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Autor: Baxter, J.W. / Birkett, E.M. / Gifford, E.W.H.

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The Narrows Bridge Over the Swan River, Perth, Western Australia

Le pont des «Narrows», Perth, Australie occidentale

Die Narrows-Brücke über den Schwan-Fluß, Perth, West-Australien

J. W. BAXTER
B. Sc., M.I.C.E.

E. M. BIRKETT
B. Sc., A.M.I.C.E., A.M.I.E. (Aust.),
Partners — G. Maunsell and Partners —
Consulting Engineers

E. W. H. GIFFORD
B. Sc., M.I.C.E. Senior Partner —
E. W. H. Gifford and Partners —
Consulting Engineers

The City of Perth, Western Australia, lies in a delightful situation on the North bank of the Swan River estuary. Suburban development has also taken place on the South bank of the river; communication had mainly depended on a ferry, but eventually a new bridge became essential for the proper development of the city. The site chosen was Mill Point, opposite the beautiful Kings Park, a prominent hill covered with mainly natural bush. The scheme for a new bridge here also envisaged the extension by filling of the banks on both sides and consequent narrowing of the river passage, and offered great possibilities for a bridge worthy of its beautiful setting (Fig. 1).

The consulting engineers were G. Maunsell & Partners; the design consultant for the deck structure was E. W. H. Gifford of Southampton; the consulting architects were William Holford & Partners. The general contractors were Christiani & Nielsen of Copenhagen in association with J. O. Clough & Son Pty. Ltd. of Perth.

The Government of Western Australia had originally proposed a crossing having a skew of about 30°. The Consulting Engineers, by means of adjustments to the shape of the filled approach banks, were able to avoid this skew completely, thus improving the appearance of the bridge and reducing its cost. They also obtained the Government's agreement to the use of B.S. 153 Highway Loading with a reduction factor of 80% instead of the Australian Standard. The latter is derived from the A.A.S.H.O. standard, in use in

North America, which is a somewhat arbitrary loading not dependent upon span, whereas the British Standard is a more logical interpretation of probable actual conditions and can be applied in proportion to local requirements. The design was also checked for a special vehicle weighing 75 tons.

The records of the borings show a layer of soft organic mud between 50 and 80 ft. thick overlying sands and clays which extend down to limestone bedrock 120 to 130 ft. below datum. The lower strata above bedrock provided a reliable founding layer and all the bridge piles reached their set in this stratum.

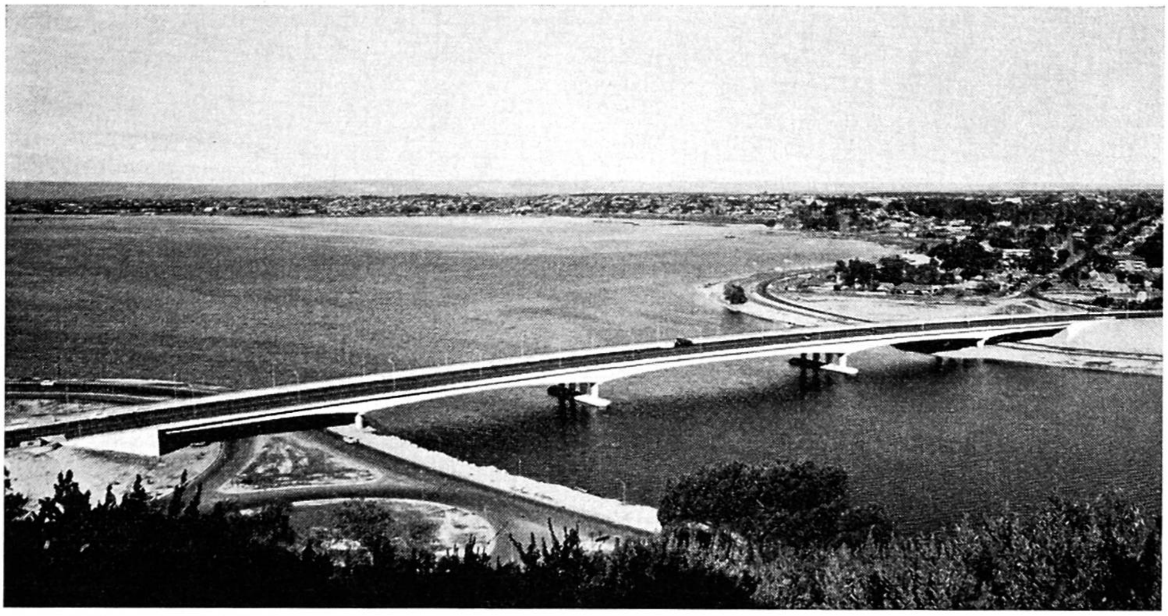

Fig. 1. View of Bridge.

It was necessary to provide for a six lane carriageway 70 ft. between kerbs with 8 ft. paths separated from a carriageway by 2 ft. kerbs and fences, and for a number of services. No median strip is used, so that the bridge may be operated on a four/two lanes basis as necessary. Navigation requirements were a height under the central span of 26 ft. above mean water level for a width of 230 ft. Tidal range is small and current low.

Several alternative designs, including one in steel, were considered; but a prestressed concrete design having five spans — of 160, 230, 320, 230 and 160 ft. — total 1,100 ft. — was finally chosen. The bridge, of deck girders, was built on formwork, and is fully continuous under live load, Fig. 2. It is anchored at the North abutment, all expansion movement being provided for at the South abutment by means of rocker bearings and a carriageway Demag joint. The columns, which are of reinforced concrete strengthened by means of cast steel double cantilever pieces, are arranged to rock, with stainless steel bearing plates top and bottom; and possible transverse movement is allowed

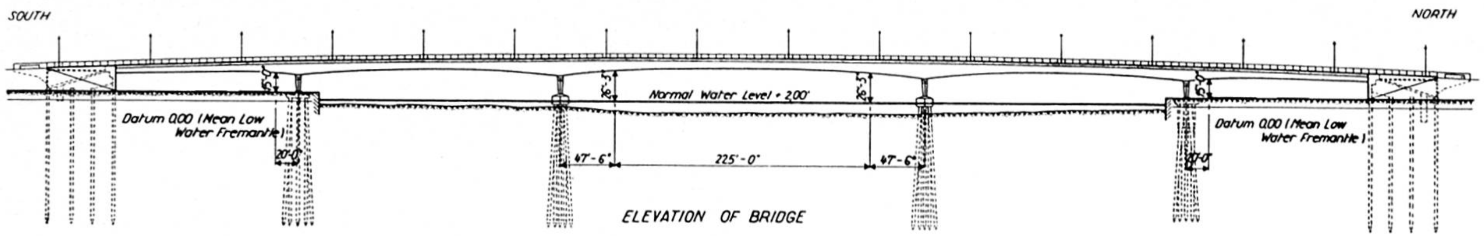

Fig. 2. Elevation.

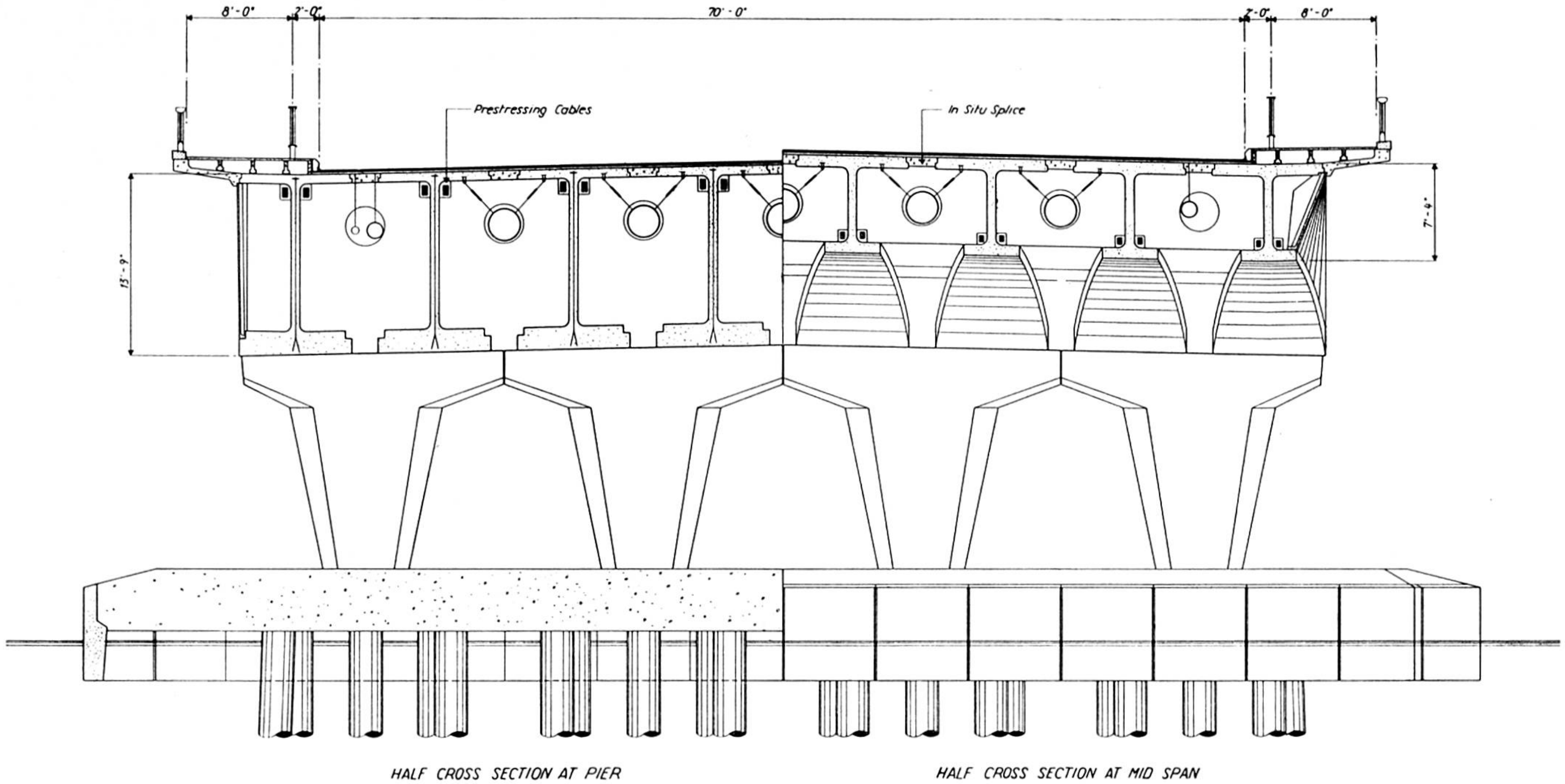

Fig. 3. Cross Section.

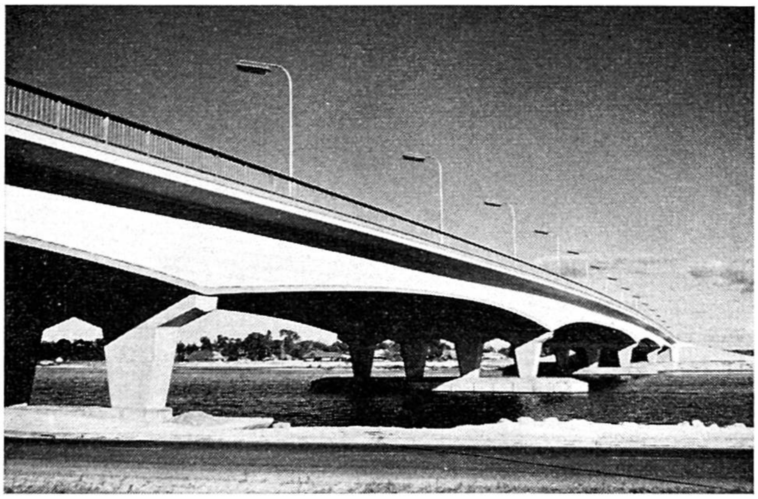

Fig. 4. Side View.

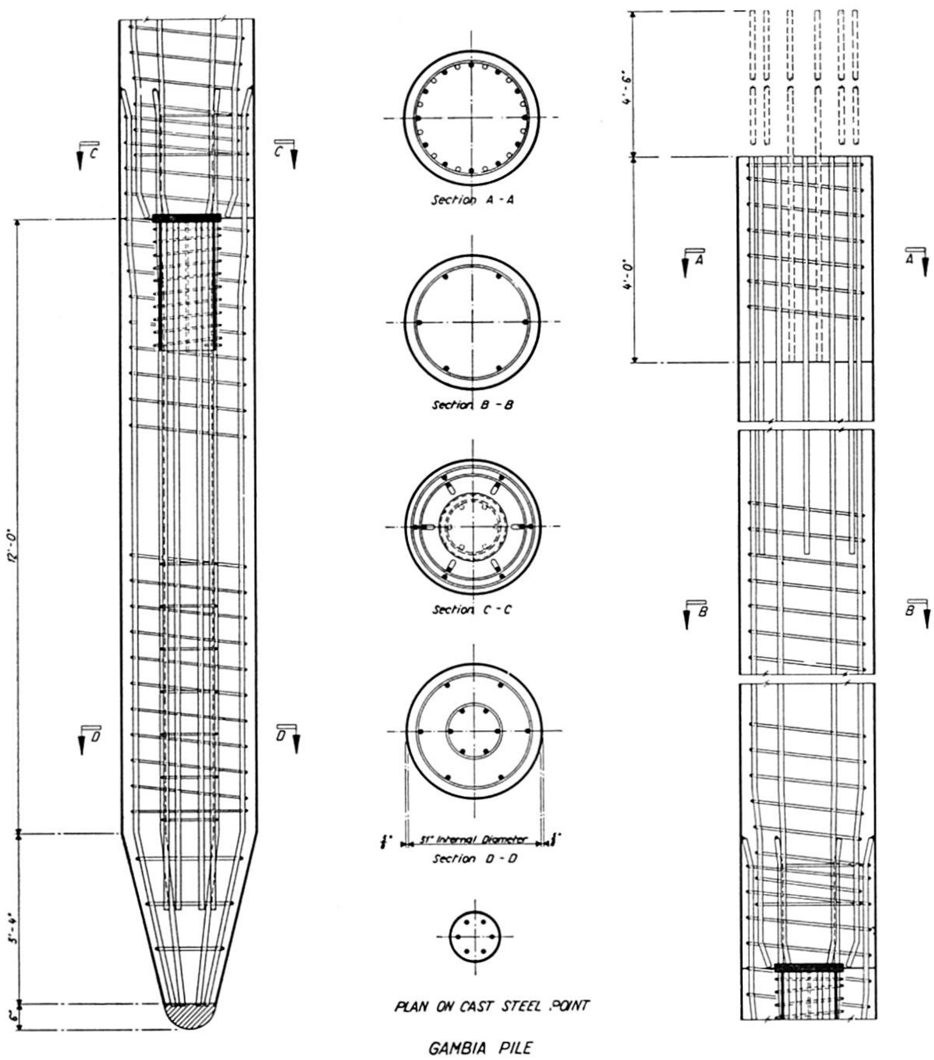

Fig. 5. Gambia Pile.

for by roller bearings. Bearing boxes are filled with "30 Equivalent Viscosity Temperature" tar to B.S. 76 type A or type B. The deck structure is of prestressed concrete, Fig. 3, and columns, piles and abutments of reinforced concrete; fences and lighting standards are of aluminium. The depth of filling material in the abutment is tapered from nil at the end of the bridge deck to the full height of the embankment at rear by means of a sloping slab.

Great care was taken over the appearance of the bridge; precast facing panels were used for the fascia beams, and for these and the footpath cantilevers white cement, white sand and crushed quartzite were used, Fig. 4. Similar materials were used for the abutments; all other concrete was made of normal Portland cement, river sand and crushed granodiorite to contrast with the white finish elsewhere.

Piling

The piles are of a type known as Gambia, Fig. 5. They consist of steel tubes of 31 in. inside diameter with conical steel points; the lowest 15 ft. of their length is filled with reinforced concrete. Driving was by a 10 or 12 ton cylindrical drop hammer on a coir packed anvil embedded in the top of this 15 ft. of reinforced concrete and the tube was lengthened as necessary during driving by welding on further lengths of tube. Hammer drops were limited to 4 ft. and were varied in proportion to the ease of driving. Finally cages or reinforcement were introduced and the pile filled with concrete. The lengths of the piles varied between 90 and 125 ft. Test piles were loaded to 400 tons but working loads do not exceed 250 tons.

The upper part of each pile was strengthened by the addition of extra reinforcement to cater for the bending moments to which this part of the pile was subject. The strength of the steel tube was ignored in design so that the structure would not be vulnerable to corrosion.

North Shore Problem

Prior to the letting of the Contract an extensive reclamation scheme was begun by pumping sand from the river bed, and this continued throughout the job. It was intended that this sand should replace the mud and that the North shore should ultimately consist of sand only down to the firm lower strata.

This was in fact generally achieved; but movement of temporary piles showed that a wedge of mud had been trapped near the North shore pier. To prevent future slips the area near the bridge was loaded temporarily with spoil while the approach banks were being built, and during this time many piles were driven. There was also considerable danger of sideways movement; and to meet this the local piles were specially designed. The lower part was

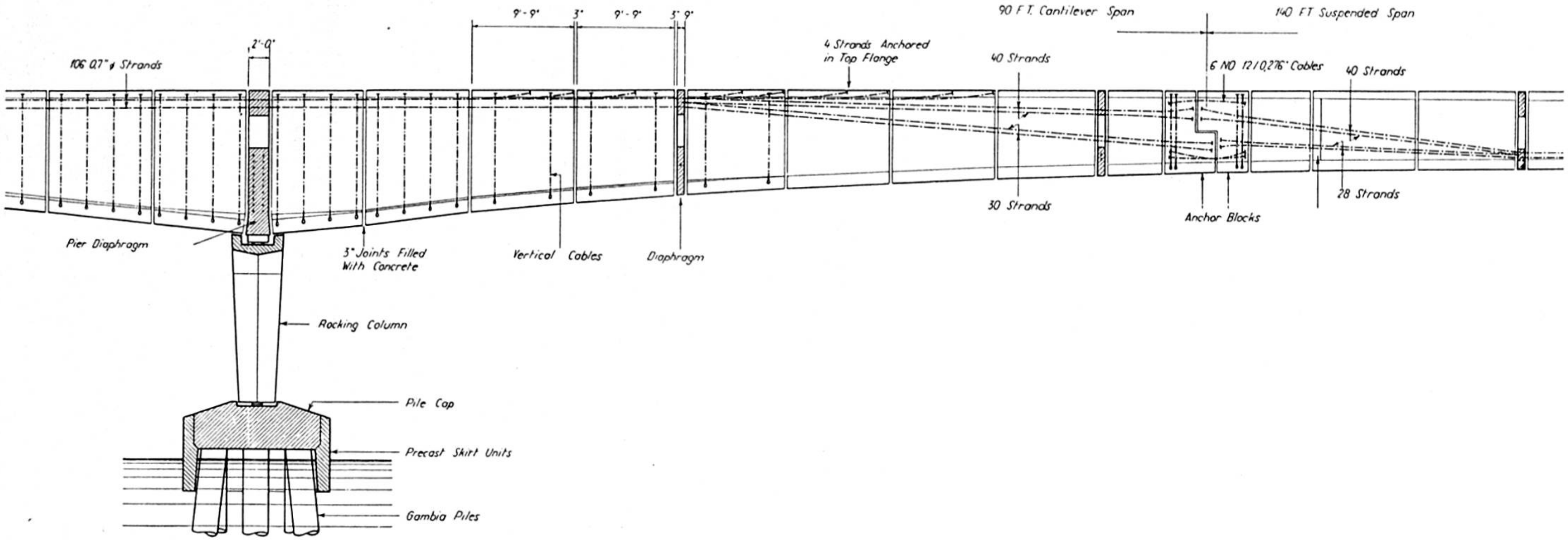

Fig. 6. Sectional Elevation of Main. Beam at River Pier.

standard; but the upper tube was swaged out in two stages to 37 and 42 inches diameter. The upper part of the pile column was precast and set in position touching the South side of the tube. By this means there was sufficient tolerance to allow for considerable movement of the soil and the tube without affecting the pile itself.

Deck Structure

The structural depths at certain points were limited by the necessary clearance gradients and road levels; within these limits span lengths and proportions were so chosen as to present the best appearance. The main beams were designed for self weight as a system of double cantilevers and suspended spans. A more satisfactory dead load bending moment distribution could be obtained in this way, with a shallower mid-span construction depth, than could have been achieved had the design been on the basis of simple continuity. The bridge was made continuous for live load by clamping together the anchorage blocks of the temporary hinges with short cables (Fig. 6).

The search for strength weight efficiency led to the evolution of exceptionally thin I beam sections, which are a particular feature of the structure. As the thicknesses of web and flanges are reduced this efficiency rises, but it was thought desirable to impose a minimum thickness of 8″. The beams were precast in 10 ft. long segments (Fig. 7) with separate diaphragms and anchor blocks.

It was not possible to accommodate within this thin section a cable big enough to carry the very large prestressing force, which was of the order of 2120 tons per beam. Internal ducts lead to the distortion of such a section and this greatly reduces efficiency. External cables were used chiefly to obviate this, though simpler casting and low cable friction were other reasons for their adoption.

In spite of the relief in shear force resulting from the slope of the bottom flange of the beam the thin webs needed vertical prestressing near the piers; and the vertical cables could be placed in ducts without difficulty because of the absence of internal main cables.

The problem of combined bending and shear at the piers was by no means an easy one. Elastic analysis was simple, because the vertical prestressing component could be adjusted sufficiently to keep the allowable principal tensile stress from shear below the chosen limit of 150 p.s.i. The principal tensile stress analysis of the whole section was, however, applicable to the elastic condition only, as the tensile cracks from bending which occur beyond the elastic range invalidated it. Since no published information on the ultimate behaviour of prestressed concrete beams subject to combined bending and shear appeared to exist, though many continuous and cantilever bridges had been built, a design procedure similar to that for normal reinforced con-

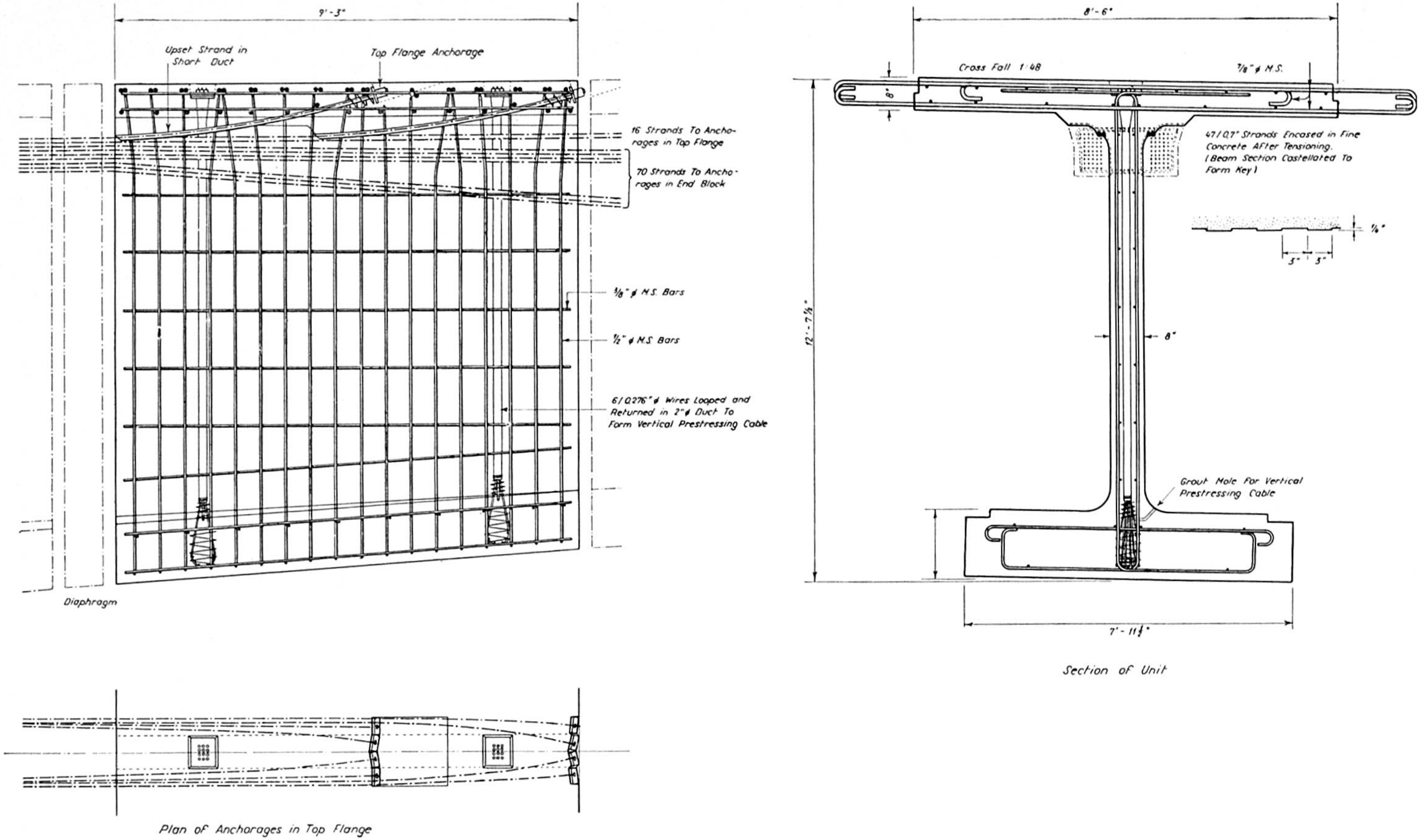

Fig. 7. Detail of Typical Beam Unit.

crete was used. A lattice system of compression in the concrete acting at an angle of 45°, and vertical tensile reinforcement, was assumed to act within the web. The vertical prestressing cables did not provide enough resistance at ultimate load, and they were therefore supplemented by normal mild steel stirrups. The net shear force acting on the beam was found by deducting from the total reaction the vertical components of the main cable force and the compression in the bottom flange resulting from the inclination of cables and flange to the beam axis.

It was decided to check design assumptions by testing a scale model, as little information appeared to exist on this subject. Such a test would also cover the validity of the assumptions made concerning bond in the main cable design. The model test not only showed that the assumptions made were on the safe side, but also that shear reinforcement was considerably overestimated, since when the beam failed by simple bending the stirrups appeared still to be working within the elastic range. The test also showed, however, that the adoption of the principal tensile stress analysis only would have led to premature shear failure.

Summary

The Narrows Bridge, the largest continuous prestressed precast bridge in the world, was completed in 1959. It was designed by British engineers using a type of pile and methods of prestressing and equipment developed in Great Britain. It has five spans of 160 ft., 230 ft., 320 ft., 230 ft., and 160 ft. giving an overall length of 1,100 ft. between abutments. It carries a six lane highway 70 ft. wide with footpaths on each side and joins the main part of the City of Perth to the extensive suburban development on the south bank of the Swan River which has hitherto been served by a single bridge, a considerable distance upstream.

Construction in prestressed concrete was decided upon after comparison between the prestressed concrete design and a second design in structural steel had shown that the bridge would be cheaper to build in prestressed concrete in the first place and would also cost less to maintain in the future.

Since the bridge occupies a prominent place in one of the country's beauty spots great attention was devoted to its appearance and British architects were engaged as consultants to ensure that the design would enhance the fine view provided by the City of Perth and its surrounding countryside.

The cost of the bridge was approximately £ 1,250,000 sterling.

Résumé

Le Pont des Narrows, le plus grand pont continu précontraint et préfabriqué du monde, a été terminé en 1959. Il a été conçu par des ingénieurs bri-

tanniques qui utilisèrent un genre de pieux, des procédés de précontrainte et du matériel développés en Grande-Bretagne. L'ouvrage comporte cinq travées de 49, 70, 98, 70 et de 49 mètres; la longueur totale est donc de 336 m entre culées. Le pont supporte une route à six voies large de 21,4 m, avec banquettes de chaque côté. Il réunit la partie principale de la ville de Perth à la banlieue en plein développement sur la rive sud de la rivière Swan; cette région était desservie auparavant par un seul pont, situé en amont à une distance appréciable.

On décida de construire l'ouvrage en béton précontraint après avoir fait une comparaison entre un projet en béton précontraint et un autre projet en acier, comparaison indiquant qu'il serait plus économique de construire le pont en béton précontraint et que l'entretien serait bien moins onéreux dans l'avenir.

Comme le pont occupe une place très en vue dans une des régions pittoresques du pays, on a apporté beaucoup de soin à son aspect et des architectes britanniques ont été engagés à titre de conseils afin de garantir que l'ouvrage rehausse le beau paysage que représente la ville de Perth et la campagne voisine.

Le coût du pont s'est élevé à environ £ 1 250 000 sterling.

Zusammenfassung

Der Bau der Narrows-Brücke, die z. Z. größte durchlaufende, vorfabrizierte Spannbetonbrücke der Welt, wurde 1959 vollendet.

Die für den Entwurf verantwortlichen britischen Ingenieure verwendeten Spannverfahren und Ausrüstungen sowie einen Pfahltyp, die in England entwickelt wurden. Die 5 Felder von 49, 70, 98, 70 und 49 m geben der Brücke eine Gesamtlänge von 336 m zwischen den Widerlagern. Die überführte Straße mit einem Gehweg auf jeder Seite hat 6 Fahrbahnen mit einer Gesamtbreite von 21,4 m und verbindet den Hauptteil der Stadt Perth mit den weitausgedehnten Vororten am Südufer des Swan-Flusses, die bis anhin nur eine weit flußaufwärts liegende Brücke zur Verfügung hatten.

Die Ausführung in Spannbeton wurde beschlossen, nachdem ein Vergleich zwischen dem Spannbetonentwurf und einer Ausführung in Stahl gezeigt hatte, daß für die Spannbetonlösung 1. die Baukosten niedriger waren und 2. mit weniger Unterhaltskosten für die Zukunft zu rechnen ist.

Da die Brücke einen wichtigen Platz in einer außerordentlich schönen Landschaft einnimmt, waren die ästhetischen Belange von großer Bedeutung, so daß man englische Architekten als Berater zuzog, um sicherzustellen, daß der Entwurf das schöne Bild der City von Perth und ihrer Umgebung noch verbessern würde.

Die Kosten der Brücke beliefen sich auf ca. £ 1,25 Millionen.