"Some Aspects of the Design of Flexible Bridging, Including 'Whale' Floating Roadways." *

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INTRODUCTION.

THE magnitude and military aspects of the Mulberry project are well known. Perhaps less apparent is the background of design, development, and operational planning which were carried out under the direction of Brigadier Bruce G. White (later Sir Bruce White, K.B.E.), M.I.C.E., in his capacity as Director of Ports and Inland Water Transport, War Office. Some of the more technical details involved in the design of the flexible sea bridging may, however, still be of interest and are described in this Paper.

The requirements which lead to the introduction of flexibility in bridge design are unique and largely confined to marine uses. The usual conception of a bridge structure is one in which stiffness and rigidity are very desirable features, whilst the bridge supports are expected to stay put within an inch or two.

The original conception of the mile-long Mulberry roadways appreciated the necessity of firm and stable foundations for the bridge spans and suggested the provision of a series of spud pontoons which would afford the necessary supports reasonably rigid and quickly established. The bridging design team, ably directed by Lieut.-Col. W. T. Everall, O.B.E., R.E., was asked to produce a bridge span, 80 feet long, with 10-foot-wide roadway, that would be safe under small movement and possibly displacement of its spud-pontoon foundations. Alternatively, consideration was to be given to the possibility of constructing a pontoon bridge.

† The Author held the rank of Major, R.E., at the time the work described in this Paper was carried out.

It is not unusual for a bridge designer to view his supports and foundations with some pessimism and this case was no exception. Consideration was given to the design of a bridge span which would be safe under excessive movement of its foundations. In the worst case (that of a pontoon bridge), it was assumed that the bridge spans must allow for movement in the supports corresponding to the behaviour of small boats in a very rough sea. Such behaviour was analysed and it was found that the movement of the bridge supports in bad weather conditions would involve :—

(*a*) Translatory movement along each of three axes.
(*b*) Rotational movement about each of three axes.

Fortunately, some of these movements can be controlled, within limits, without the introduction of excessive forces, though the value of those forces is obviously dependent on wave form and the shape, weight, etc., of the pontoons.

Design Requirements.

The problem was to design a pontoon bridge able to ride a rough sea without overstressing any of its components ; such is the basis of design of the Whale piers.

The pontoon movements can be restrained by applying certain forces. Its translatory movement athwartships, or in line with the bridge deck, can be readily controlled by the main girders of the bridge ; the movement fore and aft, or transverse to the bridge deck, can be limited by means of moorings ; but it is not practicable to restrain in any way the up-and-down movement or heaving of the pontoon, and free movement must be allowed in this direction.

With regard to rotational movements, the rolling can be readily controlled by linking the pontoon to one, but not both, of the bridge spans which the pontoon supports. In considering the cross-sectional form of the pontoon, it will be apparent that link forces will be reduced as this more nearly approximates a circle. Rotation about a vertical axis can be controlled by means of the bridge girders. Forces will be reduced if girders are spaced wide apart and pontoons are made as short as possible. With regard to the pitching of pontoons, this can be controlled in some measure by the torsional rigidity of the bridge spans if the pontoon bridge is of short length and wave heights are limited. It will be obvious, however, that a long pontoon bridge in a high sea would demand a torsional rigidity well beyond the limits imposed by strength and weight ratios of materials available. The bridge spans used in the Whale piers offered practically no torsional resistance to the free pitching of pontoons.

Valuable data on wave motion were obtained from the National Physical

Laboratory and other sources which enabled the probable limits of above movements (also time intervals of periodic movements, amplitudes, etc.) to be ascertained for the determination of dynamic forces. Float movements were assumed generally to follow a sine-curve motion for the purpose of determining acceleration forces. An investigation of data giving maximum height/length ratios for wave profiles showed that the figure was reduced as wave-length increased, but that shoal-water and surf conditions gave very high waves on short lengths. Thus the angular movement of spans due to heaving of pontoons would be reduced as the length of spans was increased. There is, however, a practical limit to span length, bearing in mind material and production difficulties, size of pontoons, etc., and 80 feet was chosen as appearing the most suitable—a decision upon which experience throws no criticism.

After fixing span length, design requirements for a wave-height/length ratios of 1 : 9 followed automatically, using available data. Thus, if wave profiles phased with span length, alternate pontoons would be on crests and the others in hollows. The wave-length would be 160 feet, the approximate difference in level of adjacent pontoons would be of the order of 17 feet, and the relative angle between adjacent spans 24 degrees. That fixed the maximum span-to-span angle which would be necessary to allow free heaving of the pontoons. With regard to free pitching of the pontoons, the N.P.L. were able to confirm that the steepest slope taken up by the free surface of the sea under storm conditions was 20 degrees to the horizontal, but that a poorly designed hull form could obtain a pitching angle up to twice that value under phasing wave conditions. It will be seen that seas advancing at an angle to the line of a pontoon bridge would tend to produce an independent pitching of the various pontoons. Provided that the pontoons were well designed and damped so that the angle of pitch did not appreciably exceed the wave slope, the relative pitching angle between adjacent pontoons would not exceed 40 degrees.

Translatory tendencies of pontoon movement would, if restrained, involve fairly large forces due to wave pressure. Such a wave pressure would be of the same order as that exerted on the plating of large ships. An analysis of Lloyd's Scantlings showed that such forces would be met by an allowance of ½ ton per square foot of exposed surface.

It was, therefore, considered feasible to allow free heaving and pitching of pontoons, coupled with restraint of all other movements, by means of bridge spans and moorings, although there was one aspect of free heaving which caused considerable concern: should a long length of pontoon bridge be subjected to phasing waves, as described above for maximum heaving conditions, the slopes of the bridge spans might reach 12 degrees which could hardly be considered a small angle movement. What then would happen to the structure which would have to find an increase and then a decrease in length every 3 seconds? The problem was met by the introduction of immense longitudinal strength such that would, if necessary, allow the bridge girders to carry the pontoons clear of the water in the troughs and submerge those on the crests. Such strength could be obtained without sacrifice of economy in metal by working the material at yield stress and translating the forces into movement by the introduction at intervals of telescopic bridge spans.

The foregoing gives an outline of some of the design problems involved. Having considered in detail, the possibilities of producing a pontoon bridge, it was decided to develop that system rather than investigate further the proposal for using spud pontoons in bridge-span supports, which would be considerably more expensive to produce.

The following is a brief description of the design of bridge spans, pontoons, and moorings.

Design.

Figs 1, Plate 1, show the standard flexible bridge span. It is designed for Class 25 loading, although the Mulberry scheme included also a stronger version to carry Class 40 loading. It is a half-through span, 80 feet long, of welded and black-bolted construction, with a steel deck and wheel-guards. The weight is 28 tons complete and the material is mild steel to B.S.S. 153. The bridge bearings are of spherical construction and designed to allow a free angular movement of one span relative to another 24 degrees together with a torsional displacement of 40 degrees along the length of each bridge span.

To allow these very large angular movements, the bearings of adjacent spans are arranged to sit one inside the other, the outer bearing only taking its support on the pontoon. By this method the main loading is taken to the pontoon through two points which are, however, mounted off-centre on the pontoon. A third connexion is made from one only of the bridge spans to the pontoon by means of a link (see Section CC, Figs 1, Plate 1) from the centre of the end cross-girder and this link carries a part of the load.

The link controls the rolling tendency of the pontoon and the position of bearings is arranged so that there shall not be a reversal of forces in the link when the pontoon tends to roll under wave action, thus eliminating hammer effects and allowing easy clearances for pins, etc. The strength of this link connexion is sufficient to carry its portion of the bridge loading in addition to exerting the maximum force necessary to capsize the pontoon.

The method by which a sound bridge span can be easily and cheaply produced, and yet twist through an angle of 40 degrees, is rather interesting. The main girders are lozenge-shaped to ensure the best disposition of chord material to withstand both bending stresses and longitudinal forces. The centre sections of the girders are of built-up-lattice construction, using welded members and bolted joints, whilst the ends are of welded box construction and incorporate the spherical bearing as an integral part of the girder end. The longitudinal forces imposed by the tendency of pontoons to

(*a*) rotate about a vertical axis, and
(*b*) move bodily athwartships

under the influence of wave action are transmitted to bridge spans through the medium of the bearings. Such forces may be cumulative along the length of the pontoon bridge. Provision is made, by means of thrust bars built into the bearings, to transmit these forces from one span to another, whilst tensile loads are resisted by means of steel-cable grommet strops accurately made and secured to the bearing housing after passing through a very large sheave worked into the girder end. The accuracy of manufacture required for these grommet strops caused some head shaking. They are formed round thimbles the holes in which are to a dimensional tolerance of $\pm \frac{1}{64}$ inch. The strops which have one leg longer than the other, are also free from permanent stretch. By this means, each span is secured to its neighbour with 16 strands of $4\frac{1}{4}$-inch S.W.R., and to break the pontoon bridge chain by the exertion of longitudinal force would require a force of over 1,000 tons. The connexions for this attachment were so simplified that a span-to-span junction could be made at sea in 15 minutes. The bearings are allowed a short travel of $1\frac{1}{4}$ inch, one inside the other. Toward the limits of this travel a braking tendency is introduced by causing the inner bearing to ride up an increasing slope thus effectively reducing shock loads on cables and thrust bars. *Fig. 2* (facing p. 390) shows the arrangement at the bearings.

At this stage it might appear that there has been produced a design for main girders which are soundly attached to the pontoons but do not appear very effective in carrying any form of deck loading. The steel decking is, in fact, formed of pressed-steel units, 2 feet wide by 10 feet long, which combine the function of stringers and lateral bracing. These units have a low torsion-resistance and are each loosely but securely fastened down to cross-girders with four bolts and nuts with split pins. All cross-girders, with the exception of that at the centre, are hinge-connected to the centre of the main girders. All cross-girders are designed so that stresses are low under large angles of twist. The centre cross-girder is the only one which offers support to the main girders. It is 3 feet deep, of riveted construction, and has no bottom flange in the normal accepted sense. Stresses due to twisting have been kept down to 4 tons per square inch, and it is interesting to note that this is a unique example of the case where the thickening of material immediately results in a stress increase.

For the purpose of evaluating shear stresses and torque, having determined torsional displacement, the following formulae were used :—

$$\theta = \frac{M_t}{\phi} \qquad \text{(Salmon)}$$

$$\phi = G\mu\tfrac{1}{3}\Sigma bt^3 \qquad f_s = \frac{3M_t \, . \, T_1}{\Sigma bt^3} \qquad \text{(Föppl)}$$

where : θ denotes angle of twist,
M_t ,, twisting moment,
ϕ ,, polar moment of area,
G ,, rigidity modulus for the material,
μ ,, a value varying between 1 and 1·3, depending on the form of section varying from L to I,
f_s ,, maximum shear stress,
b ,, breadth of an element of the section,
t ,, thickness of an element of the section,
and T_1 ,, greatest thickness of an element of the section.

For riveted construction, ϕ is 0·36 to 0·5 of the value for the equivalent solid section.

The bottom portion of the centre cross-girder was, however, treated as separate strips subjected to bending in " S " curvature.

Results were checked by loading actual members after fabrication.

The flooring is disposed in a plane through the centre of the main girders. Bearings and cross-girder connexions lie in this same plane so that the flooring can serve effectively as lateral bracing, since twisting of spans produces on the flooring no distortion other than twisting of individual units about their own axes.

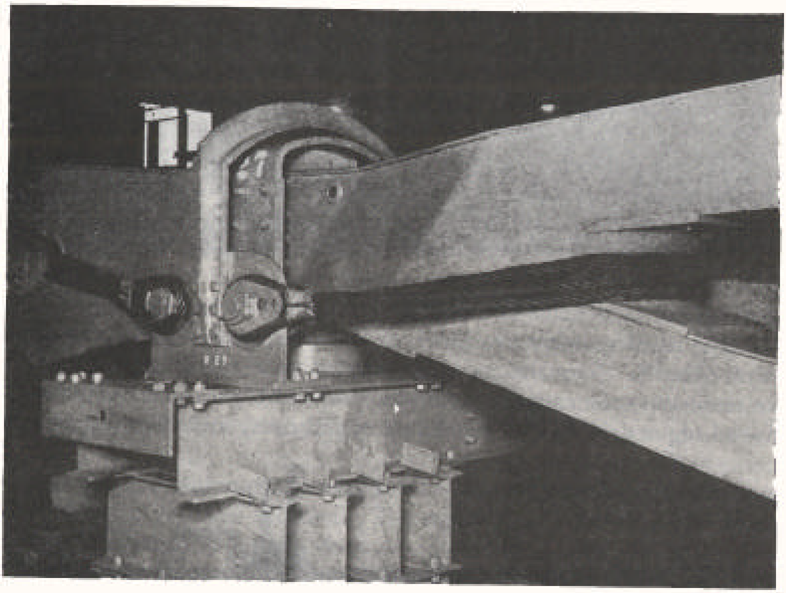
It is interesting to note that main girders do not remain straight when the span is twisted (*Fig. 3*, facing p. 391), but lie in two segmental curves under forces applied laterally by the end pairs of cross-girders. Stress considerations thus limit the width of top chords. It was, however, assumed that under maximum twisting conditions the bridge would not be loaded but would naturally have to survive for immediate use when weather moderated.

The telescopic span, shown in Figs 4, Plate 2, utilizes all the features incorporated in the standard spans. The special provision which allows a change in length when in position and, if necessary, under load, is achieved by arranging the main girders in two sections, one of which can slide within the other. The sliding joint is made at mid-span and bending-moment forces are carried by two hardwood bearings in each girder, 10 feet apart. The bearing housings are formed in the outer girder section and can be considered as fixed, whilst the inner girder section makes a simple sliding contact with greased surfaces.

The very fine limits of accuracy that are obtainable by welded fabrication are emphasized in this design which uses a black finish throughout and no machining other than for normal plate-edge preparation.

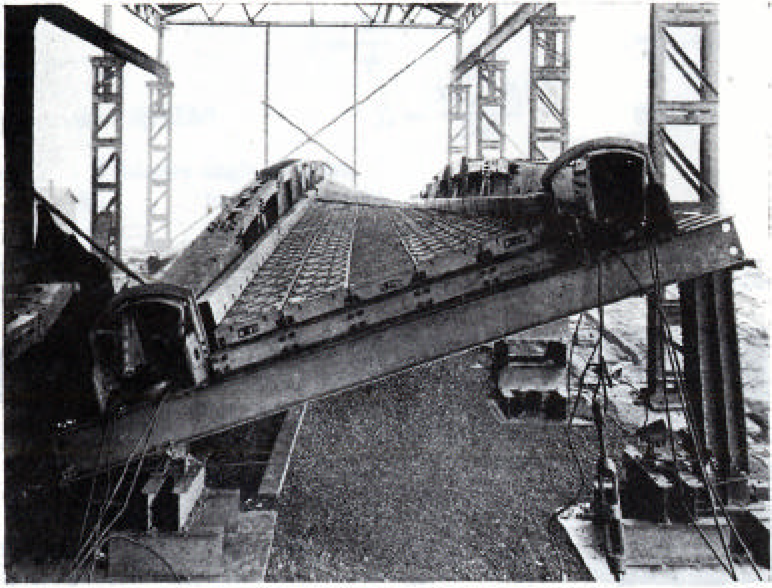
For the telescopic spans carrying the heavier Class 40 loading, the

Fig. 2.



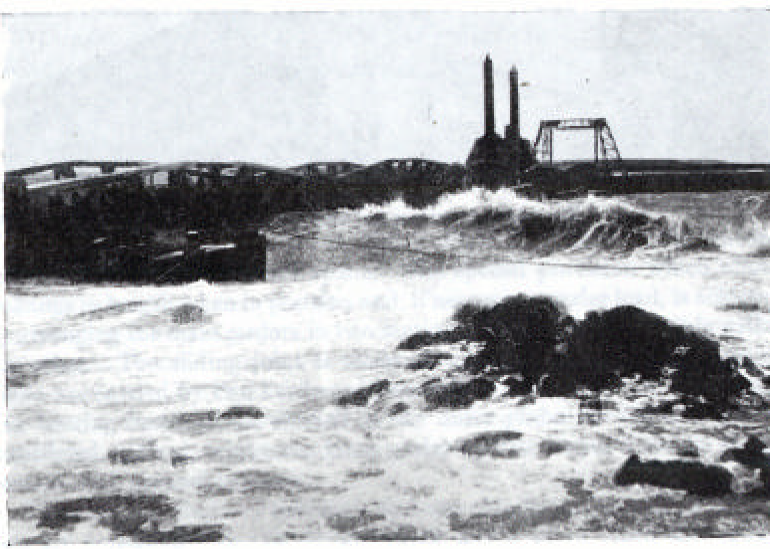
The Arrangement at the Bearings.

Fig. 3.



Telescopic Bridge Span on Test.

Fig. 5.



Sea Test under Storm Conditions.

sliding bearings are formed of bronze blocks working in spherical seatings. The flooring joint incorporates a sliding leaf designed to allow rapid fabrication and give the minimum " bump " to passing vehicles.

The telescopic spans have a 9-foot range of movement, from 71 feet to 80 feet. Their weight is 2 tons in excess of that of the standard span. Considerable ingenuity was exercised in design to keep this increase of weight to a minimum since it penalized float capacity and reduced the factor of safety (if any) of the pontoon bridge as a whole. For purposes of towing, the telescopic spans are provided with a simple locking device which fixes their length at 71 feet.

To allow a " spread " production system the spans were jig-made in components not exceeding 1 ton in weight. Tolerances in the order of $\pm \frac{1}{64}$ inch were achieved, and phased deliveries were arranged to each of two assembly depots.

PONTOONS.

In describing the design of pontoons some of the requirements must be emphasized. It was essential that they should be absolutely seaworthy and as nearly unsinkable as possible, also cheap to produce rapidly and in large numbers. They had to support, at a high level, moving " dead " loads and moving " live " loads considerably in excess of their own weight. In addition they had to impart the minimum of shock load to the bridge spans in rough sea conditions and to avoid overtwisting them (*Fig. 5* is typical of some of the conditions actually experienced). Finally it was required that they should be towed sideways without undue resistance and carry their loads when grounding in a surf on a beach which might be sand or rock.

A naval architect might be excused if he stated that the problem would not yield to a practical solution. The engineer, of course, simply has to produce his design by a given date.

Early trials were carried out using prototype bridge spans on converted Thames barges and abbreviated versions of concrete water barges. The steel Thames barges were the small 60-ton type with additional steel decking and bulkheads under the bearings which were set off-centre as described above. Those pontoons were used on the grounding section of the bridge and the bottoms were protected by timber baulks securely fastened under the bulkheads. The weight of each of the converted steel barges was 25 tons. The concrete pontoons used over the floating section of the bridge weighed 90 tons each and were provided with a central bearing position.

Prototype trials with this equipment were encouragingly satisfactory, but showed the need for many improvements, particularly with regard to pontoon design. In the first place, the question of towing a six-span length of bridge demanded that pontoons should be able to move sideways through the water with very much less resistance than the existing pontoons allowed.

Photographs and observations taken in bad weather showed that concrete pontoons pitched to angles well in excess of the wave slope and, owing to their central bearing position and great weight, hammered severely at the bridge spans, whilst the converted lighters, owing to their long length, imposed high forces due to rotational movement about a vertical axis.

Within the limits of cheap and rapid production, the pontoons (*Figs 6*) as used in the Mulberry Harbours satisfy all the requirements already outlined. They are approximately ellipsoidal in form, but modified to allow flat-plate construction, with a length of 42 feet, a breadth of 15 feet, and a depth of 8 feet. They are formed of six separate all-welded units bolted together through flanges. Each unit is of such a size that allows road or rail transportation, has been air tested for leaks and includes a manhole with airtight cover. Bulkheads under bridge bearings are heavily stiffened and extended 9 inches below the bottom to form bumpers which are shod with hardwood. Construction is from $\frac{3}{16}$-inch plate framed up with flanged stiffeners $4\frac{1}{4}$ inches by $1\frac{3}{4}$ inches by $\frac{3}{16}$ inch, spaced 18 inches apart. The bottom plating is $\frac{1}{4}$ inch thick. Deck fittings include hand-railing, 9-inch built-in bollards, and combined fairleads and deck stoppers at each end. Between the bearings and the bulkhead projections above deck is a transom formed of three 15-inch by 16-inch R.S.J.'s which carry the flooring connexions and form a springy medium to damp out small movements between pontoon and bridge spans.

The pontoons weigh 16 tons each, complete, and were found to be satisfactory in every way. They showed an excellent "dead beat" pitching action and gave a surprisingly small resistance to broadside towing. The behaviour of these pontoons in a surf was satisfactory and even when damaged in one or two compartments they would still carry the bridge spans. It was found that a tug of 1,000 horse-power would tow a six-span length of pontoon bridge at a speed of 6 knots.

An acute shortage of steel plate, however, made it impossible to provide steel pontoons for more than one half of the bridge spans, so that it was necessary to supply concrete pontoons[1] for the sections of the pontoon bridges which remained afloat at all states of the tide. They were generally of the same form with an increased weight and draught.

TRIALS.

Early trials with the equipment were carried out on a fairly exposed coast in the west of Scotland and no breakwater protection was provided. A six-span pontoon bridge was installed and remained in position for about 2 years, being used largely for the training of personnel who would be subsequently engaged in the erection of the Mulberry Harbours. Early

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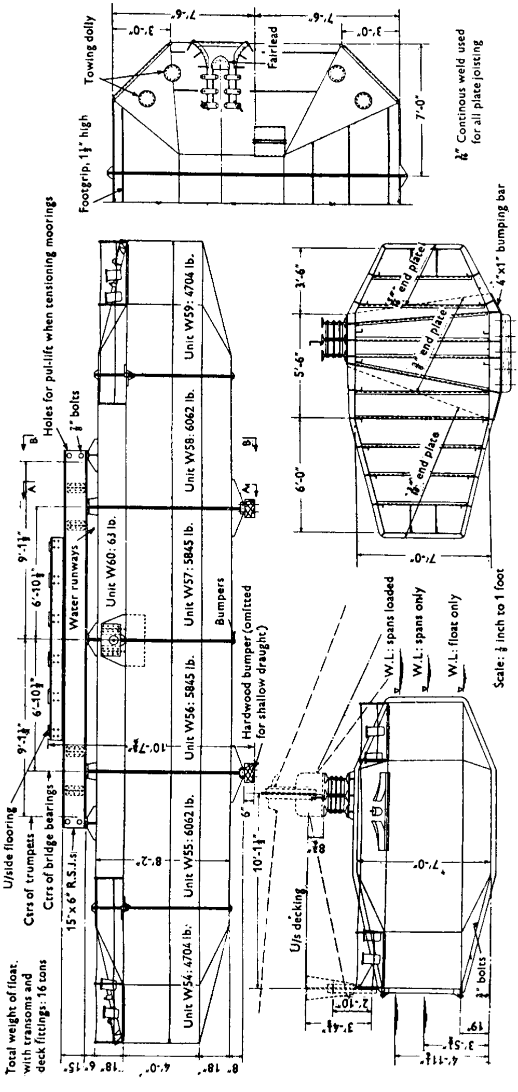
[1] C. R. J. Wood, "Reinforced-Concrete Pier Pontoons and Intermediate Pierhead Pontoons," p. 401.

Figs 6.



STEEL PONTOON FOR WHALE FLOATING BRIDGE.

exercises showed the need for a rapid method of coupling one bridge section to the next, together with a system of laying moorings quickly in shallow water without the use of special mooring vessels.

Couplings and Connexions.

The method finally evolved for coupling spans has proved entirely successful. Since every pontoon supports the end reactions of two adjacent spans it is obviously necessary to provide an additional support for one of the span ends at a junction. For this purpose an erection tank (see Figs 7, Plate 3) is provided which simply carries one end of a span at something above its normal level and at a position about 15 feet from the bearing. The erection tank is cylindrical, 8 feet in diameter and 36 feet long, of all-welded steel construction and divided internally into four compartments. Water inlets are provided in the bottom of these compartments, controlled by 12-inch sluice valves, and air outlet cocks are fitted to each compartment at the top. When towing, this erection tank forms part of the support for the rear span. The operation of coupling is simple. Using tugs, the length of pontoon bridge (usually six spans) is brought into line with the section of bridge already established. The end span bearings are located in their correct position by means of hinged trumpet shaped guides carried on the last span of bridge section already moored. The valves in the erection tank are now opened and the bridge end sinks into position with a short pause at a convenient level when cable springs are attached. The erection tank is now released and taken away. Using an erection tank at each side of a pontoon, it is a simple matter by blowing in compressed air to de-water the erection tanks and thus take the weight off the pontoon. By this method damaged pontoons were replaced without stopping traffic on the bridge.

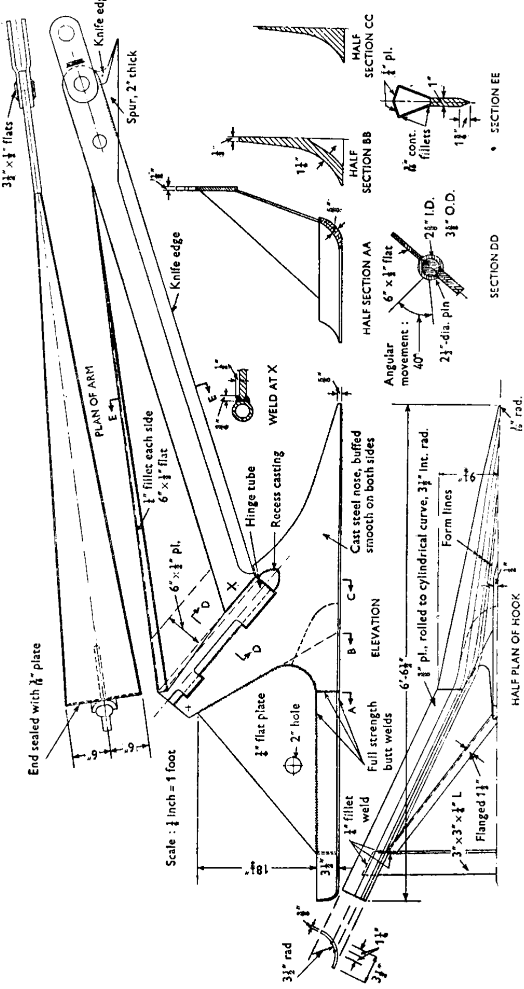
Erection tanks were also used to position telescopic spans between pier head units, in which case the spans were carried entirely on those tanks.

Mooring.

The mooring of pontoons introduced some novel features. In the first place it was necessary to maintain the pontoons in position within a range of movement of about 6 inches, irrespective of wave action and rise and fall of tide. A bridge in which pontoons could move independently transverse to the roadway would be quite unusable by wheeled vehicles in anything but the calmest weather.

The problem was solved by using very long cables (14 times the water-depth in length) set up taut with a tension varying from 5 tons at low water to about 12 tons at high water. Wave forces, etc., could increase those loads up to about 25 tons, which in itself set a fairly severe anchorage problem. Considerations of easy handling dictated a small factor of safety

Figs 8.



KITE ANCHOR.

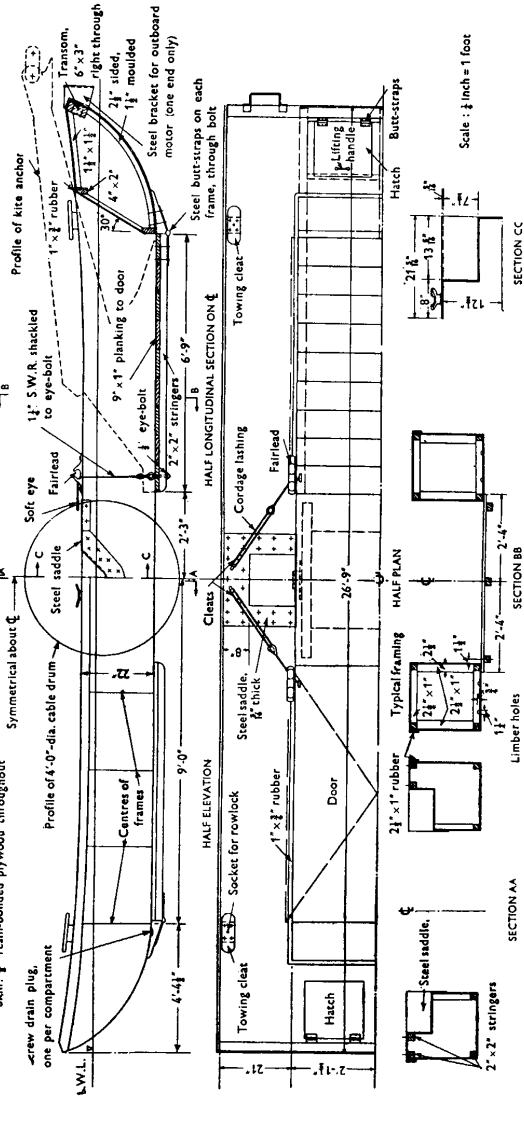
and as a compromise the mooring wires supplied were 3½-inch 6/18-construction 100/110-ton galvanized S.W.R.

With regard to the anchors it was found that all existing types for such loads were far too heavy and unwieldy, and a special design was prepared for an anchor which could be dropped in the normal way and which would burrow below the surface with increased load. Considerable trial and error was necessary and tests were carried out in the works of Messrs. Braithwaite and Co., of West Bromwich, who helped with so much of the development work. Ultimately a successful anchor weighing 6 cwt. was produced, which was capable of holding, in reasonable ground, loads up to 30 tons. This item of equipment is referred to as the " Kite " anchor and is illustrated in *Figs 8*.

The anchors are laid by means of a small craft of plywood construction called a " mooring shuttle " (*Figs 9*). It consists essentially of two floats well compartmented and braced, about 3 feet apart. At the centre is carried a drum with 1,200 feet of mooring wire. Towards each end is carried an anchor mounted on a hinged flap. These flaps are secured by means of manilla lashings which, when cut, allow the anchor to fall through the bottom of the craft. For cross-Channel towing, the shuttles, each complete with two kite anchors and one drum of S.W.R., were carried on the decks of the pontoon bridge sections. The drum is arranged to project below the bottom of the shuttles and serve as a wheel. To launch the shuttle complete it was simply pushed down a temporary ramp arranged from the end spans.

The mooring shuttles have no means of propulsion, but are towed by special shallow-draft twin-screw launches, shown in *Figs 10*. These launches pick up the shuttles after launching, tow them to the upstream anchor position and, after attaching the cable, drop one anchor. The launch towing the shuttle then makes its way downstream towards the bridge, automatically veering off cable as it proceeds. Arriving at the bridge the launch does not halt but passes underneath and continues until all the cable is veered, when, after connecting up, the second anchor is cast. The method of picking up the cable at the bridge is simply to lower a bight of wire over which the launch and shuttle pass in their mooring-laying journey. Hauling on this wire brings the mooring to the surface, whence it is transferred to the deck stoppers on the pontoon. The wires are tensioned by means of Yale pul-lifts and loose stoppers which can be attached to the mooring wire at any convenient place. This system eliminates the considerable expense which would be involved in fitting all pontoons with winches. The towing launches, which were used as general utility boats for erection, are of interest. Developed with the generous co-operation of Messrs. Camper & Nicholson, the leading yacht-builders, they combine the function of towing launch and general personnel ferry. They are robustly constructed of plywood, flat-bottomed, but surprisingly sea-worthy, with a beam of 8 feet, a draft of 2 feet, and a length of 20 feet.

Figs 9.

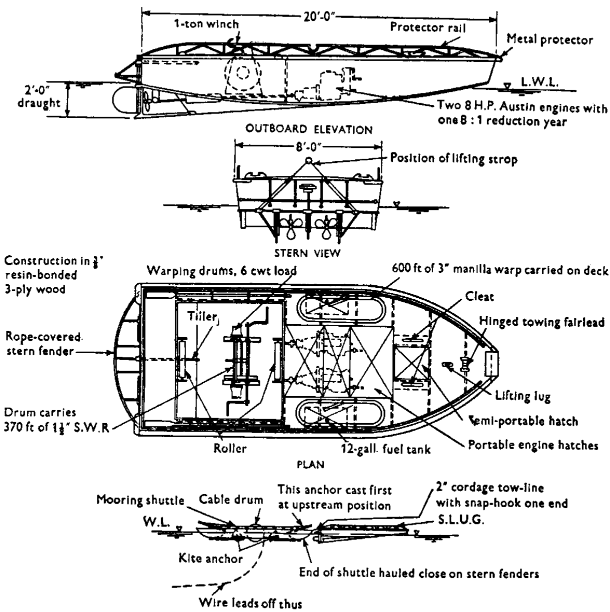


MOORING SHUTTLE.

Steel rails are provided along the gunwales for protection of the crew when passing under the bridge spans in choppy water. Some of these craft carry winches for kedging, some compressors for de-watering erection tanks, and some carry pumps to assist in mending pontoon leaks without beaching, etc.

Mention should be made of the means of connecting the pontoon bridge to the shore. This is done by means of a special wedge-shaped

Figs 10.



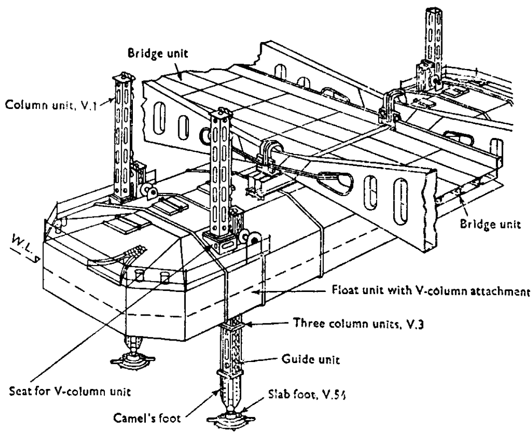
S.L.U.G. Boat used for Towing Mooring Shuttle.

float of exceptionally light construction and shallow draft (only 6 inches) at the inshore ends. Figs 11, Plate 4, show this unit, which is 80 feet long and constructed of $\frac{3}{16}$-inch and $\frac{1}{4}$-inch plate in four separate all-welded units, each 80 feet long and black-bolted together. In each unit a sluice valve is provided so that once in position the float can be scuttled. The seaward end of this " shore ramp float " carries the end of the first bridge span.

GROUNDING.

It remains only to describe the method by which the pontoon bridge can be allowed to ground on rock. First, it must be appreciated that there is some measure of choice with regard to the weather for towing and establishment of the bridge in position. Once moored and in use, however, the structure must withstand whatever weather comes along. It is certainly an experience never to be forgotton to witness the pontoons in the lee-shore surf of a summer gale pounding on a rocky bottom while craft all around drift out of control and smash themselves into heaps of tangled and twisted wreckage. But perhaps the methods used were somewhat deceptive, for although the pontoons pounded on the bottom it was arranged that no contact should be made with any sharp rocks.

Fig. 12.



PONTOON FOR GROUNDING ON ROCK.

For the section of bridge to be grounded over rock the pontoons are provided with two extra sections incorporating slots through which four legs can be operated. A simple handwheel locking device built into these extra sections allows the legs to be secured in any of a series of positions whilst a screw-adjusting " camel's foot " allows accurate intermediate adjustment. For towing, the legs are housed in their uppermost position. Immediately after the pontoon bridge is moored, the legs are lowered to the bottom and locked so that on the falling tide the pontoons and bridge spans are supported well clear of the sea bed. Using compressor tools, all sharp points of rock are dressed off immediately under the pontoons and sandbag beds are laid as required. On the next high water, and certainly before bad weather arrives, the legs must be raised to their uppermost position after which the pontoons ground on a nice soft prepared bed. The arrangement of pontoons for grounding on rock is shown in *Figs 12.*

CONCLUSION.

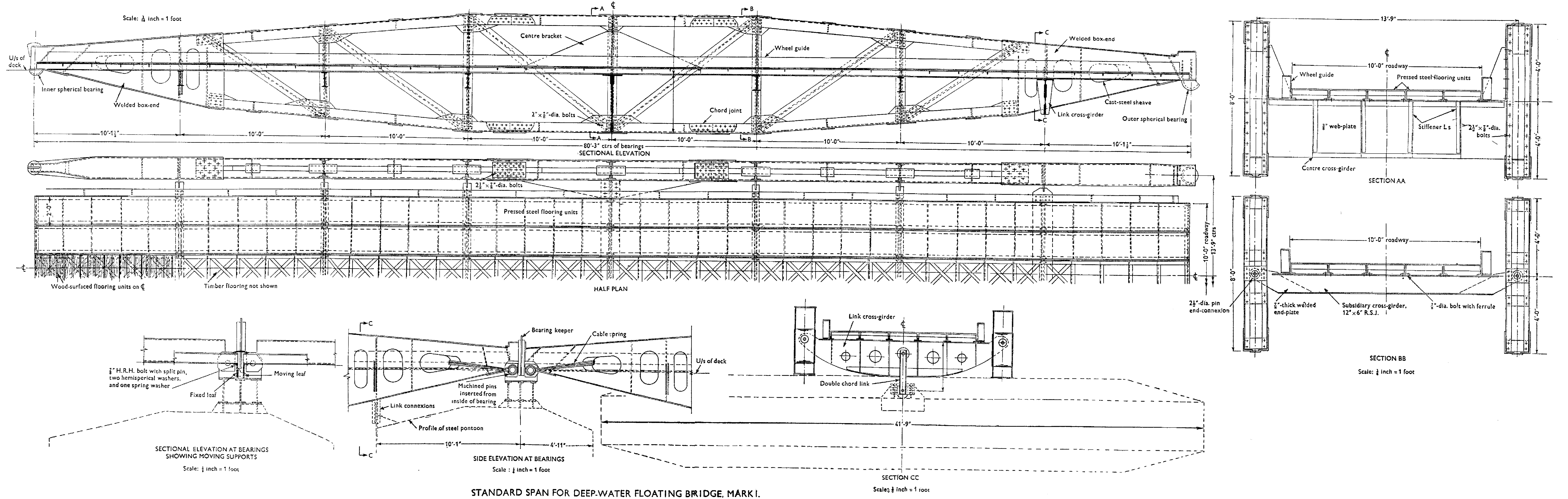
This is by no means a complete story of "Whale" bridging, for the training of personnel, Ministry of Supply problems and production with all its triumphs over seemingly impossible difficulties, the assembly in the R.E. depots at Marchwood and Richborough (where bridge spans were built at the rate of 12 per day), the towing of new sea monsters, and finally, the coupling and mooring under fire on enemy shores, each would make good subject matter for a book.

It must suffice, in this Paper, to put on record some of the design problems involved with notes on the solutions adopted, for the experience gained is probably valuable beyond the cost of the development work.

The Paper is accompanied by two photographs and nine sheets of drawings, from which the half-tone page plates, Plates 1, 2, 3, and 4, and the Figures in the text have been prepared.

SOME ASPECTS OF THE DESIGN OF FLEXIBLE BRIDGING, INCLUDING "WHALE" FLOATING ROADWAYS

FIGS. 1



STANDARD SPAN FOR DEEP-WATER FLOATING BRIDGE, MARK I.

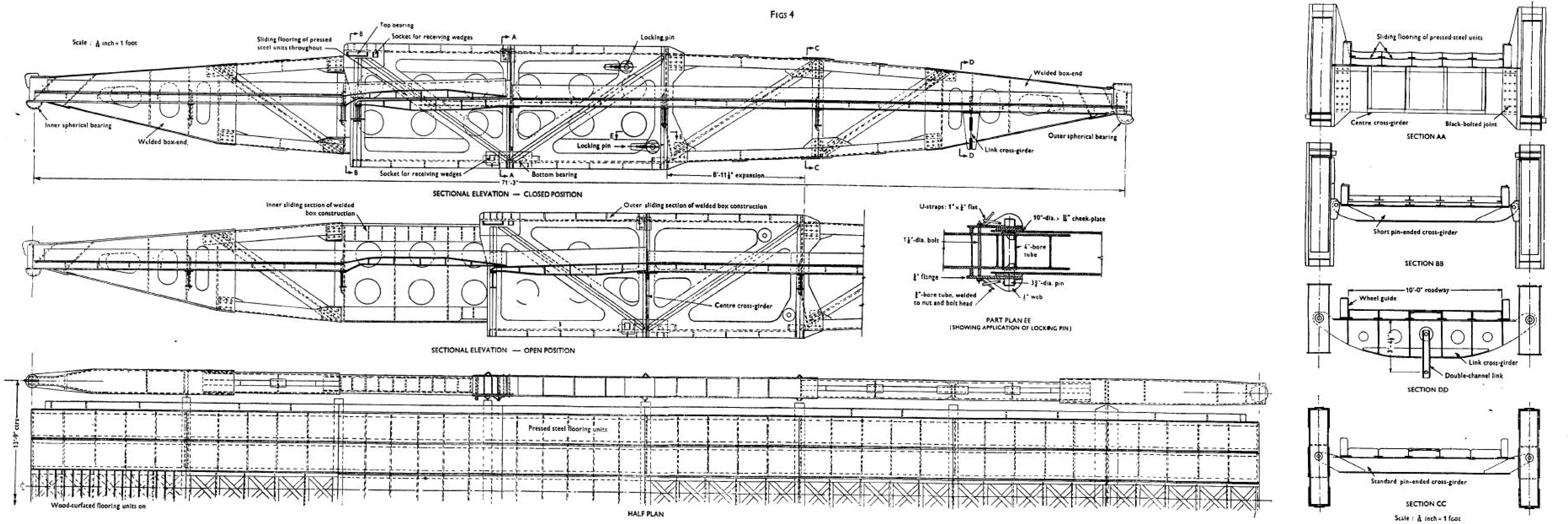
William Clowes & Sons, Limited: London.

A. H. BECKETT

PLATE 2.
FLEXIBLE BRIDGING.

SOME ASPECTS OF THE DESIGN OF FLEXIBLE BRIDGING, INCLUDING "WHALE" FLOATING ROADWAYS.

Figs 4



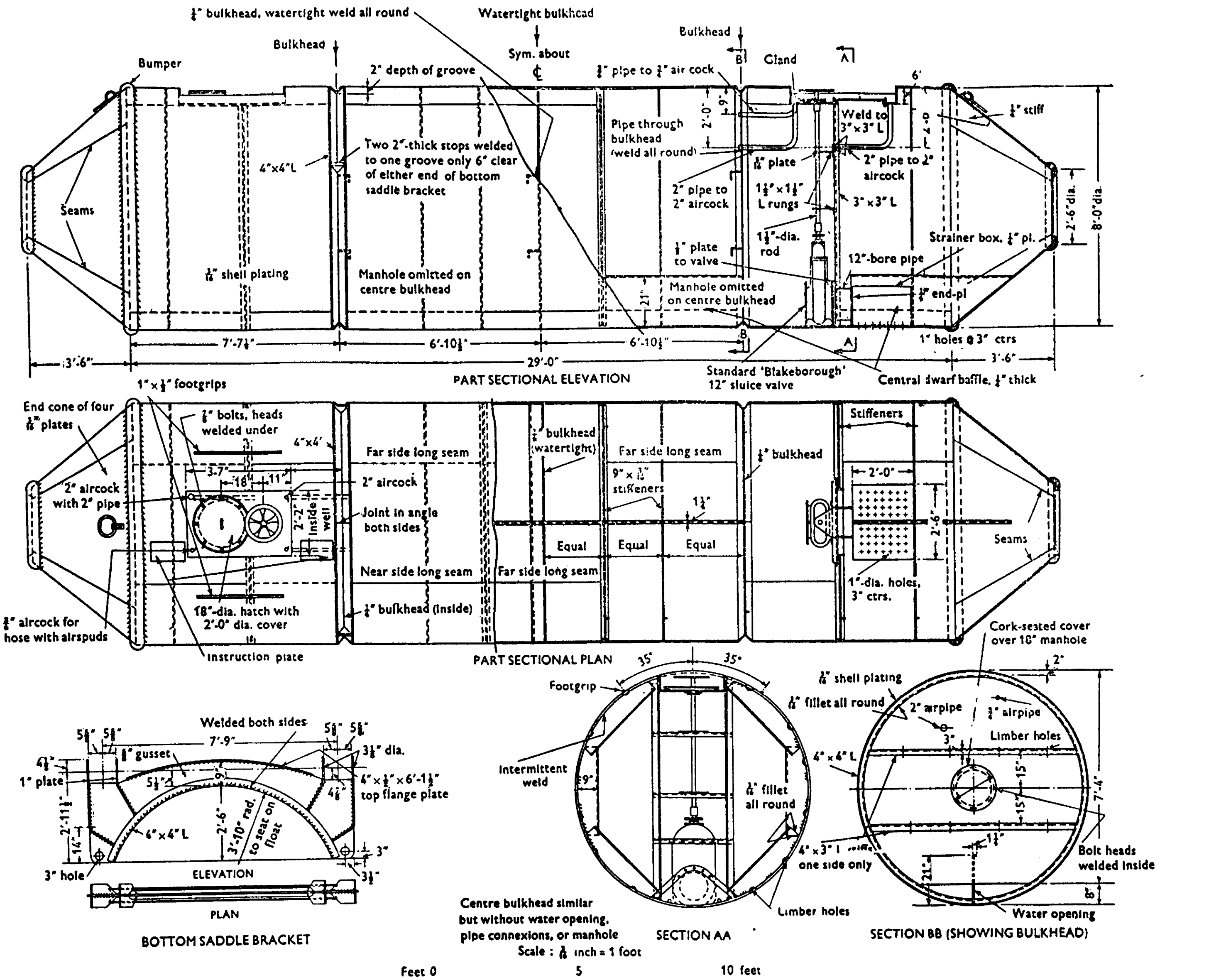
TELESCOPIC SPAN FOR DEEPWATER FLOATING BRIDGE

A. H. BECKETT

The Institution of Civil Engineers. Symposium of Papers on War-time Engineering Problems, 1948.

William Clowes & Sons, Limited : London.

FIG: 7



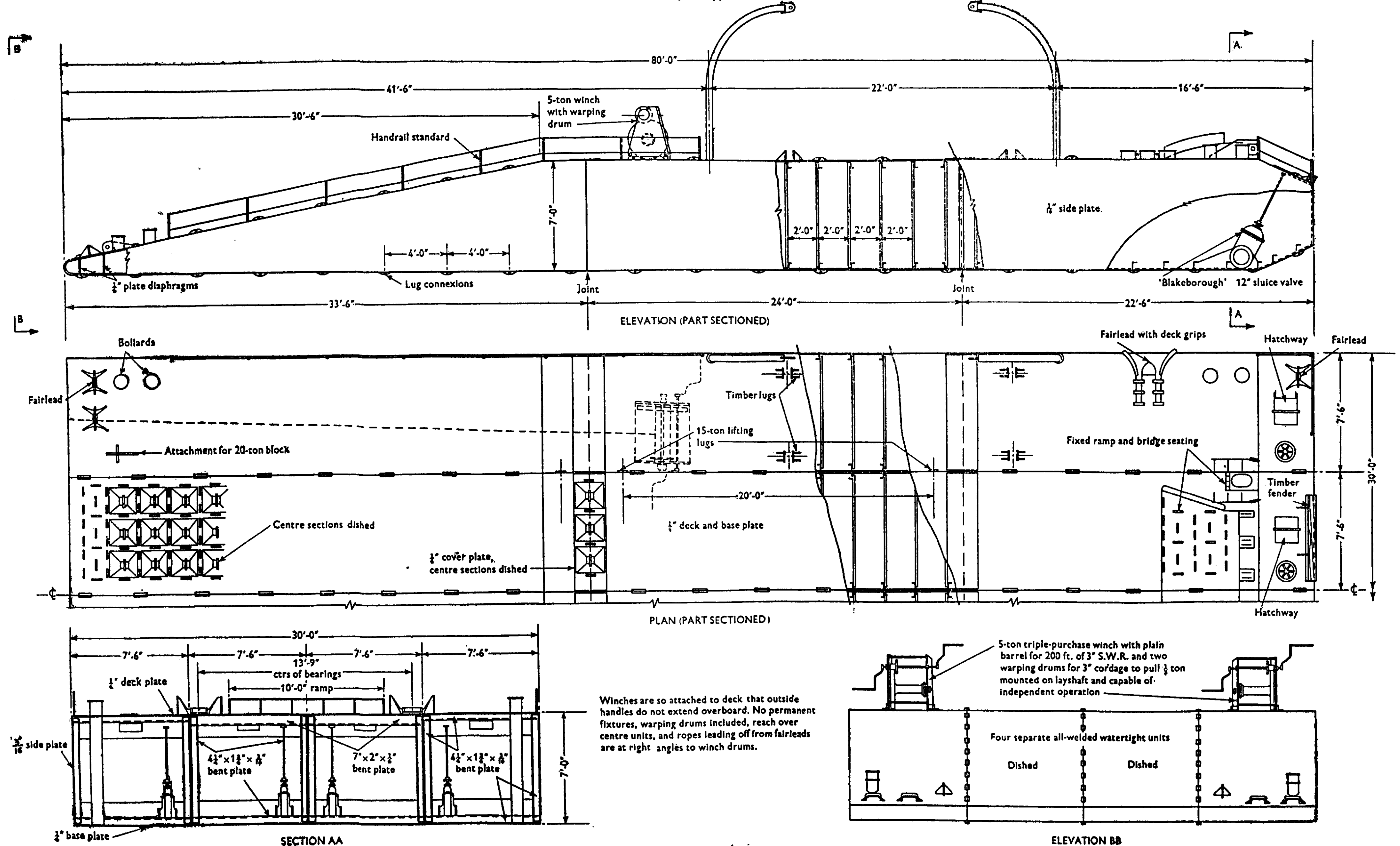
Scale : $\frac{3}{16}$ inch = 1 foot

ERECTION TANK FOR DEEP-WATER FLOATING BRIDGE

A. H. BECKETT.

THE DESIGN OF FLEXIBLE BRIDGING.

Figs 11



GENERAL ARRANGEMENT OF 80'-0 SHORE RAMP FLOAT

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