(*Paper No. 2577.*)

"Permanent Way for Viaducts."

By Herbert Tatham Procter, Assoc. M. Inst. C.E.

A glance through the Subject-Index of the Minutes of Proceedings of the Institution suggests that "Permanent Way" is a question to which railway engineers have paid great attention, and that it is almost inexhaustible. In adding one more contribution to the literature of the subject, the Author proposes to confine himself to a branch that has not hitherto been specially selected for notice in the records of the Institution, probably on account of the comparative smallness of viaducts. It now, however, seems worthy of consideration, since the construction of several important viaducts abroad, and of two notable examples in this country, viz., the Forth and Tay bridges. During the designing and construction of the last-mentioned viaduct, it was natural that the engineers, before laying down thereon nearly 4 miles of Permanent Way (2 miles of double line), should carefully consider different modes of construction, particularly those in use on other viaducts, before deciding upon the design. Whilst working for many months almost entirely on this subject, for Messrs. W. H. Barlow & Son, the Author collected the information contained in this Paper, and he hopes it may prove a useful reference for young engineers.

He proposes to discuss:—(1) The best method of laying the road; (2) guards; (3) expansion rail-joints.

Laying the Road.

In February, 1861, at the close of a lengthy discussion at the Institution, on the merits of various kinds of Permanent Way,[1] Mr. G. P. Bidder, President, observed that—

"The experience of the last twenty-five years had shown that one system had been adopted almost universally, the double-headed rails upon chairs, with cross-sleepers, a plan which had been materially improved by fishing the joints.

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[1] Minutes of Proceedings Inst. C.E., vol. xx. p. 290.

The ingenuity of inventors had been exercised, the bridge-rail and many other descriptions had been introduced; but none had met with universal success. His own conviction was that the double-headed rail, when of proper materials, with properly proportioned chairs, and properly fished, was the safest and the nearest approach to perfection that could be practically obtained."

As this view is now confirmed by the further experience of the past thirty years, the Author adopts it as an axiom. Then, since it is granted that a cross-sleeper road is in every way the best, it should be the practice of engineers to lay down this form of permanent way over viaducts. Although, in the construction of a viaduct, the permanent way is the last thing that the engineer has to pay attention to, in designing the structure the reverse is the case; for on that point depends the form of the flooring to be used, and consequently, to some extent, the form of girder. Until quite recently, it was customary to construct the flooring of a viaduct by fixing at intervals strong cross-girders resting on, and at right-angles to, the main girders; and then to place between or upon these, lateral girders, either of iron or wood, parallel to the main girders, forming a continuous support on which to place the rails, filling up the open spaces left with buckle-plates, ordinary planking, &c.; this naturally gave rise to the majority of longitudinal way-beam roads over viaducts.

Oddly enough, in the very year that the above-mentioned opinion with regard to permanent way was expressed by Mr. Bidder, Mr. William Humber, in "Iron Bridge Construction," stated, with reference to the flooring of viaducts, that the most satisfactory system that could be adopted was that in which the platform consisted of a considerable number of cross-girders placed moderately near together. The load is thus transmitted to the main-girders at a great number of points and the undulation of the platform is counteracted, and, in addition, where the platform is kept as narrow as possible, the system is actually the lightest and most economical. This statement again has been fully borne out in practice, and now the ordinary type of flooring is a platform consisting of cross-girders so close together that their top and bottom flanges actually touch alternately; thus producing a series of troughs and ridges of sufficient strength to bear any weight that the viaduct may have to carry, and of such dimensions that the troughs are suitable to receive sleepers packed in ballast at the proper intervals. Most of these floorings are well known, and need not be described; but the Author would like to direct attention to the two forms invented many years ago by Mr. W. H. Barlow, and now in general use; these were fully described and illustrated in Mr. Crawford Barlow's Paper on "The Tay Viaduct, Dundee."[1]

With such facilities for laying cross-sleeper and ballast roads over viaducts and bridges, there can be little doubt that this kind of road will take the place of the longitudinal way-beam road. The advantages of the former over the latter are numerous. It is simpler to lay, to adjust, and to renew. It avoids serious difficulty from camber in girders. It deadens noise and vibration. It distributes the moving load over the whole width of the flooring. It allows expansion and contraction of the rails to take place independently of the viaduct. It is less costly, because it lasts longer—the wear and tear of longitudinal beams exposed to the weather being greater than that of sleepers bedded in ballast; and, in addition to the wear from natural causes, there is, in the case of a longitudinal road which must be fixed to the flooring, the tearing of the attachment-bolts, due to the unequal expansion and contraction of the timber way-beam and the metal girders. The single drawback is that the ballast road is heavier; and, where great strength is required, the depth of the troughs is often greater than is necessary to contain the sleepers and a sufficient quantity of ballast, and the extra ballast adds useless weight; although this may be considerably reduced by several simple expedients, involving but slight increase in cost: *e.g.*, by confining the ballast to that portion of the trough immediately under the sleeper; by placing across the troughs, at the requisite depth, arched diaphragms, like buckle-plates, supported, if necessary, by angle-bars; by circular or semi-circular pipes fixed at the bottom of the troughs, and other such-like simple contrivances. The ballast itself should be very carefully prepared from light and suitable materials: a mixture of ashes and slag will be found serviceable—moisture greatly increases the weight of ashes, but has little effect upon slag, as the following figures taken from actual weighings will show:—

Ashes, dry and not punned	weigh	. 42	lbs. per cubic foot.
,, damp ,,	,,	. 60	,, ,,
,, very wet and punned hard	,,	. 84	,, ,,
Slag, dry and coarse	,,	. 71	,, ,,
,, ,, and small	,,	. 75	,, ,,
,, [2] wet and small	,,	. 76	,, ,,

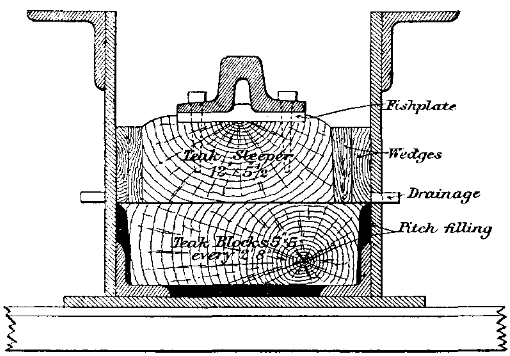
Thus, by placing the coarse slag in the bottom of the troughs,

[1] Minutes of Proceedings Inst. C.E., vol. xciv. p. 87.

[2] After being soaked in water for half-an-hour.

and then adding the fine slag and ashes, perfect drainage is ensured, weight avoided, the life of the sleepers prolonged, and they are laid in the usual way. In all cases where ballast is used in troughs, it is necessary that the ironwork be well asphalted or tarred, and also that there be ample provision for drainage. Should a longitudinal-sleeper road be requisite, the designing and laying becomes a complicated affair. The method of attachment of a longitudinal way-beam to a wooden flooring presents no difficulty; but, when the attachment is to metal, the case is different, as the beam has to be continually altered or renewed, in consequence of the wear and tear arising from vibration and unequal expansion. To attach the beam directly to a metal decking is almost out of the question, as it involves inserting bolts,

Fig. 1.



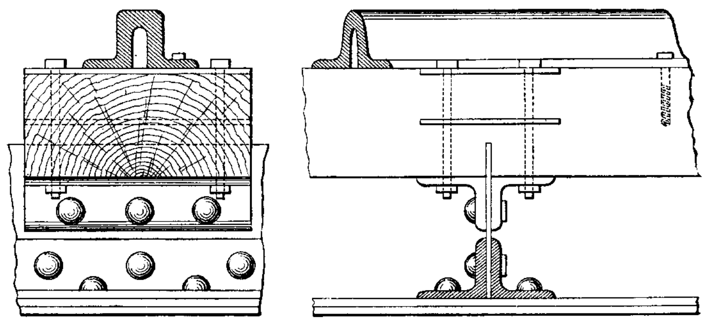
FORTH BRIDGE.

or screwing up bolt-heads from underneath; and this, in many cases of hog-backed, bow-string girders, &c., where the decking is on the bottom boom of the girders, is an expensive and lengthy proceeding.

The elaborate construction of the longitudinal road over the Forth Bridge may be taken as a proof of the necessity for avoiding these difficulties. A cross-section of this is shown in *Fig. 1.* It will be noted that the fitting of the way-beam requires six pieces of timber; also that the trough in which the timber is contained is built of three plates and four angle-bars (two of these latter being for the guard). The difficulties are certainly overcome; the timber has only a frictional attachment to the metal of the viaduct, it is well encased and so should wear well, no lateral motion can take place, and the road is probably as elastic as any longitudinal road can be; but the method of construction can hardly be considered suitable for an ordinary viaduct.

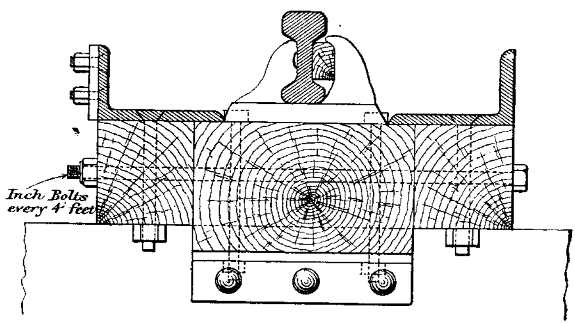
The Britannia Tubular Bridge over the Menai Strait, furnishes another instance of the difficulties of attaching a longitudinal road to an iron flooring composed of plates riveted to tee-bars, strengthened at 6-feet intervals by the insertion of transverse keelsons that stand up to a height of 9 inches from the level of

Figs. 2.



BRITANNIA TUBULAR BRIDGE (OLD ROAD).

Fig. 3.

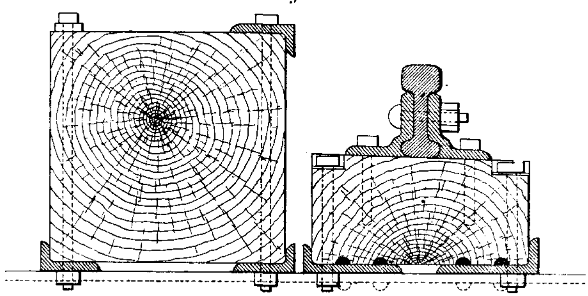


BRITANNIA TUBULAR BRIDGE (NEW ROAD).

the floor. On each side of these keelsons, 2 inches from the top, are riveted horizontal angle-irons 14 inches long (*Figs. 2* and *3*) immediately under the way-beams, which are then slotted to receive the keelsons, and are securely bolted down to the angle-irons upon which they rest. At the joints of the timber and rails, plates are used to ensure a firm connection. The rail first used was an ordinary bridge-rail, *Fig. 2*, but this has since been changed to the bull-headed rail and chair generally in use on the London and North Western Railway, *Fig. 3.* At the Conway Bridge, similar in most respects to the Britannia and opened at about the same time, the permanent way was laid in the same manner; but the bull-headed rail was used from the first, the chairs being placed 2 feet on each side of the keelsons to give greater elasticity; and a heavy rail was used, probably on account of the greater distance, viz., 4 feet, between the chairs.

An effective and simple method is to rivet on to the surface of the decking two angle-bars to contain the base of the beam, (*Fig. 4*). This may be done while the decking is being riveted up; and the shoe thus formed by the angle-bars becomes part of the floor, supported by and attached to each ridge, while in each trough it is unsupported; and, consequently, if the beam is attached by bolts to the shoe directly over a trough, the bolt-

Fig. 4.



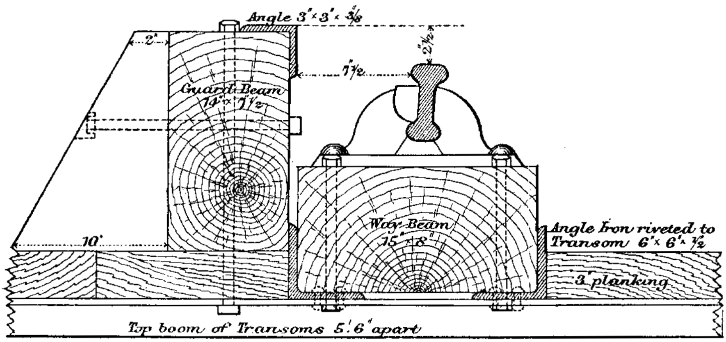
NEW TAY VIADUCT—DESIGN SUBMITTED.

heads or nuts can be manipulated from the upper side of the flooring. The shoe thus formed will effectively prevent lateral motion of the beams, and vertical motion is prevented by the vertical bolts. The angle-bars used must depend on the scantling of the way-beam; thus, for an ordinary way-beam of, say, 14 inches by 7 inches, two angle-bars of 5 inches by 2½ inches by ½ inch would be ample, as in *Fig. 4.* On the Montrose Bridge, *Fig. 5*, a way-beam, 15 inches by 8 inches, is used, with angle-bars 6 inches by 6 inches by ½ inch.

On two of the Cheshire Lines viaducts over the Manchester Ship Canal, where the decking is similar to that used on the New Tay Viaduct, an attachment like this is used, the Railway Company having stipulated for a way-beam, 24 inches by 6 inches, covered with galvanized sheet-iron, to accommodate a double chair and guard-rail. The angle-bars are 4 inches by 4 inches by ½ inch, and a horizontal bolt passes through the vertical limb of the angle-bars and the way-beam at every 2 feet 6 inches, the beam being tightly packed with strips of greenheart. By having a 4-inch vertical limb to the angle-bars the attachment of the way-beam is a simple matter; but it must be borne in mind that such projections are awkward additions to the decking during construction. Another questionable feature in this case is the size of the way-beam, 24 inches by 6 inches, which has had to be made in two pieces; the chair used is only 16 inches wide, and a way-beam of 16 inches by 8 inches might have been used with advantage.

It is interesting to observe the changes in the mode of laying that have occurred in the practice of the London and North

Fig. 5.



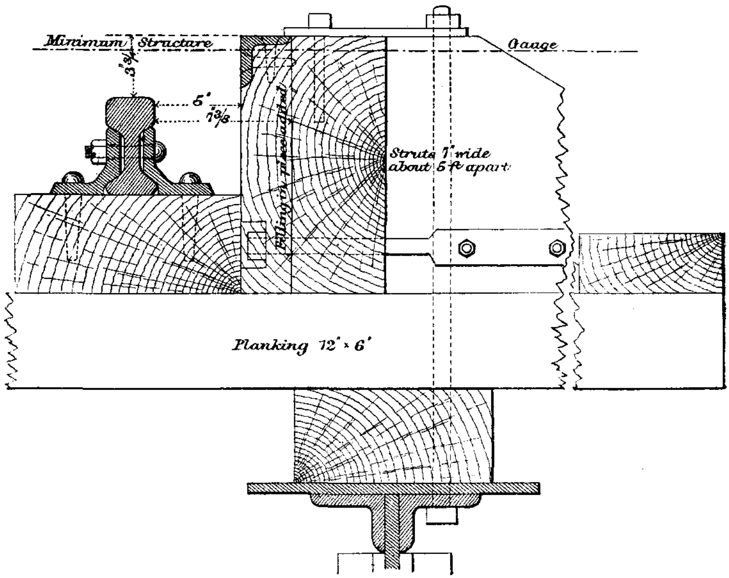
MONTROSE BRIDGE.

Western Railway Company. They first laid a bridge-rail on the Britannia Bridge, which they subsequently changed to an ordinary rail and chair, having found this to work satisfactorily on the Conway Bridge, and, doubtless, wishing to adhere to a uniform system of permanent way; now, on the new deviation viaduct of the main line over the Manchester Ship Canal, they are reverting to a longitudinal road and bridge-rail similar to that in *Figs. 2.* In cases of old viaducts or other situations, where a longitudinal road is necessary, the Author is of opinion that it is a mistake to use chairs and bull-headed rails, as these not only raise the bearing-surface of the rail, and thus increase the lateral stress on the attachments of the way-beam, but they do away with the main advantage to be derived from a longitudinal way-beam, viz., continuous bearing, which can be obtained by the use of a bridge-rail, as in *Figs. 1* and *2*, or a flat-bottomed rail, as used by the Great Western Railway; or, if it is thought desirable to adhere to the rail in general use on the system, this can be done by the adoption of angle-bar fish-plates, as in *Figs. 4* and *6*, which is a pattern much used on the viaducts of the Midland Railway.

Guards.

The question of what forms an efficient guard on a viaduct appears (as may be seen from a glance at the various types shown

Fig. 6.

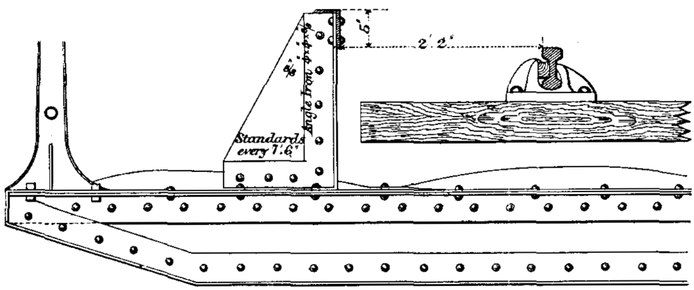


Halesowen Viaduct.

in the *Figs.* that accompany this Paper, nearly all of which have been passed and are types now in use) to admit of various interpretations by the Board of Trade Inspectors. The official requirement runs thus: "In important viaducts substantial guards should be fixed outside, above the level of and as close to the rails as possible, but not so as to interfere with the steps or any of the working-parts of the engines or trains." This regulation was no doubt framed in the days of the cross-girder and timber flooring, alluded to above. Then it was essential that the train should not leave the immediate vicinity of the rail, or it would break through the thin timber flooring between the cross-girders. Now, with steel or iron floorings over the whole surface of a viaduct, if a train does leave the rails, it stands as good a chance of remaining on the top of the flooring in one place as another; and, consequently, if the guard be placed at the extreme edge of the viaduct, to prevent the train from going over the side, it may possibly be considered as useful (it is certainly out of the way) there, as in any other position. The Author does not state this as his view, but suggests it as an explanation of the reasons why the guards shown in *Figs. 7* and *10* have been sanctioned.

The obvious suggestion of the regulation under discussion is that a duplicate guard-rail should be placed on the outside of the running rail and slightly above it (*Fig. 8*), in much the same way that a check-rail is used, and this has been done in many small

Fig. 7.



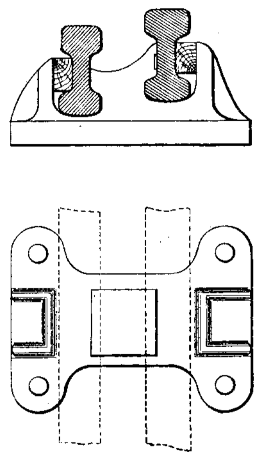
STIRLING BRIDGE.

viaducts, and is being used on two of the deviation viaducts in connection with the Manchester Ship Canal. It was arranged thus in the old Tay Bridge, and a somewhat erroneous idea existed at the time of the catastrophe—is even quoted now—that the probable cause of the failure was the train leaving the metals and colliding with the girders. If this were so, the guard-rail used could not be deemed an efficient one. But the evidence given at the inquiry on this point pointed rather to the probability that the rear carriages of the train were canted over by the force of the wind, the leeward guard-rail in all probability keeping the wheels on the rails.

Fig. 8 is the form of double chair which was used on the old Tay Bridge, the guard-rail being 2 inches away from and 1 inch above the running-rail. Comparing with this the wheel, with flange, as used on the North British Railway, *Fig. 10*, it will be difficult to see how such a wheel could get off the line.

The guard-rail is usually fixed, as shown in *Fig. 8*, by means of a double chair, but, should such chairs be unobtainable for any reason, two ordinary chairs may be used, as shown in *Fig. 13*, the outer one being raised by packing. This, of course, has several objections; the space between the rails is increased, and would allow of the wheel getting off, in which case it would jolt over the chairs until brought to a standstill. An objection to all guard-rails of this class is that cases have been known where pieces of metal, &c., have fallen from a train and become fixed between the guard- and running-rails, and have actually thrown the train off the line. A form of guard which also nearly conforms to the Board of Trade regulations is shown in *Figs. 1* and *3*, and it may be added that these have proved effective time after time. In this case the rail runs in a trough, which is formed in various ways. If a vehicle is de-railed, it simply runs in the trough instead of on the rails. It is interesting to note that this form of guard is used on both the first and last great engineering marvels in metallic bridge-building in this country, viz., the Britannia Tubular Bridge and the Forth Bridge, to which *Figs. 3* and *1* respectively relate. On both of these bridges there is evidence of the guard having been effectual. In the case of the Britannia Bridge, when the permanent way was first laid, no guard of any description was provided (*Fig. 2*); and, in order to make a bearing for the two angle-bars that form the trough, it was necessary to bolt on to the existing way-beam two other beams resting on the keelsons (*Fig. 3*). Doubtless, if the road were being relaid throughout, a more convenient form of timbering might be adopted. Of the two types shown, a casual observer would probably prefer the one just described (*Fig. 3*), as its attachment seems simpler. It has also, on each side of the rail, a plain level metal surface for a derailed train to run on. But the Forth Bridge type has many advantages—chiefly those of resistance to lateral motion (the trough forming part of the floor); protection to the timber, being

Figs. 8.

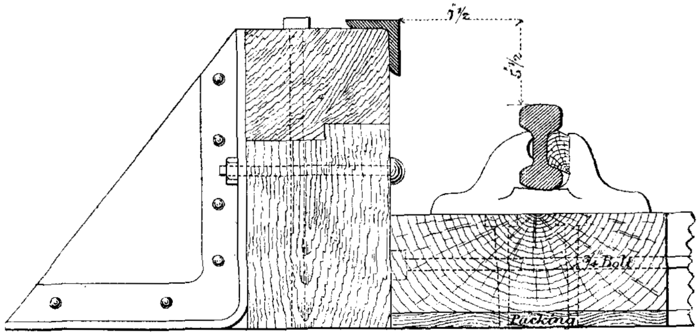


Old Tay Bridge.

encased all round; and the arched form of the way-beam causing a de-railed wheel to run clear of the spike-heads. Both forms are no doubt expensive and troublesome to lay, but are thoroughly reliable and satisfactory in use.

Passing to another type of guard which is still "near the rail and above the level of it," large timber baulks, as illustrated in *Figs. 4* and *12*, are much used on old timber structures, particularly in America. These need little remark. The attachment to the flooring is the important point to pay attention to. The method advised in the first part of this Paper for securing way-beams applies here also, if the decking is of iron (*Fig. 4*). What has to be chiefly guarded against is the liability to overturn if a heavy weight strikes against the inside; and various

Fig. 9.



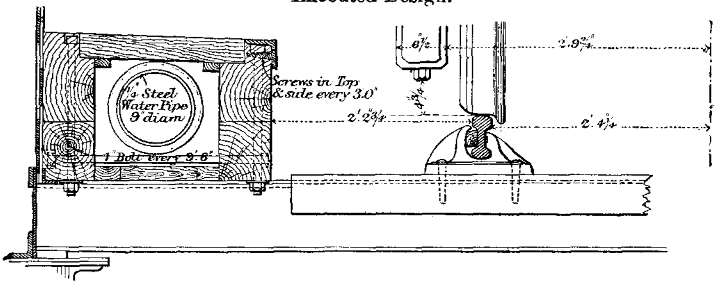
RIBBLE BRIDGE.

methods of struts, angle-irons and bolts, are shown to prevent this (*Figs. 4*, *6*, *9* and *12*). A small angle-bar should always be placed on the corner of the baulk nearest to the rail, and is neater when let into the timber. The height of the baulks depends on the rolling-stock that passes over the viaduct. *Figs. 1* to *14* illustrate types used by different railway companies, hence the difference in the height of the top of the guards above the rail-level, to comply with the regulation that the guard must be "so placed that it does not interfere with the steps or any of the working parts of the engines or trains." The Author, in working out designs for the guard for the New Tay Viaduct, was of course guided by the rolling-stock of the North British Railway. A guard of this kind may be easily attached to a cross-sleeper road by means of fang-bolts and short angle-bars; the attachment

NEW TAY VIADUCT.

Fig. 10.

Executed Design.



Designs submitted.

Fig. 11.

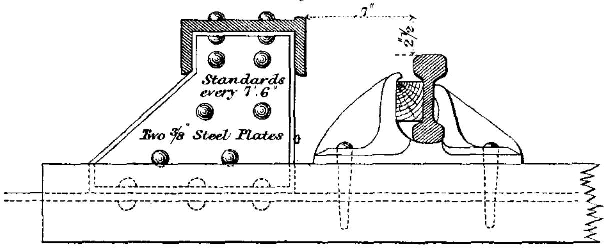


Fig. 12.

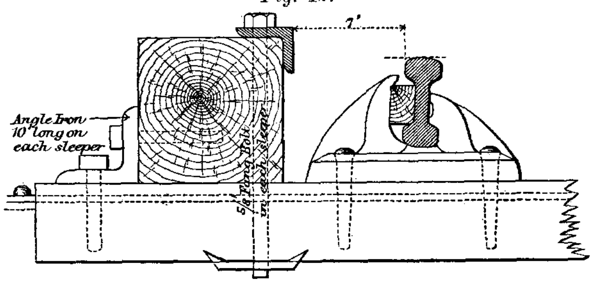
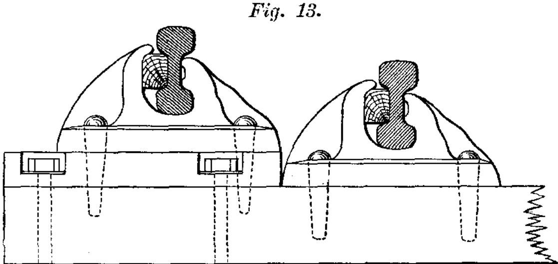


Fig. 13.

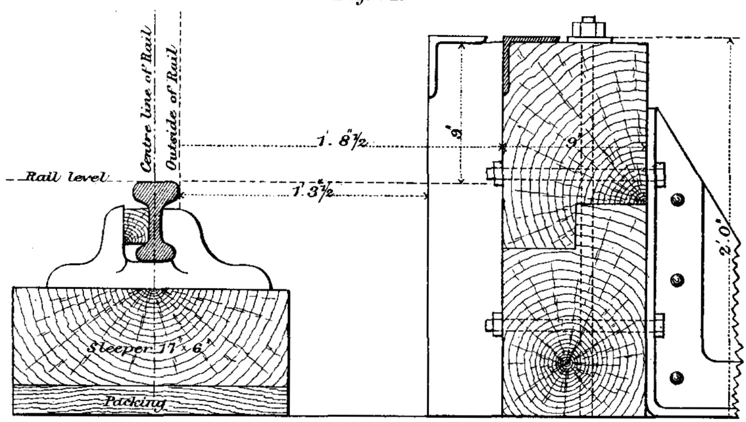


being to the sleepers and not to the deck-plating (*Fig. 12*). Guards may be constructed of heavy channel-bar, or even angle-bar (*Figs. 7* and *11*), supported at intervals by standards attached to the decking. This is becoming a favourite guard on new viaducts, and is applicable to both longitudinal and cross-sleeper roads. The standards, being placed on the ridges, do not interfere with cross-sleepers, which can pass under the channel-guard, as in *Fig. 11.* This form of guard is now extensively used on the North British Railway, and at one time it was intended to erect one on the New Tay Viaduct; but, in this case, although the guard-rail was all important, there was a secondary consideration in the form of a 9-inch water-main which had to be carried over the bridge. This main had also to be suitably protected against variations of temperature and damage from the traffic, thus involving a strong and somewhat bulky casing that projected almost to where the guard would be placed. Hence arose the idea of increasing the strength of the case and protecting it with an angle-iron on the outside corner; and it finally assumed the form shown in *Fig. 10*, which illustrates the guard actually employed on that bridge. There is, of course, a similar guard on the other side of the viaduct, which contains telegraph- and signal-wires. Both are strengthened by struts placed at about every 9 feet, in addition to 3-inch planking framed into the top; they are asphalted, and form convenient and safe footpaths for workmen along the sides of the viaduct. *Figs. 4*, *11*, *12* and *13* were designs submitted for the New Tay Viaduct, with a view to meet more nearly the Board of Trade regulations. But as there was no question as to the capability of the flooring, even if a train left the rails, and as there existed, on the neighbouring bridge over the Forth at Stirling (*Fig. 7*), a "sanctioned" example of a guard considerably removed from the running rail, those designs were abandoned in favour of that shown in *Fig. 10*, for the reason explained above. The Earn Viaduct also has a guard similar to that in *Fig. 7*, 2 feet 2 inches from the rail, but rising 15 inches above it.

Before leaving this part of the subject, two cases may be mentioned where difficulties have arisen as to the position of the guards. The West Lancashire Railway Company were made, under protest, to fix a guard on the River Douglas Bridge (*Fig. 14*), $15\frac{1}{2}$ inches from the rail; this was afterwards altered, as shown, to $20\frac{1}{2}$ inches.

A more noteworthy instance is that of the Halesowen Viaduct on the Midland Railway, illustrated in *Fig. 6* previously referred to. Here the guard was originally fixed, and sanctioned by the Board of Trade, $7\frac{3}{8}$ inches from the running-rails, and the height above the rails was more than 3 inches—that is, higher than the minimum structure gauge. This was afterwards altered, the height being reduced to 3 inches, and a filling-piece added to the side, so as to reduce the distance to 5 inches from the rail. This viaduct, like that of the Tay, has a sharp curve in one portion, and, consequently, the way-beam is canted to allow for super-elevation, and a check-rail is also used. In the case of the Tay Viaduct, some difficulty was experienced in laying the rails and guard on the sharp curve; the rails, of course, followed the curve, while the guard followed

Fig. 14.



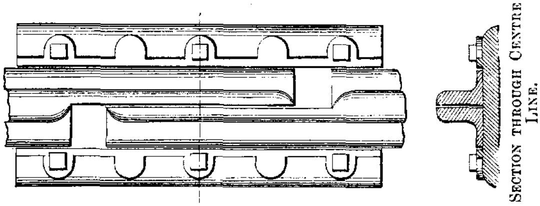
River Douglas Bridge.

the line of hand-rail—that is, of the girder—and had a tendency to become tangential to the rails.

Expansion Rail-Joints.

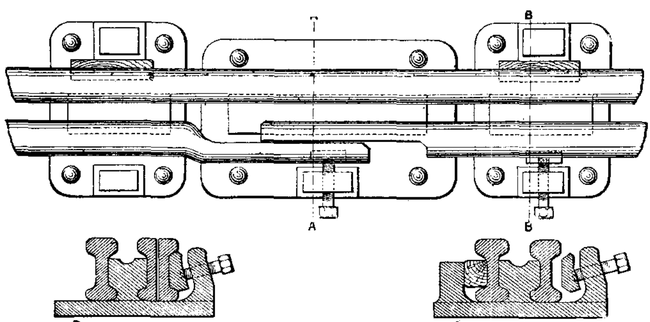
Now that bridge spans are increasing so greatly, the expansion and contraction of the great lengths of metal used presents important questions. As the bridge itself expands, so approximately do the rails also; and where the former expansion is provided for, the latter must also be considered. This is particularly important in longitudinal roads, which are invariably attached to the bridge itself; hence the advisability of cross-sleeper and ballast roads wherever feasible. In the nature of things, it is not to be expected that a simple rail of iron, probably shaded at times from the sun, should expand exactly as does a complicated lattice-girder or the limbs of a cantilever. If the rail is fixed to a way-beam, which in turn is attached to the platform of the structure, the expansion of the rail and its supports being unequal, the attachments must tend to work loose. The Author suggests that working loose is due more to this cause than to the jar and vibration caused by passing trains. Hence the advantage of the absence of all attachment, except that afforded by ballast, between the sleepers and the floor of a viaduct. It was probably not until the building of the Britannia Tubular Bridge in 1845, where there are two spans of about 460 feet, that

Figs. 15.



Britannia Tubular Bridge (Old Rail-Joint).

Figs. 16.

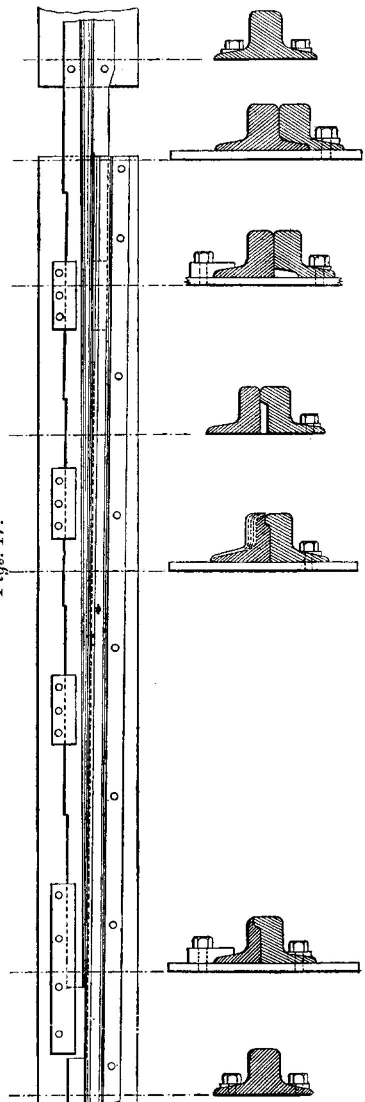


Britannia Tubular Bridge (New Rail-Joint).

any special arrangements were made for the expansion and contraction of the rails, estimated in this case at 3 to 4 inches. Here two split solid bridge-rails of somewhat primitive form provided for this expansion (*Figs. 15*). It will be noticed that the divided rails simply rest in a groove that ensures their mutual contact; but no attempt is made to hold them down; also, that no check-rail is placed at the joint; but provision is made for the slight alteration in gauge by placing the joints, not opposite to one another, but about 6 feet apart. This arrangement necessitated the whole of that 6-feet length of rail being unattached to the floor, and therefore liable to lateral motion.

In the Conway Bridge, built at the same period, a similar joint was made; but, in this case, with an ordinary flanged-rail and chair; a check-rail was also used. These features have since undergone alteration. A bull-headed rail has been substituted for the bridge-rail at the Britannia Bridge. A system of chairs holds the split-rails at the expansion-joint, as shown in *Figs. 16*. The two defects in the original joint being overcome by the rails being securely held down and by the addition of check-rails.

Figs. 17.



FORTH BRIDGE.

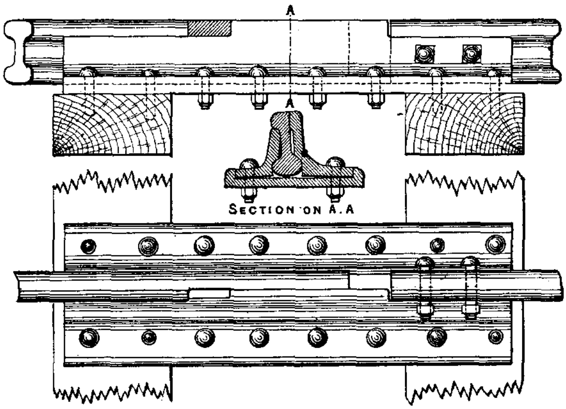
Figs. 17 show the expansion rail-joint in use at the Forth Bridge. Here movement is allowed for to the extent of 2 feet at the sliding-ends of the central girders; at the ends of the fixed cantilevers, 1 foot is allowed for, and smaller movements are provided for elsewhere. The rail-joints at these places are all arranged on the same principle. As before mentioned, a bridge-rail is used, and runs in a trough. The rail on one side of the joint is continued across into the opposite trough, the projection being tapered to a point on the outside at 1 in 63; the rail it would otherwise butt against being bent outwards at the same angle, the contiguous flanges being cut away. The flange on the inside of the tapered rail is cut in steps to the same angle—the length of the steps being fixed by the amount of movement required—and at each step there is a clip securely fixed to a plate, on which the tapered rail simply rests, but to which the other rail is securely bolted. The tapered rail can thus slide in either direction, but is kept down on the plate by the clips, and hard against the other rail by means of the sloping steps. Thus the correctness of the gauge is ensured.

The total expansion and contraction to be provided for in the New Tay Viaduct was estimated at 5 feet; the length of the viaduct being about 10,500 feet, and the extreme variation in temperature 75° Fahrenheit. Expansion was provided for at 32 places, and as there were consequently 128 expansion rail-joints, it was necessary that they should be of a simple kind. The maximum movement allowed for in one joint was 3 inches; and *Figs. 18, 19* and *21* show some of the joints proposed. The one first selected was that illustrated in *Figs. 19*, and several of these were made and placed on the viaduct; it being thought that by joining two chairs, thus forming a continuous bearing for the weak part of the rail, all difficulties would be overcome. Such was not the case, however; as, owing to the elasticity of the road, the key at the joint did not prevent the rails from springing vertically, and considerable "hammering" was produced. The joint was consequently replaced by the one shown in *Fig. 20*, where it will be seen that the rails are tongued and grooved into one another, and strongly fished. This joint has proved satisfactory. It may here be mentioned that, during the first 12 months, daily observations were made of the movements due to variation of temperature, on a length of 516 feet. The greatest variation of temperature recorded during the year was 55° Fahrenheit, and the maximum movement of the rail 1·6 inch. In any case where continuous angle-iron fish-plates are used and only a small movement is anticipated, a joint like that in *Figs. 18* might be adopted with advantage. The rail is very slightly interfered with, one of the top flanges only being taken off; and the fish-plate on that side, being strengthened and continued up to the level of the rail, would prevent any hammering of the wheels whilst passing over the gap caused by contraction. The same result would be obtained by the specially-constructed chair shown in *Figs. 21*.

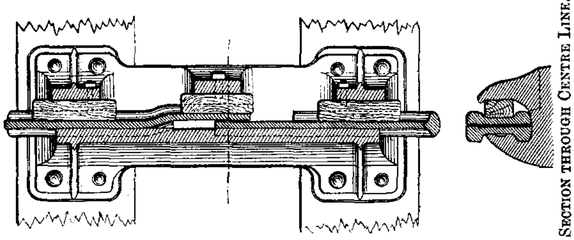
In support of the opinion expressed in this Paper—that a cross-sleeper and ballast road is preferable to a longitudinal way-beam

New Tay Viaduct.—Rail-Joints.

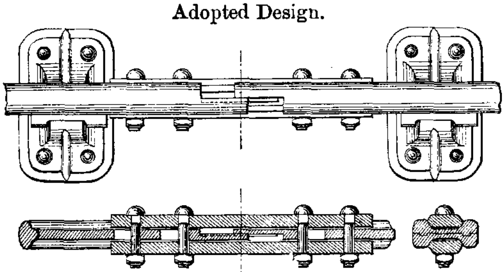
Figs. 18.



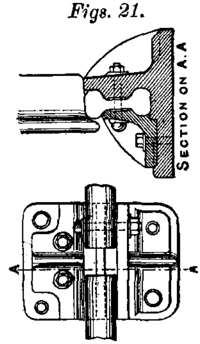
Figs. 19.



Figs. 20.
Adopted Design.



Figs. 21.



road over a viaduct—and further, to bear out some other statements, the Author would quote an extract from a letter from the Chief Engineer of the North British Railway, dated 12th October, 1891, on the working of the road as laid on the New Tay Viaduct after more than three-and-a-quarter years' trial.

"There is no appreciable increase in the cost of maintenance of the road.

"There is no vibration on the bridge sufficient to disturb the ballast in the troughs, and the number of slack fish-bolts is no greater on the bridge than on other parts of the line.

"The expansion rails and rockers work very smoothly and act very quickly.

"The road compares very favourably with a longitudinal-beam road.

"It is much more easily kept in line and level, repairs are more easily executed when required, and trains run smoother over a road with transverse sleepers than with longitudinal beams.

"No vehicle of any kind has, as yet, left the rails on the bridge."

The Paper is accompanied by 2 sheets of drawings from which the *Figs.* in the text have been prepared.