron being tested with and across the grain by each. *B* and *C*, Plate CXV., show the nature of these tests. Two pieces are cut from the selected plate, and one is heated in a smith's fire, while the other is kept for the cold test. They are bent upon a cast-iron slab, with rounded corners, having a radius of half an inch each; each piece being bent in the two directions by repeated blows with a large hammer. B.B. plates of one inch thick are expected to bend cold, without fracture, to an angle of fifteen degrees with the grain and five degrees across the grain; half-inch plates to thirty-five and fifteen degrees respectively; while three-sixteenth inch plates and under must bend to ninety degrees with the grain and forty degrees across the grain.

The hot forge tests of plates of one inch thick and under are one hundred and twenty-five degrees with the grain and ninety degrees across.

The cold forge tests of B. quality plates are ten and five

degrees, with and across the grain, respectively, for one-inch plates; thirty and ten degrees for half-inch plates; and seventy-five degrees and thirty degrees for plates three-sixteenths inch thick and under.

The portion of plate tested both for hot and cold tests is to be 4 feet in length across the grain, and the full width of the plate with the grain. The plate should be bent at a distance of 3 to 6 inches from the edge.

D, *E*, *F*, *G*, *H*, *I*, and *J* show various forms of angle-iron, and *K*, *L*, *M*, and *N* of beam iron forge tests, all but *J* and *N* being made when hot. The former is a cold bending test with the grain, and the latter is the result of nicking and bending, in order to determine the fibrous quality of the iron in the beam. As will be seen, these tests are very exacting; but they are none the less necessary, as the smithing operations these angle, etc., irons have to undergo are frequently very distressing. The greater number of these tests are to detect "reediness," lamination, or looseness in the fibrous structure of the iron, these defects occurring more frequently in angle, T, and beam irons than in plates.

Armour bolts and rivet iron (see *O*, *P*, *Q*, *R*, and *S*) are both submitted to the same kind of forge tests, which consist in bending the iron double, when cold, and in punching holes of the same diameter as the iron at right angles to each other, the iron being red hot. Neither of these tests should show any fracture. The fibrous character of the iron is frequently examined by cutting a nick on one side, and then doubling the iron; the character of the fracture, whether fibrous or otherwise, determines the quality of the material (see *T*). The malleability is determined by beating up the point when cold, as shown at *U*; also by beating down the head when hot, as shown at *V*.

Mention may be made, in passing, of the percussive tests to which armour bolts are submitted, after manufacture, by letting a "tup" of about one ton weight fall a distance of about 30 feet upon the head in such a way as to cause elongation of the bolt. The number of blows before breaking, and the appearance and position of the fracture, are criterions of the quality of the material.