

(*Paper No. 3666.*)

# “Swing-Bridge over the River Avon, at Bristol.”

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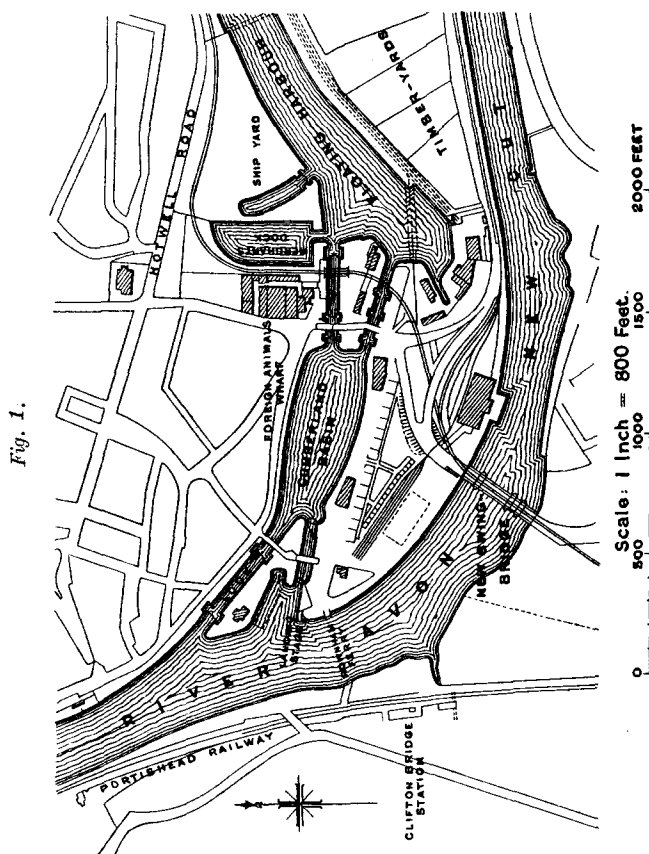
THE bridge which is the subject of this Paper conveys both a carriage-road and a double line of railway across the River Avon at a point about  $\frac{1}{4}$  mile above the entrance to Cumberland Basin (*Fig. 1*). It forms an important part of a large scheme of extension carried out by the Great Western Railway Company to deal more effectively with the dock-traffic at Bristol. Before its construction, railway-accommodation was provided only to the wharves on the south side of the Floating Harbour, and all the traffic from these wharves had to join the main line at the Bristol Joint Station where the traffic was very congested. Further, vehicles had no means of crossing the river between Bedminster bridge, and the Clifton suspension-bridge, a distance of about 2 miles, and much inconvenience resulted.

The railway-extensions which necessitated the construction of this swing-bridge included the provision of railway-accommodation to the wharves on the north side of the Floating Harbour, the extension of the railways on the south side to the timber-wharves, and the building of a central goods-depot at Canons Marsh, where dock-traffic can now be marshalled. The bridge provides an outlet for the railway at the west end of the Floating Harbour, and forms a junction with the Portishead branch of the Great Western Railway, whence the trains can join the main up or down line without passing through Bristol station.

Negotiations between the Corporation of Bristol and the Great Western Railway Company resulted in the promotion of a joint Bill in Parliament in the Session 1897 for a combined road- and railway-bridge. The consent of Parliament was duly obtained, but the work

could not be started at once owing to somewhat prolonged negotiations for the purchase of the land on the south side of the river.

The river-traffic for which provision had to be made consists for the most part of the smaller coasting vessels and barges which enter



the docks by Bathurst lock and basin. The larger vessels use the deeper lock at Cumberland basin, which is farther down the river than this bridge.

#### GENERAL DESCRIPTION.

The bridge, which the Author believes to be the only double-decked swing-bridge of anything like its size in existence, carries the two lines of railway on the bottom, and the roadway and two footpaths on the top boom. The general arrangements are shown in Figs. 2

and 3, Plate 4. There are two approach-roads on each side of the river which converge before they reach the bridge; the gradient of the approach-roads on the north or Gloucestershire side is 1 in 30, and of those on the south or Somersetshire side 1 in 60. The double-decked type of bridge was adopted in order to avoid level crossings, which would have been necessary if both road and railway had been on the low level.

The swinging portion of the bridge weighs nearly 1,000 tons, and is pivoted on a masonry pier, which will be referred to as the "centre" pier, and which is situated slightly inside low-water line on the south side of the river. The two arms of the swing-span are unequal, being 121 feet 6 inches and 81 feet respectively, and all the river-traffic passes on the north side of the centre pier where there is a clear waterway 85 feet wide. The bridge is turned by hydraulic power, the engines being situated in a house which is supported on columns above the roadway, and which also serves as a look-out tower from which to signal to ships coming up or down the river.

The work was carried out in four contracts, namely, foundations, superstructure, machinery, and interlocking.

#### FOUNDATIONS.

The datum line shown in the Figures is 7·58 feet below Ordnance datum; it represents the level of the sill of the old entrance-lock at the Cumberland basin, and is 3 feet above the sill of the new lock. The bed of the river at the bridge is about 2 feet above datum; and at low water, except in times of flood, there is a depth of only about 3 feet of water in the river at this point. The level of high water of ordinary spring-tides is 30 feet above datum, and that of ordinary neap-tides 20 feet above datum.

The principal portions of the contract for the foundations were the north pier and the centre pier, which are both situated in the bed of the river, and had to be constructed inside dams, as it was necessary to found them on the red marl, which overlies the new red sandstone, and which at these points was found at depths varying from 8 to 14 feet below datum.

Before work commenced, the level of the ground on the site of the north pier was about 8 feet above datum, so that it was usually entirely left by the tide at low water. This pier consists of a cement-concrete foundation, about 12 feet 6 inches thick, laid within a rectangular dam, 25 feet by 64 feet 6 inches internal dimensions, or 3 feet larger in each direction than the concrete foundation, and surmounted by a concrete pier faced with masonry in cement mortar.

Each side of the dam consisted of a single row of piles, 12 inches thick, driven as closely as possible and caulked with oakum. King-piles, about 11 feet between centres, with diamond-pointed shoes, were first driven by a pile-engine fixed on a floating pontoon. Stout walings were then bolted on the outside and inside of the king-piles near the top, and also as low down as the mud would allow. Intermediate sheet-piles with shoes were then driven, starting from each king-pile, until they left a space small enough for a closing-pile. Before driving the closing-piles, screw-jacks and wedges were used to force the sheet-piles as close together as possible, and the closing-piles were specially dressed to fit the space left. The closers were usually entirely successful, although in a few instances they required careful caulking before they were quite tight. Additional walings and internal struts were then fixed, and bags of clay were laid about 2 feet deep around the outside of the dam, in order to protect the mud from scour in times of flood. The points of the piles were driven to about 13 feet below datum or about 2 feet below the level at which the foundation was finally laid. The top of the dam was at about 34 feet above datum, so that all ordinary spring-tides could be kept out. At mud-level two sluice-doors were provided, which could be worked from the top of the dam by means of a screw handle working on a long rod attached to the door, so as to allow of water being let in or out as required.

The excavation inside the dam was executed in three lengths, the middle portion being completed, and the concrete laid to a depth of 6 feet, before the end sections were started. The first few feet of excavation was through river-mud, which was followed by silt and stones, overlying a bed of gravel about 6 feet thick; below this was a thin bed of marly clay, and next the red marl on which the foundation was laid, about 10 feet 6 inches below datum. Although the foundation was carried about 3 feet deeper than had been anticipated, it was all safely put in with a very moderate amount of pumping, the only pumps used being a No. 5 and a No. 6 pulso-meter. A slight blow occurred during a flood when the masonry was about 2 feet high, but it was easily stopped with bags of clay when the flood subsided. When the pier had reached a level about 6 feet above the sills of the sluices, pumping became unnecessary, as the slight leakage on each tide did not fill the reservoir thus formed, and the water which did get in could be let out through the sluices at low water.

When the masonry had reached the level of ordinary spring-tides the dam was removed by drawing all the piles except a few which

were cut off just above the concrete foundation. Under the maximum distribution of load on the bridge the pressure per square foot on the foundation amounts to 2·9 tons per square foot.

The concrete used throughout this contract is 7-to-1 Portland-cement concrete with a moderate number of displacers. The aggregate was broken Pennant stone and Bideford sand. The masonry facework is of the kind known as rock-faced random-coursed rubble, the stones being square on all beds and joints. The stone used for facework is entirely hard mountain limestone from the Chepstow quarries. The caps to the pilasters are of hard red sandstone from the Forest of Dean, known as Wilderness stone.

The centre pier was built inside a single-pile dam of similar construction to that used at the north pier. The concrete foundation was intended to measure 43 feet by 37 feet, and the internal dimensions of the dam at the top were 3 feet more in each direction. The piles, however, ran inwards somewhat in driving, and the concrete foundation was actually laid solid to the piles. The piles of this dam, as in the case of the north-pier dam, were driven to about 2 feet below the level at which the foundation was finally laid. In order to try to keep the dam water-tight, bags of clay were packed up against the sides to a height of 4 or 5 feet above the mud, and were kept in position by a row of steel rails driven upright into the river-bed about 2 feet 6 inches apart, and about 3 feet from the outer face of the dam.

The excavation proceeded satisfactorily, and two No. 6 pulsometer pumps were sufficient to keep the site dry until a level of 4 feet below datum was reached, when a blow occurred at the south-west corner. This blow was stopped by working tidally, a trench being made on the outside of the dam and filled with clay after the piles had been caulked. This enabled the dam to be pumped out again, and the excavation was proceeded with. When, however, it had been carried 2 feet deeper, another blow occurred, and although many attempts were made to stop the blows, it was not found possible again to make the dam water-tight at high water; the remainder of the excavation was therefore done at low water, when the head was not sufficient to reopen the blows. The sluices were kept permanently open during this period of the work, and an 8-inch centrifugal pump was used, in addition to the two pulsometers, in order to dry the dam as quickly as possible when the tide fell below the level of the sluices.

The head of water above the bottom of the foundation was 18 feet, even at low tide, and at high tide it was as much as 45 feet: it will readily be understood, therefore, that the construction of a water-tight dam presented considerable difficulties, especially as it

was not possible to make a coffer-dam, as the extra width would have reduced the fairway of the river too much.

The excavation was carried out in two sections, and about 12 feet of concrete was laid in the down-stream half before the excavation was completed in the up-stream half. On the completion of the concrete foundation, which is 16 feet thick, the tide was again excluded from the dam and the masonry work was all built in the dry.

The general design of the pier is shown in Figs. 2 and 3, Plate 4. The facework, as in the case of the north pier, is of random-coursed rubble masonry and the backing is of 7-to-1 cement concrete with displacers. The bed-stones on the upper surface, which take the roller-path and centre-pivot castings, are of Cornish granite fine-axed on the bearing-surfaces. The maximum pressure on the foundation of this pier also amounts to 2·9 tons per square foot.

Both the north pier and the centre pier are provided with fender-piling consisting of 12-inch by 12-inch pitch-pine timbers as shown in Figs. 2. In the case of the centre pier, jetties with strongly constructed dolphins at the ends, and of sufficient length to protect the bridge when open, are built on both up- and down-stream sides.

The river end of the south abutment (Figs. 2), on which the rear end of the swing-span bears, is founded on concrete taken down to the marl at a depth of 15 feet below datum, and laid inside a single-pile dam to exclude the high tides. Very little water was encountered until the bed of gravel overlying the marl was reached, after which pumping had to be carried on continuously.

The remainder of this abutment consists of two walls, one on each side of the railway and running parallel with it (Figs. 2). Cross girders, 2 feet deep at the centre, span between these walls, and carry the roadway over the railway until the former bends away towards the east and is carried on an embankment. These walls are of rubble masonry with facework similar to that of the centre and north piers, but are built in lime mortar and founded on 12-inch by 12-inch pitch-pine piles about 45 feet long, which are driven to the marl.

In designing this and all the other piled foundations the maximum load allowed on a pile was 25 tons. The piles were driven with a 1-ton monkey falling 10 feet, until the total set for the last five blows did not exceed 1 inch.

The Towpath pier consists of a small retaining-wall founded on piles, behind which two pits, each 9 feet square at the bottom, were sunk to the level of the gravel bed (which at this point is about 17 feet below datum) and concrete columns were put in. These columns

form the foundation to carry the north ends of the girders of fixed span No. 3 and the south ends of the girders of span No. 2.

Abutments Nos. 1 and 2 of the north approach support the north-approach spans: they are built of rubble masonry similar to that used in the south abutment, and founded on 12-inch by 12-inch pitch-pine piles about 38 feet long. A cross section of abutment No. 2 is shown in Figs. 2.

#### SUPERSTRUCTURE.

The girder-work throughout is of mild steel of British manufacture, made by the Siemens-Martin acid process, the specified breaking-stress in tension being between 27 and 32 tons per square inch, with a minimum elongation of 20 per cent. on a length of 8 inches.

The working-stresses adopted in designing the various girders were:—

Main girders of swing-span . . .	{ $5\frac{1}{2}$ tons per square inch net, in tension and compression.
„ „ approach-spans . . .	{ 6 tons per square inch net, in tension and compression.
Cross girders of all spans . . .	{ 5 tons per square inch net, in tension.
	{ $4\frac{1}{2}$ tons per square inch gross in compression.

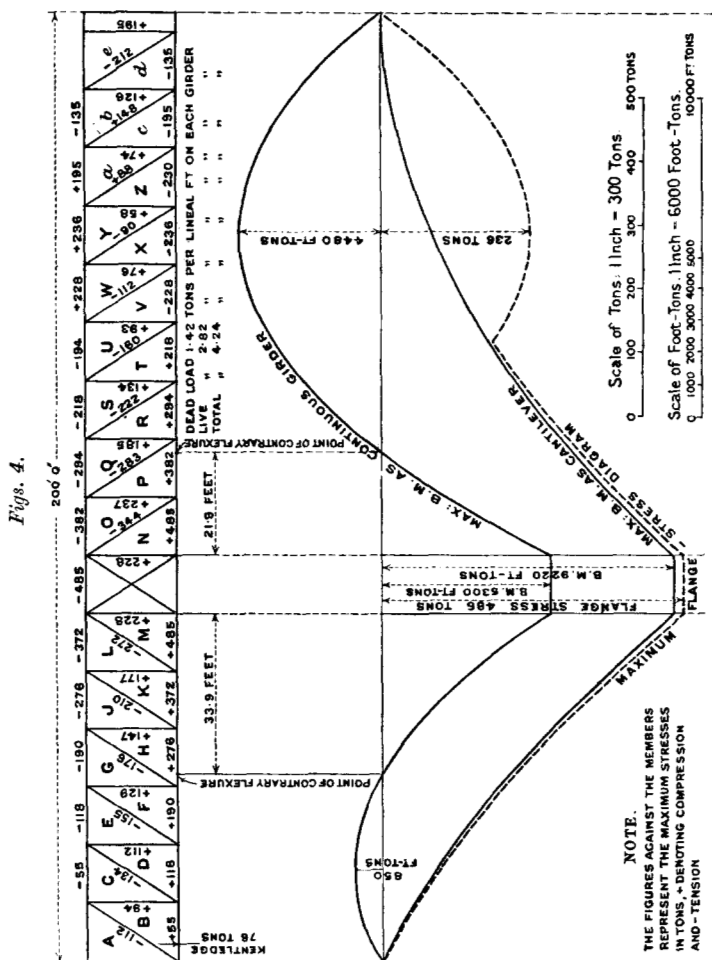
In calculating the stresses in the girders, the rolling load on the railway was assumed to be a string of heavy goods-locomotives, equal to 1.66 ton per lineal foot on each pair of rails with a maximum load of 18 tons on an axle. The live load on the roadways was assumed to be 1.5 cwt. per square foot, and the roadway cross girders were designed to carry two steam-rollers, weighing 20 tons each, passing one another.

The total length of the swing-span is 202 feet 6 inches, the radius of the nose end being 121 feet 6 inches, and that of the rear end 81 feet. The two main girders are 27 feet 9 inches apart between centres, and are divided into bays of 12 feet 3 inches, with a single system of triangulation, counter-braced at the bay over the centre pivot, the other diagonals being arranged so that they are in tension when the bridge is swinging.

The depth of the girders is 19 feet between main angles, the ratio of length to depth being 10.5 to 1. They were built with a rise from the centre pivot towards the two ends, the total rise at the nose end being 2 inches, and that at the rear end  $1\frac{1}{2}$  inch, in order to ensure the ends not deflecting below the horizontal while swinging. The booms are of U section, the main angles being

5 inches by  $3\frac{1}{2}$  inches by  $\frac{5}{8}$  inch, the stringer-plates 1 foot 8 inches by  $\frac{1}{2}$  inch, and the flange-plates 2 feet 6 inches wide, their total thickness at the centre being  $3\frac{1}{2}$  inches.

Figs. 4 and 4a give the bending-moment and shearing-stress dia-

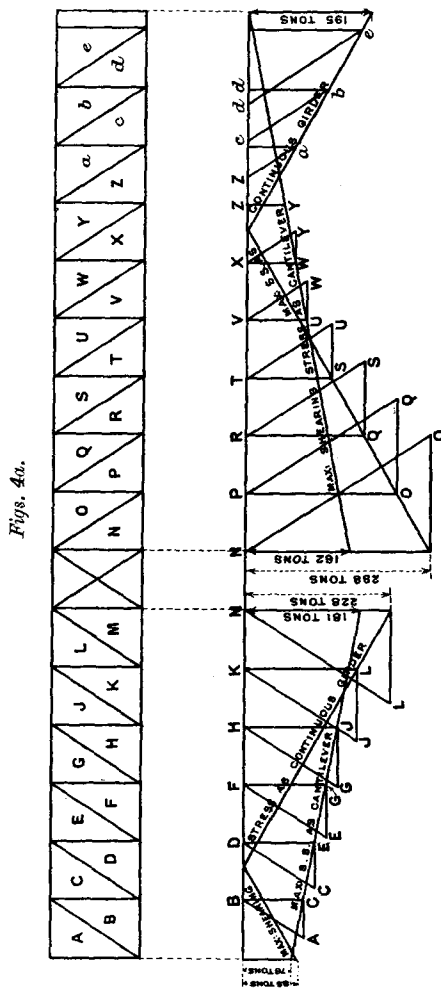


grams for the main girders, both when swinging, in which case they are considered to carry only the dead weight of the bridge, and also when at work as a continuous girder and loaded with the maximum live load throughout in addition to the dead load. There is also a



curve which shows the maximum flange-stress which can occur at any point under either condition of loading.

The lower deck carries a double line of railway. The cross girders are 26 feet long, 2 feet deep at the centre and 15 inches at



the ends, and rest on the boom-angles of the main girders. They are connected to the vertical members of the main girders by means of brackets, the plates of which pass through the top flange of the cross girder and are riveted to the web. The rail-bearers are 12 feet

3 inches long and 15 inches deep, with a  $\frac{3}{8}$ -inch web and 4-inch by 4-inch by  $\frac{1}{2}$ -inch angles for flanges. This deck is plated with  $\frac{5}{16}$ -inch flat steel plates, 3 feet wide, laid transversely and connected together by steel tee-bars which act as butt-straps and stiffeners. The permanent way consists of 87-lb. flat-footed rails laid on longitudinal jarrah sleepers, 14 inches wide and 5 inches deep.

The roadway cross girders are 2 feet deep, the top flange being level with the top of the main girders. They are carried by large brackets which are connected to the vertical members of the main girders and which also serve the purpose of stiffening the bridge. The headway from rail-level to the underside of the roadway cross girders is 14 feet 6 inches.

The roadway is 20 feet wide and is carried on buckled plates 5 feet 9 inches by 3 feet 4 inches and  $\frac{5}{16}$  inch thick, buckled upwards to the extent of 3 inches at the centre. These plates are carried by longitudinal bearers 12 inches deep, and transverse trimmers consisting of bulb-tees 7 inches deep. There are two footpaths 5 feet 6 inches wide, carried on  $\frac{3}{16}$ -inch corrugated steel plate.

The surface of the roadway on the swing-span is made with creosoted prismatic oak sets, 4 inches deep, laid on coke-breeze concrete with a layer of Callender bitumen sheeting between the concrete and the sets. On the approaches the roadway is laid in the same way, except that  $\frac{3}{4}$  inch of rock-asphalt is substituted for the bitumen sheeting under the wood blocks. The coke-breeze concrete is made in the proportions of 3 parts of coke-breeze, 1 part of Bideford sand, and 1 part of Portland cement, and weighs about 100 lbs. per cubic foot.

The rivets are  $\frac{7}{8}$  inch in diameter throughout the work, except in the rail-bearers, floor-plates, and a few other places where the plates are thin, in which cases the rivets are  $\frac{5}{8}$  inch or  $\frac{3}{4}$  inch in diameter. For the riveting done at the works hydraulic riveters were used as far as possible, the remaining rivets being put in with the Boyer pneumatic-hammer riveter, which was also used for nearly all the work done on the site, very few rivets being put in by hand.

The kentledge, of which there is about 156 tons, is placed in the last bay at the rear end of the bridge, underneath both roadway and railway floor-plates, and also in the boxes at the rear end of the main girders. It consists of cast-iron slabs laid transversely between the bottom flanges of heavy longitudinal girders, the space between these slabs and the floor-plates being filled with concrete made of scrap-iron and cement.

Span No. 3 on the north approach carries the road and railway from the north pier to the Towpath pier and is of similar construc-

tion to the swing-span, except that the main girders are farther apart, the distance between their centres being 37 feet 9 inches. This extra width is required on the railway floor as the rails are on a curve, and it also enables the roadway on the approach to be made 25 feet wide. The total length of this span is 75 feet 9 inches, and the north ends of the main girders are specially stiffened so as to support the south ends of the girders of span No. 2, which carries the roadway only from the Towpath pier to the masonry abutment No. 2. These girders are 103 feet long, 7 feet 6 inches deep, and 2 feet 6 inches wide, with double plate-webs 1 foot 9 inches apart. The ratio of length to depth in these girders is about 14 to 1, which is not the most economical ratio, but was adopted for the sake of appearance, the idea being to keep the top of the parapet at a uniform level throughout the bridge. The roadway is 25 feet wide, with a footpath 5 feet wide on each side, and is carried on trough flooring, laid longitudinally, supported by cross girders 36 feet long, 2 feet 3 inches deep at the centre, and 10 feet apart from centre to centre. Similar trough flooring is used on the south approach-span.

Expansion-bearings are provided at the north ends of spans Nos. 2 and 3, consisting of cast-iron bearing-plates attached to the bottom booms and free to slide on steel castings attached to the bed-stones, the lower castings being provided with gun-metal bearing-strips on the upper surface.

Span No. 1, which carries the roadway over a railway-siding between abutments Nos. 1 and 2, has a clear span of 28 feet only, and is made with square trough flooring 19 inches deep and of 12-inch pitch, laid longitudinally and provided with light parapet-girders on each side (Figs. 2, Plate 4).

As the turn-table of the bridge is below the level of high water at equinoctial spring-tides, it was necessary to put a water-tight casing round the top of the centre pier to prevent damage by flooding. This casing is of steel plates  $\frac{3}{8}$  inch thick, and is carried on steel brackets fixed to the masonry (Figs. 6, Plate 4). It is made water-tight on the bottom by means of a layer of fine concrete 4 inches thick. Valves are provided in the bottom of the casing, so that any rain-water which collects in it may be let out.

#### TURN-TABLE (Figs. 5 and 6, Plate 4).

The lower roller-path is of cast steel, 30 feet 3 inches in diameter on the centre line of the rollers, and 2 feet wide on the upper surface. It is divided into twelve sections, the joints making an angle of  $15^\circ$  with the radius, in order to avoid uneven wear. The upper

and lower surfaces, and also the ends of each section, are machined. The sections are connected together by four  $1\frac{1}{2}$ -inch turned steel bolts and also a 2-inch cover-plate bolted on the underside of the path. The path is laid on a finely-dressed granite bed in which recesses had been cut for the cover-plates, and these recesses were subsequently grouted up, so that the cover-plates form a key to prevent the path from moving. The path is also held down by forty-eight  $1\frac{1}{2}$ -inch cotter-bolts, and twenty-four  $1\frac{1}{2}$ -inch lewis-bolts. The pressure on the granite bed-stones under the path will not exceed  $4\frac{1}{2}$  tons per square foot under any condition of loading.

A cast-steel rack of 6-inch pitch, into which work the two pinions for turning the bridge, is fixed to the outside of the path and connected thereto by means of  $1\frac{1}{4}$ -inch countersunk bolts 12 inches apart.

The rollers, thirty-four in number, are also of cast steel, 2 feet 6 inches in diameter on the centre-line and 2 feet long, and are turned to such a taper that the sides if produced would meet at the centre pivot. The axles are of steel and  $3\frac{1}{2}$  inches in diameter, passing through gun-metal bushes in the rollers; they have a longitudinal groove on the upper side of the whole length of the bearing, through which a  $\frac{3}{8}$ -inch copper oil-tube passes; this tube is perforated along the top and the outer end is bent upwards to receive the oil. Spiral grooves are also provided on the gun-metal bushes for distributing the oil. The axles are 4 feet 8 inches long and the space between the outside of the roller-frame and the water-tight casing is sufficient to allow any axle to be removed in case of necessity.

The roller-frame consists of two rings, which carry the inner and outer carriages of the rollers, and are connected together by steel plates and cast-iron distance-pieces. The inner ring is connected by means of steel angles and flat bars to a cast-iron collar which is free to revolve on the centre pivot.

The carriages are of cast iron, and are carried on the inner and outer rings of the roller-frame. The carriage on the inner ring is provided with a split steel bush which seizes the axle and prevents it from turning, the roller being free to revolve on the axle. The adjustment of the roller is effected by means of nuts on the inner end of the axle. The weight on each roller when the bridge is swinging is about 29 tons, which is equal to 1.2 ton per lineal inch.

The upper roller-path is of cast steel, and is similar in construction to the lower path. It is bolted to the underside of the annular girder, which is connected by radial arms to an octagonal cast-iron collar free to revolve on the centre pivot.

The annular girder is 2 feet 6 inches deep and 3 feet wide, of box section, with diaphragms at intervals of 2 feet 9 inches. It is made very stiff, as its function is to distribute the weight of the bridge evenly over the rollers. The main angles are 6 inches by 4 inches by  $\frac{9}{16}$  inch, the webs  $\frac{1}{2}$  inch, and the flanges  $\frac{5}{8}$  inch thick. The annular girder is bolted to the underside of each main girder by means of forty-six 1-inch turned steel bolts, and also to the cross girders and rail-bearers which pass over it. These rail-bearers and cross girders are made extra strong so as to give increased stiffness to the annular girder.

The centre pivot (Figs. 6) is of cast iron 2 inches thick, resting on a granite bed-stone into which it is dowelled, and is also held by eight  $1\frac{3}{4}$ -inch lewis-bolts. It has two bearings, to take the centre collars of the roller-frame and the annular girder respectively.

#### METHOD OF ERECTION.

The swing-span was erected in its normal open position upon a timber staging consisting of the permanent jetties at the centre pier with an additional row of piles driven on the south side, the whole of the timber-work being braced together and decked over. The piles of this staging were so arranged that no pile would receive a load of more than 15 tons at any period of the erection of the steel-work. Access to the centre pier was obtained by means of a timber gantry from the south bank of the river, carrying temporary rails in continuation of the Great Western Railway approach-line. By this means all the steelwork of the turn-table and water-tight casing was conveyed to the site by rail, the girder-work itself being delivered by barges at the centre pier.

Before commencing to erect the turn-table, the casing of the centre pier was fixed and made water-tight. The turn-table (including its centre pivot, lower roller-path, rollers and roller-frame, upper roller-path, and annular girder) was then built up, each part being levelled and adjusted with the utmost care, and the whole being revolved and tested before any of the weight of the main girders was allowed to come upon it, in order to ensure each roller receiving an equal share of the weight of the bridge.

The centre portions of the bottom booms of the main girders, which had been riveted up on staging, were next placed on the annular girder and bolted down in their final positions, after which the entire lengths of the two bottom booms were laid down on blocks supported by the staging and adjusted to give the correct rise

towards the ends. The centre cross girders and rail-bearers were then placed in position and a temporary line for a travelling crane was laid down on them. The crane which ran on this road was used for erecting the remaining cross girders and rail-bearers, and also the vertical and diagonal members of the main girders: the whole of the work was erected from the centre both ways, and the top boom was bolted on as the work proceeded. For the erection of the roadway-girders and for riveting purposes, a travelling stage about 3 feet lower than the underside of the cross girders was built to run on rails on the railway-deck, and spanning the full width between the main girders. As soon as the roadway-girders had been erected, the travelling crane was dismantled and lifted on to the roadway, where it was used for the erection of the machinery-tower. During the whole of the erection the girders were supported on staging so that the whole structure was at rest when the riveting was done, which could not have been the case had the erection been carried out on the cantilever principle. The fixed span, No. 3, was erected in its correct position on timber frames resting on sills on the bank of the river. The main girders for span No. 2, which weigh about 50 tons each, were delivered on the site in three sections, and were erected and riveted on the ground-level, being afterwards raised into position by jacking and packing with timber. The girder-work for the north approach was conveyed from the works to the site by road.

The boilers, compressors, smiths' shop, etc., for the whole work were situated on the south bank of the river, the compressed air for riveting being conveyed by pipes over a gantry on to the centre pier, and under the bed of the river to the north side.

#### TURNING-MACHINERY.

The bridge is worked by hydraulic power derived from the Bristol Docks Committee's pumping-station, which supplies power for all their hydraulic machinery at the city docks.

The working-pressure is 750 lbs. per square inch, and the water is carried to the centre pier under the bed of the river in 2½-inch copper pipes, which are laid in duplicate to prevent stoppage in case of a burst pipe. The pipe is carried up the side of the centre pier and under the bottom roller-path. It then passes up through the centre pivot, at the top of which it has a swivel-joint, and is carried thence under the railway deck-plating and up one of the legs of the machinery-tower to the engines.

The turning-engines are three-throw reversible hydraulic engines with rams 4 inches in diameter and 14 inches stroke. Two engines are provided, the second being used only in case of a break-down. These engines, by means of spur-pinions and wheels, drive two horizontal shafts, at the ends of which bevel-gearing drives vertical shafts placed at diagonally opposite corners of the tower. These shafts pass through bracket bearings attached to the legs of the tower, and also through bearings in steel boxes, which form part of the annular girder, and at their lower ends carry pinions 1 foot 11 inches in diameter on the pitch-circle, which engage with the circular rack on the bottom roller-path and thus turn the bridge (Figs. 5, 6 and 7). The reduction in speed from the crank-shaft to the horizontal shaft is in the ratio of 63 to 17, and that from the horizontal to the vertical shaft 38 to 13, giving a total reduction 10·7 to 1.

While the bridge is swinging, the whole weight is carried on the live ring, and when the bridge has been swung into position across the river the ends of the main girders are lifted slightly by means of four 60-ton hydraulic presses, one attached to each end of each main girder, acting against cast-iron bearing-blocks on the abutments. As soon as the girders have been lifted, sliding blocks are moved into position over the bearing-blocks and the presses are released, so that the sliding blocks then take the reactions at the abutments. The sliding blocks are moved in and out by means of hydraulic cylinders and rams, fitted with chains with a multiple of 2 to 1, placed in the bottom booms of the main girders and worked by a lever in the machinery-house (Fig. 8, Plate 4).

The cylinders of the lifting-presses are of cast steel lined with gun-metal, and have rams 16 inches in diameter, of cast iron cased with gun-metal. The working-stroke of the ram is  $3\frac{1}{2}$  inches, but the actual amount that the girders are lifted is only  $\frac{7}{8}$  inch at the nose end and  $\frac{5}{8}$  inch at the rear end;  $\frac{1}{4}$  inch of these amounts is allowed for clearance in moving the sliding blocks in and out, so that the permanent lift only amounts to  $\frac{3}{8}$  inch at the nose end and  $\frac{3}{8}$  inch at the rear end. The cut-off of the ram is arranged by means of lock-nuts on the piston-rod which engage with the top of the cylinder. The pressure-water is conveyed to the presses by means of pipes from the machinery-tower where the lever is situated. When the pressure is removed, the rams are overhauled by means of balance-weights attached by chains to the piston-rods and acting over sheaves.

An automatic locking-bolt worked by a spring is provided in the middle of each end of the swing-span. The bolt is 3 inches

by 4 inches in section and has a stroke of 5 inches. The spring keeps the bolt normally shot, but when the bridge is being closed the bolt is pressed back by striking the ramp of a steel rubbing-plate on the abutment, and when the bridge reaches its correct position the bolt is automatically shot into a cast-steel socket let into the masonry of the abutment. When it is required to open the bridge the bolt is withdrawn by means of a treadle-lever in the machinery-tower which actuates it by means of chains.

The time taken for the complete operation of opening or closing the bridge is about 2 minutes 15 seconds.

#### NAVIGATION-SIGNALS AND LIGHTS.

The navigation-lights provided for controlling the passage of ships through the bridge-way at night-time are arranged with a view to always swinging the bridge so that the nose end will point up-stream when open: the reverse direction is intended to be used only to prevent an accident in the event of a ship getting out of control when going down-stream and approaching too near to the bridge to allow it to be swung up-stream. The lights provided are:

(i) A red light showing all round, fixed on the centre of the swing-span immediately above the machinery-tower. This light is provided with screens so that the red light can be obscured through arcs of  $180^\circ$  on either the up-stream or the down-stream side when the bridge is open.

(ii) Two green lights fixed one at each end of the down-stream girder of the swing-span above the level of the handrail to the roadway. Each of these lights is permanently masked through an arc of  $90^\circ$  as shown in Figs. 2.

(iii) Two green lights, one on each of the pilasters of the north pier. These lights are each masked through an arc of  $90^\circ$  on the north side, so that they are visible from the river, but not from the north approach-road.

When the bridge is open for ships to pass through, the red light at the centre can be obscured on either the up- or the down-stream side, and this is the signal for ships to approach from that side. The illuminant for these lights is oil.

During the day-time the signalling is carried out by means of two cones hoisted on a flag-staff on the machinery-house; of these cones one is a north cone (point upwards) and the other a south cone (point downwards). When the bridge-way is closed for navigation, both cones are hoisted, and when the bridge is opened, the north cone is lowered as a signal that vessels may pass down-stream, or the



south cone is lowered as a signal that vessels may pass up-stream. The two cones are never lowered simultaneously, as vessels are not allowed to pass each other in the bridge-way. The yard on which the cones are hoisted is fixed so that it points across the river when the bridge is open, and up- and down-stream when the bridge is closed to vessels. This ensures both cones being visible from the river when the bridge is open.

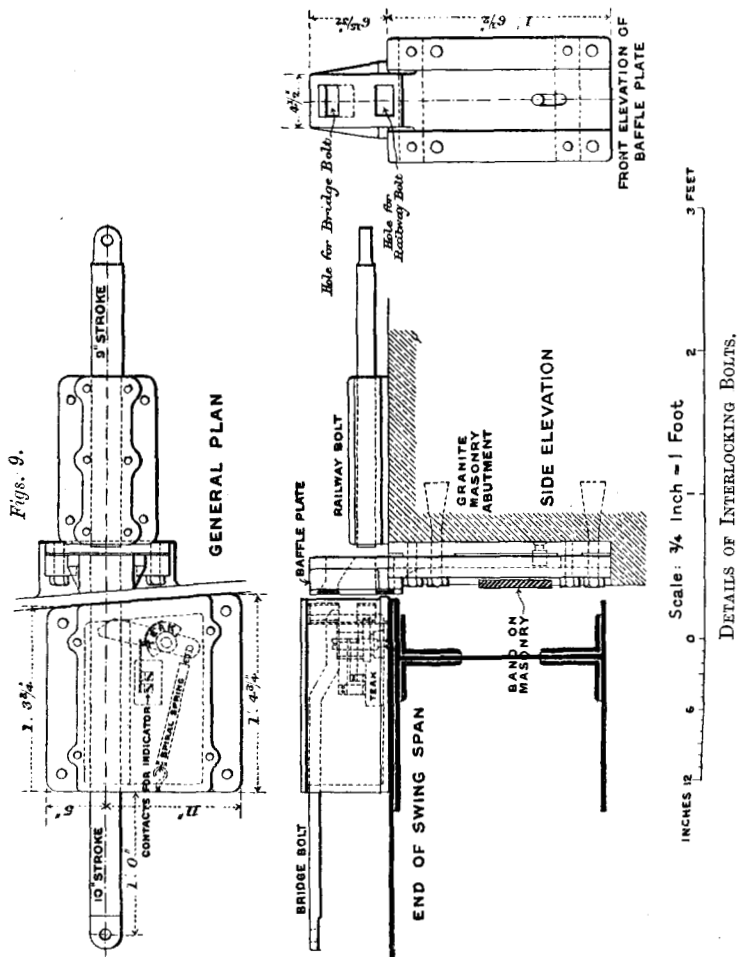
The bridge-master is in telephonic communication with two stations each about  $\frac{1}{4}$  mile distant, one above and the other below the bridge, and from these stations he receives warnings at night or in foggy weather of the approach of vessels.

*Interlocking and Indicating.*—The levers for working the machinery are interlocked with the railway-signals so that the bridge cannot be opened until the railway-signals are set against the trains, and the catch-points are open on each side of the bridge. This is effected by means of two pairs of interlocking bolts (*Figs. 9*), one pair being situated at each end of the bridge on the railway-deck level. One bolt of each pair is on the bridge, and is worked from the machinery-tower, and the other, which is on the abutment, is worked from the railway signal-cabin. Assuming the bridge to be set for railway-traffic, both bolts are shot, and the bridge bolt cannot be withdrawn until the railway bolt has been withdrawn. Conversely, when the bridge bolt has been withdrawn, the railway bolt cannot be shot again, as a baffle-plate is moved in front of it and remains there until the bridge bolt is again shot.

When the bridge-master wishes to swing the bridge for river-traffic, he rings, from the machinery-tower, a bell in each of the railway signal-cabins, and as soon as the signalmen have withdrawn their bolts he receives a reply signal. The withdrawal of the railway bolts mechanically releases the lever by which the bridge bolts are actuated, and he withdraws these bolts. This movement back locks the railway bolts and electrically releases the lifting-press lever, which he then pushes over; and as soon as the ends of the bridge are lifted correctly, the sliding-block lever is electrically fixed. When the sliding blocks are properly withdrawn, the ends of the bridge can be lowered, and the action of lowering frees the starting-valve handle, enabling the bridge to be swung open. When the bridge has been turned to its open position, one of the screens can be raised by means of a lever to obscure the red light for one direction only.

In order to close the bridge the screen must first be lowered so that the red light is again shown; then the bridge is turned to the railway position and the shooting of the automatic locking-bolts electrically frees the lifting-press lever; this lever is then pushed over, and the

lifting of the ends of the bridge frees the sliding-block lever ; the sliding blocks are then inserted and the lifting-press lever is pulled over to lower the ends of the bridge ; this electrically releases the interlocking-bolt lever which is moved over, thus electrically locking



the turning, sliding-block, and lifting-press levers, and mechanically releasing the railway bolts, which being shot put an electric lock on the interlocking lever.

Electric indicators fixed in the machinery-tower give the following information to the bridge-master.

1. Railway bolt : shot or withdrawn.
2. Lifting-presses : up or down.
3. Sliding blocks : in or out.
4. Automatic locking-bolt : shot or withdrawn.
5. Bridge set for road or river.

Of the first four indicators, there are two sets, one for the nose end and the other for the rear end.

The drawings for the work were prepared by the late Mr. J. M. McCurrich, M. Inst. C.E., Engineer of the Bristol Docks, and the work was carried out by his successor, Mr. W. W. Squire, M. Inst. C.E., the Author acting as Resident Engineer. The Author wishes to express his thanks to Mr. T. B. Cooper, B.Sc., Assoc. M. Inst. C.E., for assistance in preparing that portion of the Paper which refers to the foundations.

The Paper is accompanied by five drawings and two tracings, from which Plate 4 and the Figures in the text have been prepared ; also by three photographs.

## APPENDIX.

TABLE OF WEIGHTS OF SWING-SPAN.

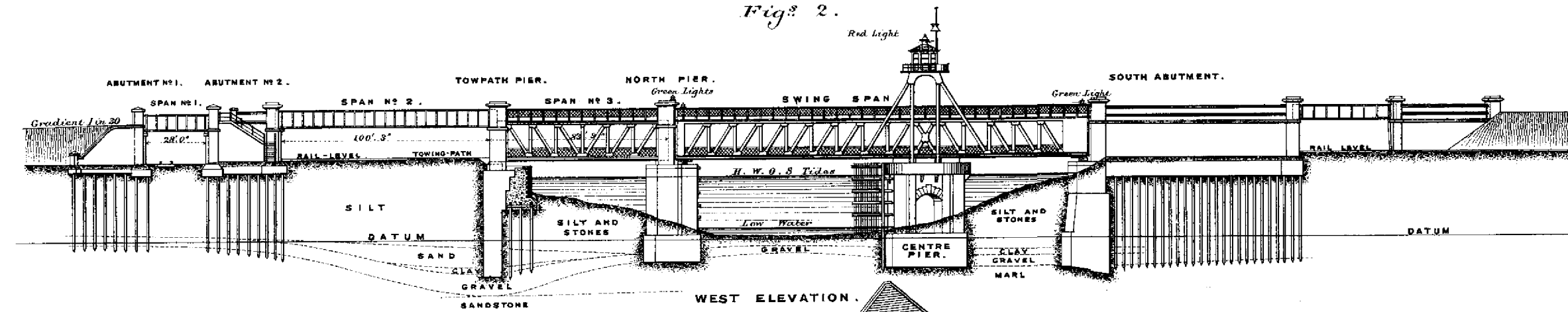
	Tons.	Tons.
Steelwork in main girders . . . . .	231	
Steelwork in longitudinal and cross girders, deck plating, etc. . . . .	234	
Steel and cast iron in handrailing . . . . .	21	
Steelwork in machinery-tower . . . . .	42	
Cast iron and cast steel in curbs to footpaths . . . . .	12	
Steelwork in annular girder . . . . .	35	
Steel and cast iron in roller-frame . . . . .	14	
Cast steel in rollers . . . . .	51	
Oak blocks, concrete, asphalt, etc., in footpaths and roadway . . . . .	99	
Permanent way . . . . .	18	
Turning-machinery, pipes, etc. . . . .	36	
Timberwork, etc., in machinery-house . . . . .	12	
Kentledge . . . . .	156	
Cast steel in top roller-path . . . . .	29	
Total weight of swinging parts . . . . .	—	990
Cast steel in bottom roller-path . . . . .	52½	
Cast iron in centre pivot . . . . .	2¾	
Weight of fixed part of turn-table. . . . .	—	55½
Total . . . . .		1,045½

## STEELWORK IN APPROACHES.

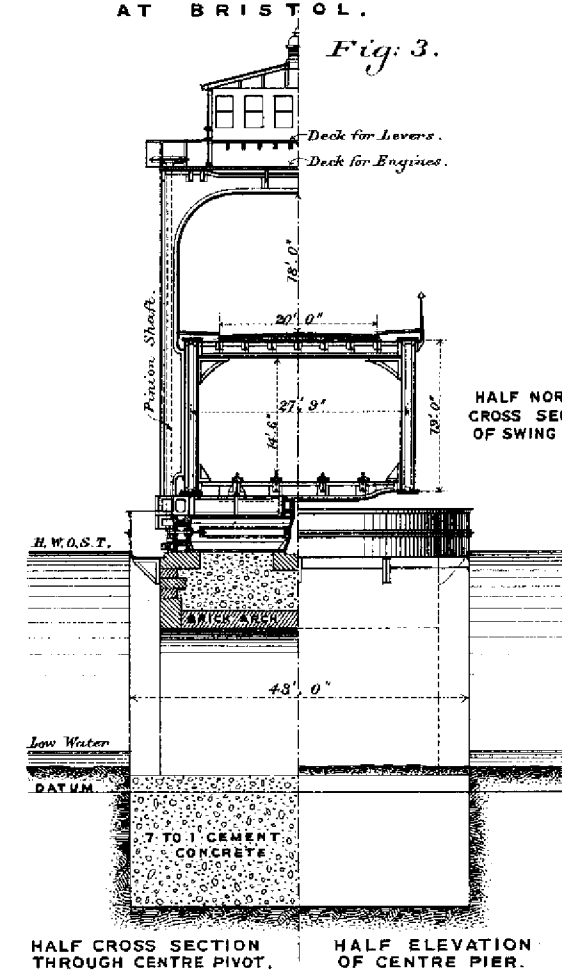
<i>Fixed Span No. 1:</i>	Main girders . . . . .	9½	
	Trough flooring . . . . .	37½	
		—	47
<i>Fixed Span No. 2:</i>	Main girders . . . . .	102	
	Cross girders and trough flooring . . . . .	102	
		—	204
<i>Fixed Span No. 3:</i>	Main girders . . . . .	87	
	Cross girders, floor-plating, etc. . . . .	136	
		—	223
<i>South Approach:</i>	Main girder, cross girders and trough flooring . . . . .	116	
		—	116
	Total steelwork in approaches . . . . .		590 tons.

SWING BRIDGE OVER THE RIVER AVON  
AT BRISTOL.

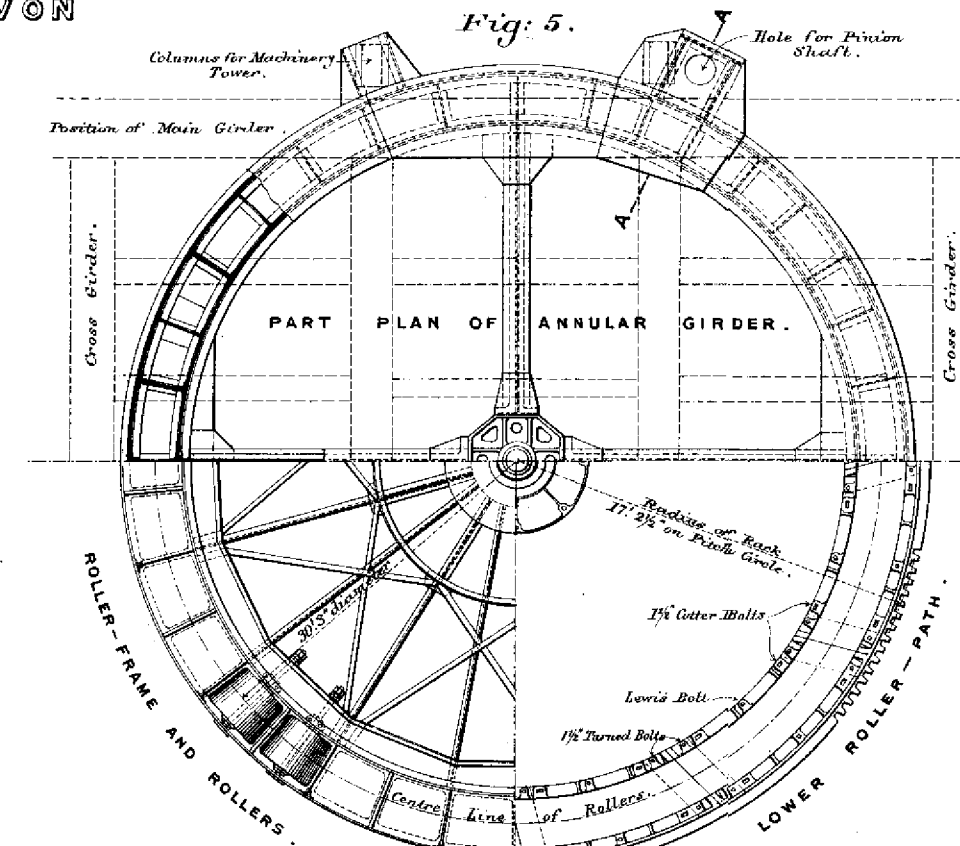
*Figs 2.*



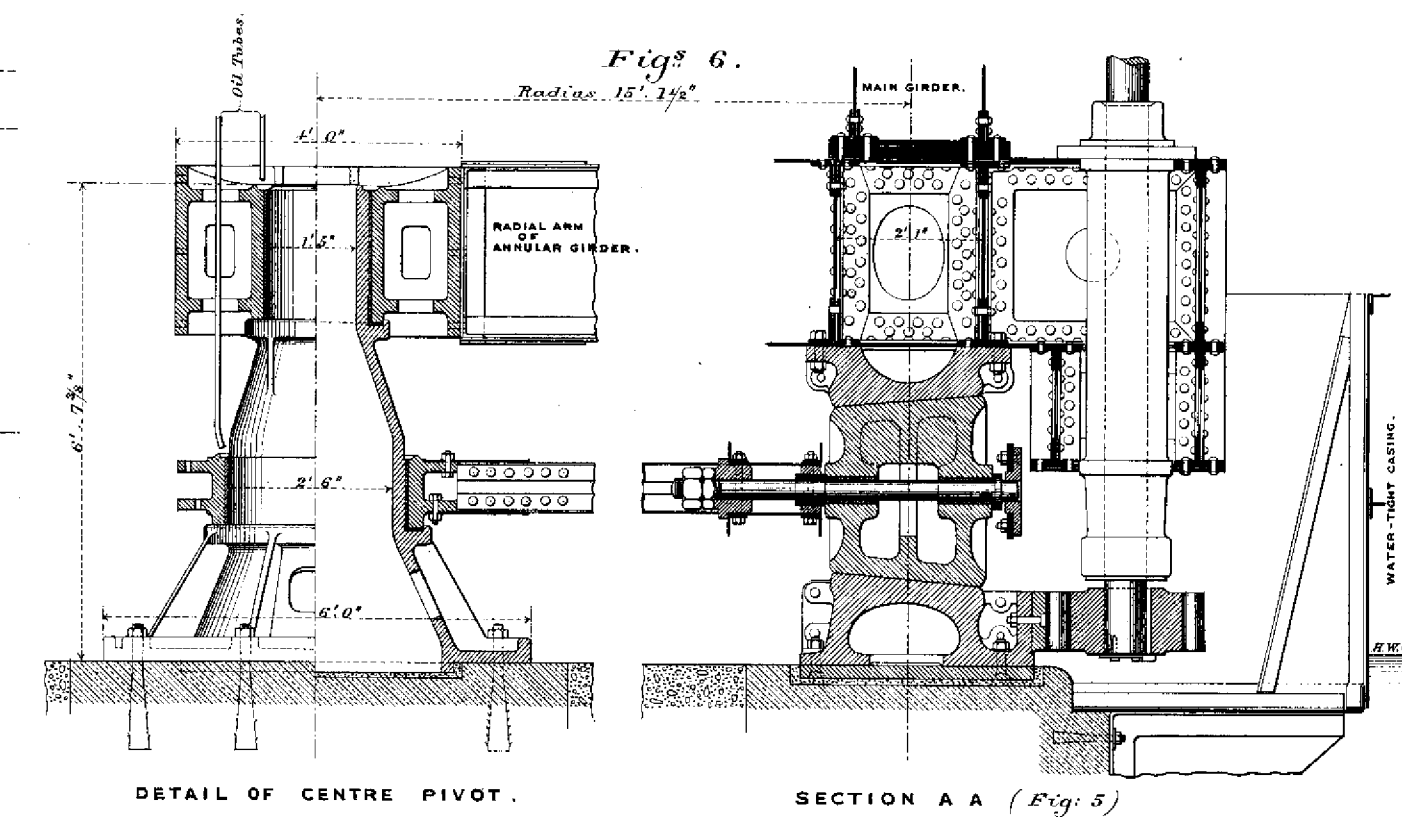
*Fig: 3.*



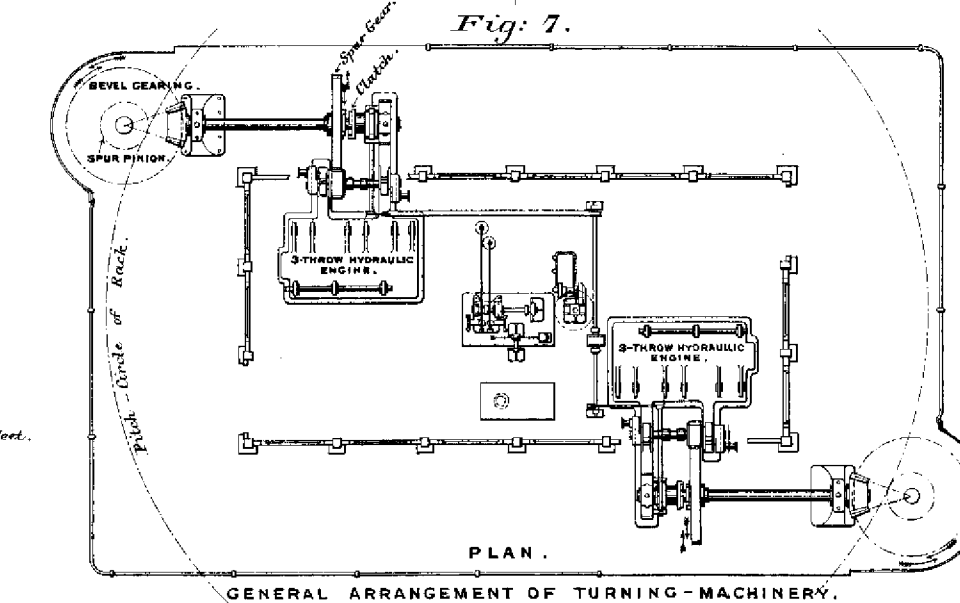
*Fig: 5*



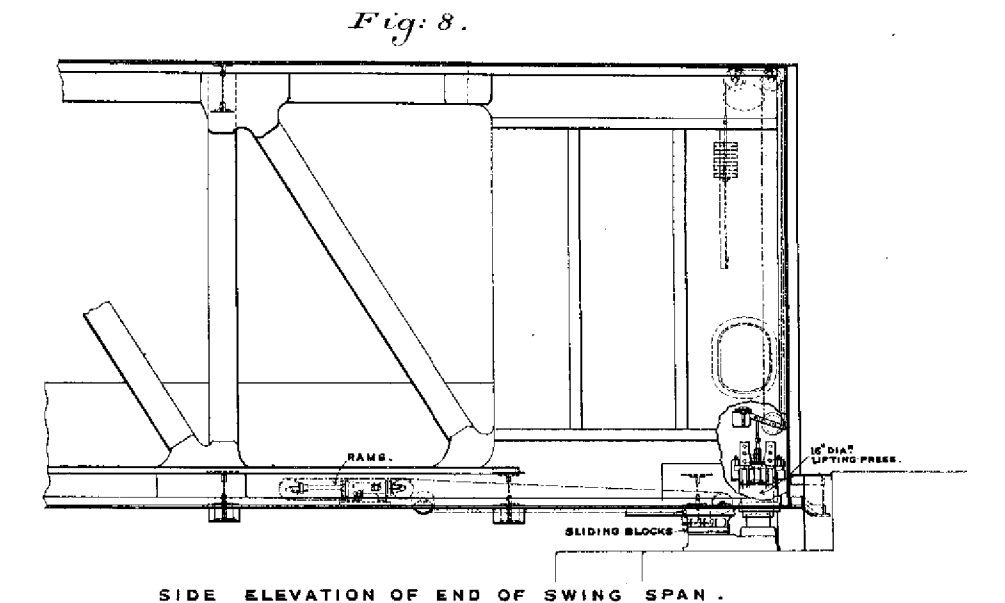
*Figs 6.*



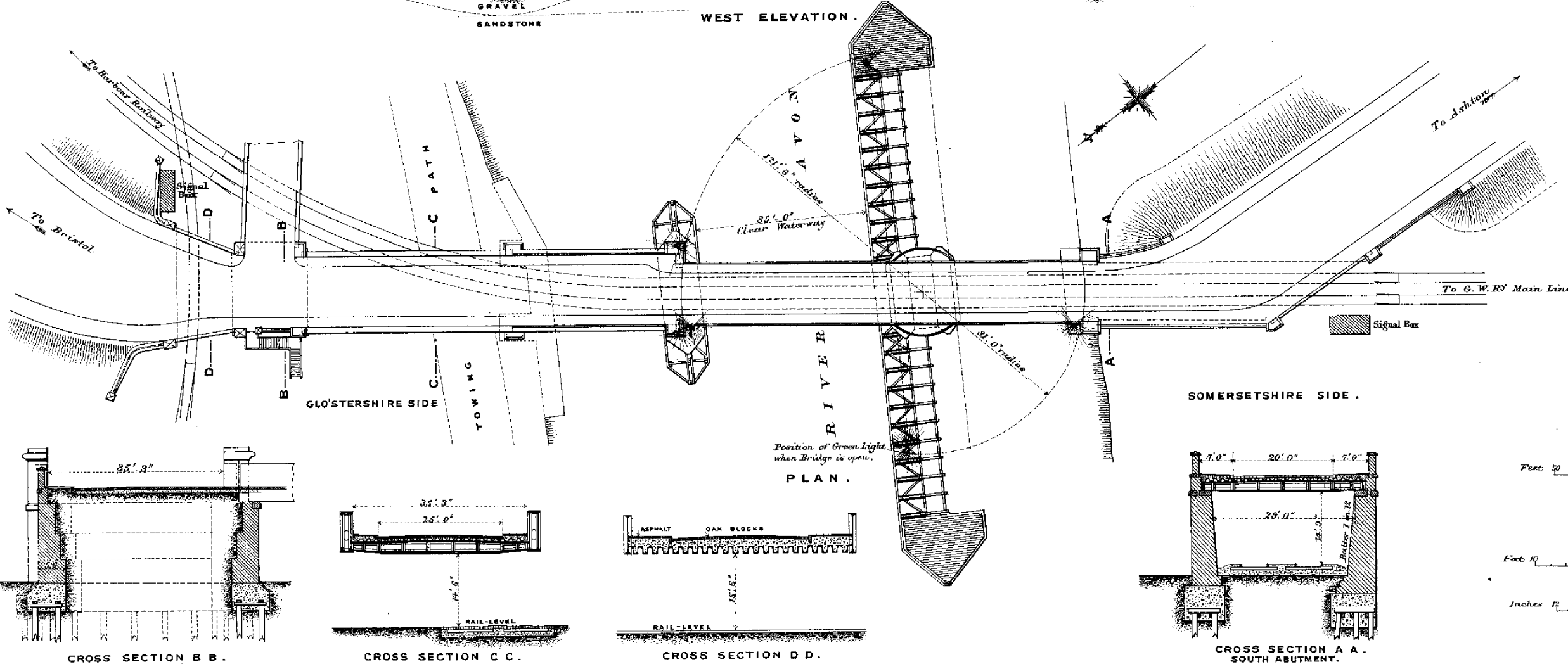
*Fig: 7.*



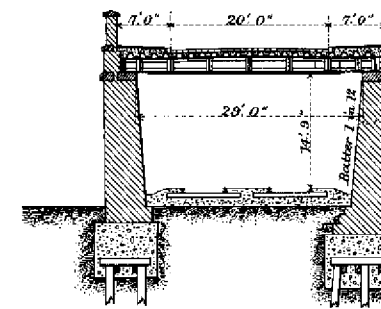
*Fig: 8*



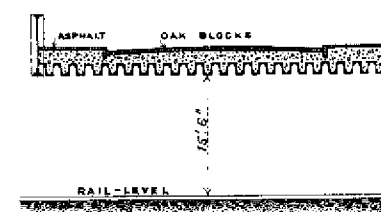
## PLAN



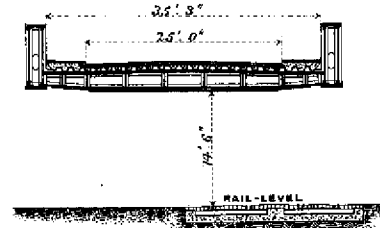
CROSS SECTION A A.  
SOUTH ABUTMENT.



CROSS SECTION D D



CROSS SECTION C C



CROSS SECTION B B

