Sydney Harbour Bridge

Report
on
Tenders

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22406

SYDNEY HARBOUR BRIDGE.

REPORT ON TENDERS.

To the Under Secretary for Public Works.

In accordance with the instructions of the Minister for Public Works and Railways, I have the honor to report :—

1.—The Firms Tendering.

On 16th January, 1924, tenders were opened in the Minister's room, when each tender was initialled by the Minister and the Under Secretary for Public Works.

Six firms submitted twenty tenders, viz. :—

Sir Wm. Arrol & Co., Glasgow, in conjunction with Sir John Wolfe Barry & Co., London	Two tenders.
Dorman Long & Co., Middlesbrough and Sydney	Seven tenders.
Canadian Bridge Company, Walkerville, Ontario	Two tenders.
McClintic Marshall Products Company, New York	Five tenders.
English Electric Company of Australia Ltd., Sydney	Three tenders.
The Goninan Bridge Corporation, Newcastle	One tender.

The specification and plans issued by the Minister, as authorised by the Sydney Harbour Bridge Act of 1922, invited tenders for bridges of the cantilever and arch types in accordance with the official designs, but subject to certain variations allowed by the specification. Tenderers were not invited to submit independent designs, as has been frequently stated in the press.

Much has been said and written, wise and otherwise, about the superiority and economy of suspension bridges over all other types for the Sydney Harbour Bridge. On my advice as Chief Engineer, tenders were called for cantilever and arch bridges only; tenders, however, have been

submitted for suspension bridges, and I have given these tenders the same careful consideration as the tenders submitted for cantilever and arch bridges.

Fourteen of the sixteen tenders submitted by the first four firms above mentioned are in accordance with the specification and plans issued by the Minister as the basis of tendering, but the so-called "inverted arches" of the Canadian Bridge Company, and of the McClintic Marshall Products Company, are really suspension bridges designed in general conformity with the specification; but these tenders, however, do not come within the scope of the Sydney Harbour Bridge Act.

The three tenders of the English Electric Company of Australia, Limited, are for a suspension bridge with a continuous stiffening truss, whilst the tender of the Goninan Bridge Corporation of Newcastle is for a cantilever-suspension bridge, the centre span of which is really an independent suspension bridge hung from cantilever arms. The four tenders of the two last-mentioned firms do not come wholly within the scope of the specification or of the Sydney Harbour Bridge Act.

Associated with the English Electric Company of Australia are Dr. D. B. Steinman and Mr. H. P. Robinson, of New York city, both well known in engineering circles in America, whilst the Goninan Bridge Corporation of Newcastle is tendering in conjunction with the firm of Baume Marpent, of Haine St. Pierre, Belgium, also a firm of the highest repute as bridge fabricators and builders.

The English Electric Company of Australia have their main works at Clyde, modern shops well equipped for the manufacture of hydraulic, electric, and refrigerating machinery of the highest class, but this firm has not had experience in the fabrication of the class of bridgework required for the Sydney Harbour Bridge.

The Goninan Bridge Corporation have shops established at Newcastle carrying out general engineering fabrication and repairs as are required at a coal-mining and shipping centre.

Four out of the six firms tendering, viz., the McClintic Marshall Products Company, Sir Wm. Arrol & Co., the Canadian Bridge Company, and Dorman Long & Co., have shops established in other parts of the world, capable of, with little if any additional expense, fabricating a bridge of the magnitude of the Sydney Harbour Bridge, whilst the firm of Baume Marpent is an old-established firm of similar repute. These five firms rank among the foremost bridge fabricating establishments and contracting firms of the world.

Messrs. Dorman Long & Co., is also an Australian firm, having two well established structural steel fabricating shops in Australia—one at Sydney, the other at Melbourne—already constructing medium heavy steel structures, similar work to that required for the approach spans, cross-girders and decking of the Sydney Harbour Bridge.

The other three firms, Sir Wm. Arrol & Co., the McClintic Marshall Products Company, and the Canadian Bridge Company have as yet no Australian establishments or connections, but they all have made arrangements to fabricate portion of the steelwork locally, if any of them should be awarded the contract.

2.—Summary of Tenders.

The following summary gives the types of bridges, amounts of tender, the total tonnages of metalwork, the tonnages to be fabricated in New South Wales, the tonnages to be imported and the places of fabrication outside New South Wales, if imported. The tonnages do not include the gunmetal plates and castings for the portals or the steel rails for the railway tracks.

Firm.	Type of Bridge and Amount of Tender.					Fabricated Metalwork.			
	Arch.	Cantilever-Arch.	Cantilever.	Suspension.	Centilever-Suspension.	Total tonnage.	In N.S.W. Tons.	Imported.	
								Tonnage.	Country.
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.				
Mr. Bradfield's Estimate	4,339,530 0 0	.....	.....	.....	.....	*46,600	All.	Nil.	.....
Do do	.....	.....	4,704,840 0 0	.....	.....	†61,000	All.	Nil.	.....
Sir Wm. Arrol & Co.	.....	.....	4,978,488 7 8	.....	.....	57,653	13,495	44,158	Scotland.
Do	4,645,351 7 8	.....	.....	.....	.....	40,228	13,682	26,546	do.
Dorman Long & Co., A1	3,499,815 15 0	.....	.....	.....	.....	50,626	All.	Nil.	.....
Do A2	4,233,105 4 7	.....	.....	.....	.....	49,146	All.	Nil.	.....
Do A3	4,217,721 11 10	.....	.....	.....	.....	50,288	All.	Nil.	.....
Do B1	.....	3,709,686 2 6	.....	.....	.....	56,953	All.	Nil.	.....
Do B2	.....	3,941,728 6 3	.....	.....	.....	56,362	All.	Nil.	.....
Do C1	.....	.....	4,551,758 13 3	.....	.....	65,453	All.	Nil.	.....
Do C2	.....	.....	4,310,812 1 0	.....	.....	65,303	All.	Nil.	.....
Canadian Bridge Co....	.....	.....	5,313,404 9 4	.....	.....	38,064	4,230	33,834	Canada and U.S.A.
Do	.....	.....	.....	5,091,202 18 4	.....	38,015	5,400	32,615	do.
McClintic Marshall Products Co., A	.....	.....	6,499,377 0 0	.....	.....	50,283	13,000	37,283	U.S.A.
Do B	.....	.....	5,958,356 0 0	.....	.....	49,115	15,000	34,115	do.
Do C	.....	.....	5,654,531 10 0	.....	.....	50,191	17,000	33,191	do.
Do D	.....	.....	.....	6,047,547 0 0	.....	43,059	15,000	28,059	do.
Do E	6,053,565 0 0	.....	.....	.....	.....	45,854	12,000	33,854	do.
English Electric Co. of Australia ...	.....	.....	.....	5,609,125 2 1	.....	46,108	All.	Nil,	.....
Do ...	.....	.....	.....	4,943,763 0 5	.....	46,108	All.	Nil.	.....
Do ...	.....	.....	.....	5,109,333 12 11	.....	46,108	All.	Nil.	.....
Gonnian Bridge Corporation Ltd. ...	.....	.....	.....	.....	10,712,015 19 8	43,939	24,236	19,703	Belgium.

* Nickel steel 3·67 per cent. of tonnage. † Nickel steel 28·3 per cent. of tonnage

3.—A Review of the Tenders Submitted.

The Goninan Bridge Corporation Limited.

The tender of this firm, Plan No. 1, is for a bridge of the cantilever-suspension type. The tender provides for a length of bridge of 3,810 feet; the main bridge consists of cantilevers, the anchor arms of which are 560 feet long and the harbour or cantilever arms are each 280 feet long, supporting a central span of 1,040 feet, the distance centre to centre of main piers being 1,600 feet. The central span is a straight wire cable stiffened suspension bridge, the cables of which are connected directly to the top chords of the cantilever arms; these take the tension from the cables and transfer the loads to the main piers and the anchorages. On the cantilever arms, subsidiary trusses take the loading from the floor system and transfer this loading to the lower panel points of the cantilevers which panel points are 80 and 100 feet apart. The stiffening truss of the suspended span forms a continuation of the subsidiary truss system. There are three approach spans of 167 feet 5 inches centres of bearings on the city side and three approach spans on the northern side each 143 feet centres of bearings.

This type of cantilever-suspension bridge was originated by the Strauss Bascule Bridge Company of Chicago, U.S.A., but no bridge of the type has yet been built. Statically, this particular combination of two distinctly different types of structure does not improve on either. The suspension portion of the structure suffers all the disabilities and more of an ordinary suspension bridge with none of its advantages. It is stiffened by a two-hinged truss, only 29 feet deep, and is, therefore, liable to severe general and local deflections under the heavy railway loading, which, combined with the deflections of the cantilever arms, will, according to the tenderer's own calculations, produce a maximum vertical movement of 7 feet 3¼ inches. Compared with the corresponding deflections of a true cantilever bridge or an arch bridge as submitted for tenders, or with the stiffened suspension bridge submitted by the English Electric Company of Australia, this cantilever-suspension structure is much less rigid under live load and temperature.

The stresses and deformations have been thoroughly investigated and recorded, expansion joints, brakes, and traction girders and similar details have been well considered. All eyebars are of heat-treated carbon steel, and other truss members are built of silicon, carbon, or nickel steel, with the result that a bridge with a comparatively low tonnage of steelwork has been obtained but at the sacrifice of homogeneity and rigidity as well as appearance.

The appearance of the bridge does not commend itself; the wide open panel subdivision of the cantilever arms does not harmonise with the closely spaced hangers of the suspended span, whilst the long straight upper chords of the anchor arms, where they junction with the lower chords at the anchorage, form an inelegant apex; the anchors are not well proportioned and the appearance of the bridge as a whole is not pleasing.

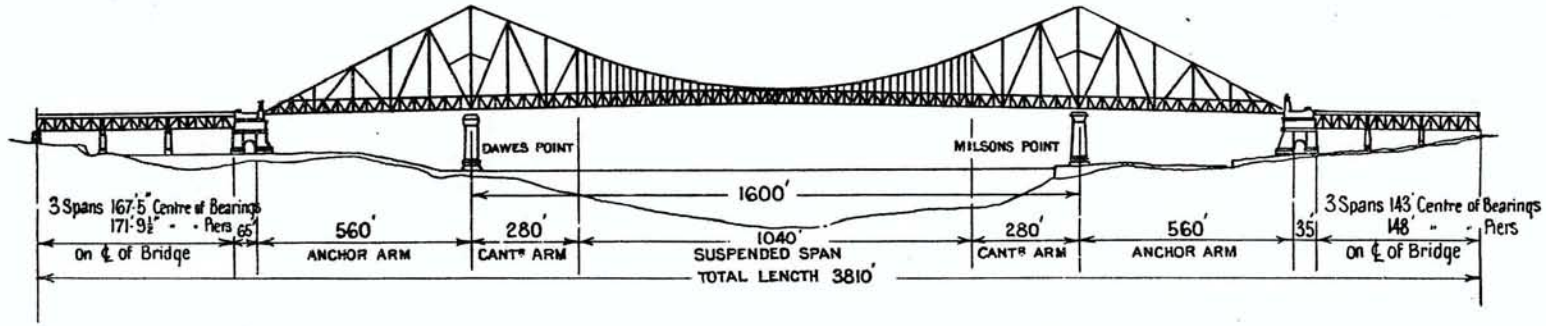
The tender is submitted in conjunction with Mr. J. B. Strauss, of Chicago; Monsarrat and Pratley, Consulting Engineers, of Montreal; and Messrs. Baume Marpent, of Belgium, in which country it is proposed to

fabricate about 45 per cent. of the steelwork, mainly from British steel. This tender, £10,712,015 19s. 8d., is the highest of all the tenders received; neglecting price, the bridge has nothing to commend it as regards design, appearance or fabrication in Australia.

PLAN No. 1.

CONINAN BRIDGE CORPORATION

TENDER FOR A CANTILEVER SUSPENSION BRIDGE



Granite facing throughout ... ... £10,712,015 : 19 : 8

3. A Review of the Tenders Submitted—*continued.*

The English Electric Company of Australia, Limited.

The three tenders submitted by this firm, Plan No. 2, are for a stiffened suspension bridge; the principal tender, £5,609,125 2s. 1d., provides for granite-faced piers and abutments as specified; the second tender, £4,943,763 0s. 5d., provides for concrete-faced piers and abutments, whilst the third, £5,109,333 12s. 11d., is for brick-faced piers and abutments with granite quoins, the steel superstructure being the same in each tender. [*Photograph No.* 1.]

The tenders provide for a length of bridge of 3,810 feet. The main bridge is a suspension bridge of 1,600 feet centre span, having a continuous stiffening truss suspended between the towers from the main cables, but between the towers and the anchorages, the stiffening truss is not suspended from the back cables, which are straight, but the truss spans this distance of 375 feet as a girder supported at the anchorages and continuous over the towers. Advantage has been taken of the headway diagram at the main piers to increase the depth of the stiffening trusses to 110 feet and they are similarly increased to 87 feet 6 inches at the quarter points of the central span, between which points the main cables are used as top chords of the stiffening truss. The cables have a versine of 180 feet. The three southern approach spans are 204 feet centres of bearings and the three northern approach spans 180 feet 8 inches centres of bearings.

The design has been prepared by Messrs. Robinson and Steinman, of New York City, U.S.A. Dr. Steinman is well known in professional circles in New York, whilst Mr. Robinson is, perhaps, the greatest authority extant on the erection of suspension bridges. For the purposes of this tender they have designed a stiffened suspension bridge whose stiffening trusses take the form of continuous girders on four supports, the trusses having variable depths. The design is modelled on that of a bridge built in 1887 at Mannheim, Germany, by Professor Gerber. By a judicious selection of the truss outline, by combining the main cable with the top chord of the stiffening truss over the central portion of the main span, and by increasing the depth of the stiffening truss at the intermediate supports and quarter points, Messrs. Robinson and Steinman have produced a suspension bridge of novel design more rigid than any existing suspension bridge.

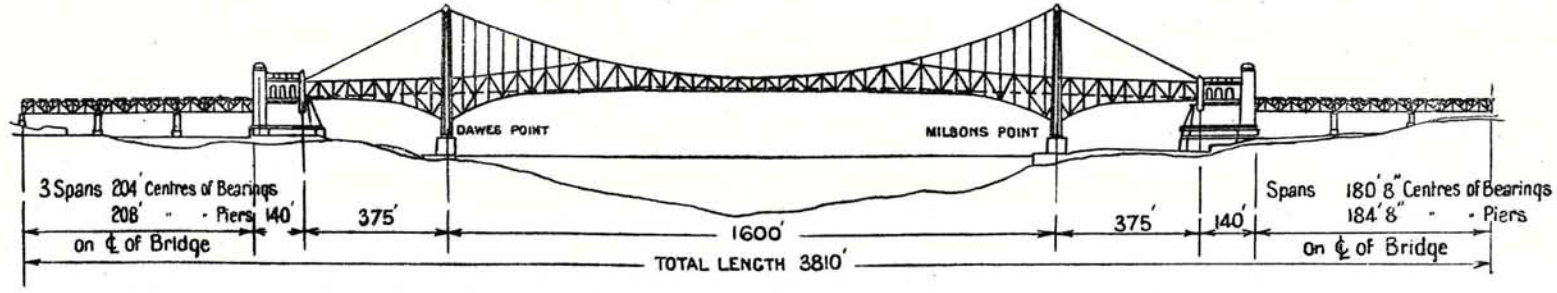
The stress analysis has been carried out by means of a particularly brilliant graphic analysis following on preliminary analytical calculations on the approximate method. The structure is indeterminate, the stiffening truss itself being indeterminate before the addition of the cable.

In the design of the approach spans, deck system, piers and abutments, the designers have followed the conditions of the official specification, but have not done so in the design of the members of the stiffening trusses, using a less exacting specification, consequently to conform to the official specification the weights of the stiffening trusses would have to be increased, and with them, the weights of the cables and towers. The maximum live load deflection at the centre of the span is given as 1·28 feet and the temperature deflection at the same point 0·9 feet, a total of 2·18 feet. These values have been obtained by a graphical method of analysis; as a check I have made an analytical computation whereby the resulting

PLAN No. 2.

THE ENGLISH ELECTRIC CO. of AUSTRALIA LTD.

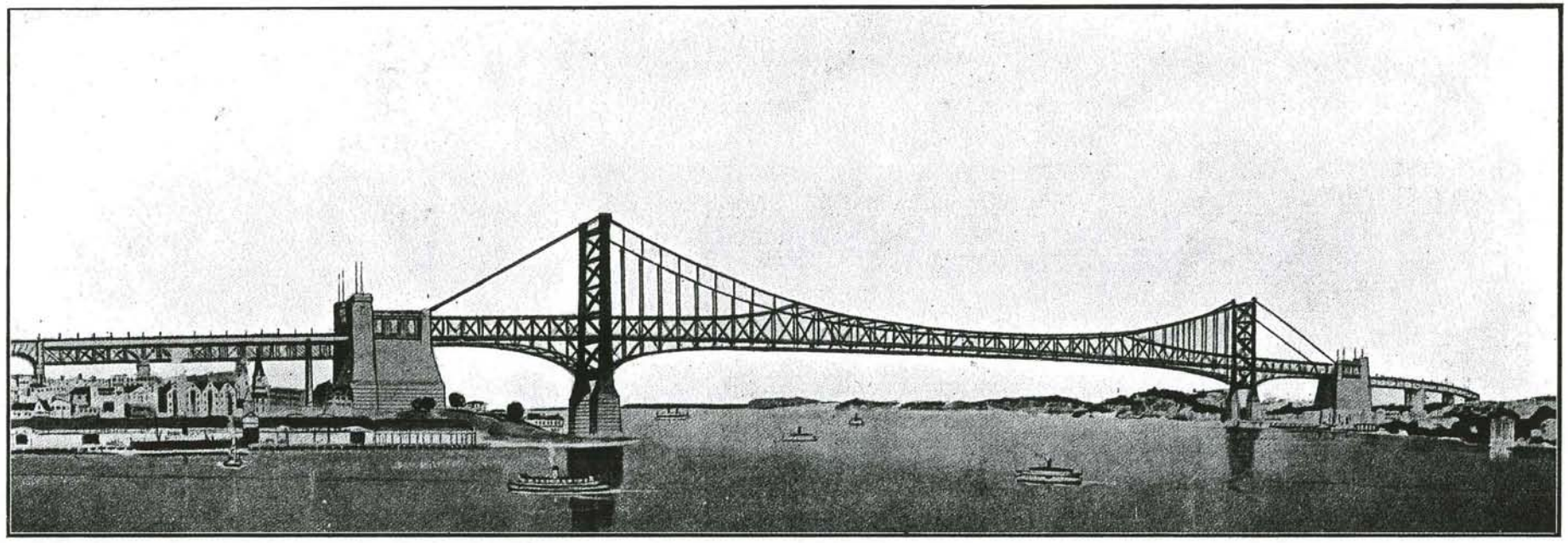
TENDERS FOR A SUSPENSION BRIDGE



Alternative 1. Granite facing throughout ... ... **£5,609,125 : 2 : 1**

Alternative 2. Concrete facing throughout ... ... **£4,943,763 : 0 : 5**

Alternative 3. Brick facing with granite quoins ... ... **£5,109,333 : 12 : 11**



Photograph No. 1.—English Electric Company of Australia.

deflections were computed to be 1·54 feet and 1·60 feet respectively, or a total of 3·14 feet. This suspension bridge is remarkably rigid, but rigidity has been obtained by sacrificing beauty of outline in the stiffening truss.

The perspective, as depicted in the painting submitted with tender, shows the bridge in its best setting. It must be borne in mind, however, that there is a tendency for the cables and suspenders of a suspension bridge to vanish from view on account of their slimness, when seen from a moderately distant point. With the main cables barely visible and the wire rope suspenders invisible, the bridge would not have a pleasing outline, and the angularity due to the increase in depth of the stiffening truss at the quarter points and over the towers would detract from its appearance.

3. A Review of the Tenders Submitted—*continued.*

The McClintic Marshall Products Company.

This firm has submitted five tenders, three tenders for cantilever bridges, one tender for a suspension bridge, called in tender an inverted arch, the fifth tender, in conjunction with Mr. C. A. P. Turner, of Minneapolis, for a three-hinged arch, Plan No. 5.

For material imported from America, the pound sterling hsa been taken as the equivalent of 4·50 gold dollars.

Tender A.—This tender is for a cantilever bridge, Plan No. 3, following closely the official cantilever design in general dimensions, but the outline of the web system has been modified, most of the large compression web diagonals having been reversed in slope thereby becoming tension members, for which heat-treated carbon steel eyebars are used. This modification has been made to take advantage of the Tariff Board's decision in regard to steel eyebars whereby the duty was eliminated on eyebars manufactured in Britain and 10 per cent. duty imposed on those manufactured in the United States. In the web system also additional sub-members, verticals and horizontals have been added with the result that, though the upper chords are thereby given a smoother curved outline, the web bracing becomes a network of steel and is less attractive. Silicon steel is used for all main built-up members, carbon steel for the deck, and all eyebars are of heat-treated carbon steel.

The main span is 1,600 feet centres of piers, the cantilever arms supporting the centre suspended span of 600 feet are each 500 feet long, whilst the anchor arms are also 500 feet long. On the southern side there are three approach spans of 204 feet span, and on the northern side three approach spans of about 180 feet span centres of bearings. The total length of bridge tendered for is 3,810 feet. The tendered cost is £6,499,377.

The stresses upon examination have been found correct. The method of erection is by building the anchor arm on falsework on either shore and the cantilever or harbour arms without falsework, the suspended span to be lifted bodily in position.

No calculations are submitted giving the estimated deflections, but all departures from the general outline of the official cantilever design, as by decreasing the height at the towers, and by reversing the slope of the web members to enable tension eyebars to be substituted for built-up compression members, have made the structure more flexible than the official cantilever bridge. The resultant main span live load deflection will be about 2 feet.

In the tender it is a stipulation that the guaranteed percentage of elongation for the heat-treated steel eyebars is to be 5 per cent., not 6 per cent. as specified, as the firm making these eyebars will not guarantee 6 per cent. Otherwise the material to be used is in accordance with that specified.

Tender B.—This tender, Plan No. 3, has been prepared for the express purpose of taking every legitimate advantage of the clearance allowance for shipping; the height of the main piers has been reduced by 90 feet, and, as a consequence, the quantity of masonry. [*Photograph No. 2.*]

The main bridge consists of two cantilevers with anchor arms of 400 feet, *i.e.*, 100 feet shorter than in the official design, the cantilever arms are 500 feet long supporting the centre suspended span of 600 feet. The approach spans have been modified to suit the shorter anchor spans, and consist, on the southern side, of four spans each 177 feet 6 inches, and, on the northern side, of four spans of about 161 feet centres of bearings.

In outline, the cantilevers differ radically from the official design. The lower chords are cambered away from the suspended span and, at a point midway along the cantilever arms, slope sharply downwards to the main pier. Having a depth of 114 feet 7½ inches between chords at the centre of the suspended span, the upper chords of the bridge are practically level throughout. Web bracing of the main structure is so arranged to give a constant length of subdivided panel of 50 feet and at the same time to utilise tension diagonals as far as possible, for which heat-treated carbon steel eyebars are used.

The floor system provides for subdividing the panel length of 50 feet into three equal stringer spans, intermediate cross-girder loads being taken by longitudinal girders in the planes of the trusses and applied to the main panel points. There are four trusses in the main span as against the two in the official design; the roadway is included between the inner trusses which are 62 feet centre to centre, each pair of railway tracks is included between each outer pair of trusses, 34 feet centre to centre, whilst the footways are cantilevered beyond the outermost trusses, the approach girders being rearranged to suit.

The vista from either end of the bridge through these three openings between the four main trusses, the two outer openings 29 feet wide, and the centre opening 57 feet wide, a distance of nearly half a mile, would certainly not be pleasing. The wider open deck of the official design, 98 feet 6 inches between the main trusses, is much preferable.

The stresses have been investigated and are satisfactory.

The flat top chords make it possible to erect the main bridge by means of a creeper traveller on the top chords which erects the two inner trusses ahead of itself and the two outer trusses behind itself, the suspended span being cantilevered out from the cantilever arms until both sides meet at the centre.

Complete sets of upper and lower laterals are provided; the upper laterals continuing in portal frames down the inclined compression members which meet at the main shoe. Strong sway frames are provided at each vertical to so connect the four trusses that each may take its full share of the live loading.

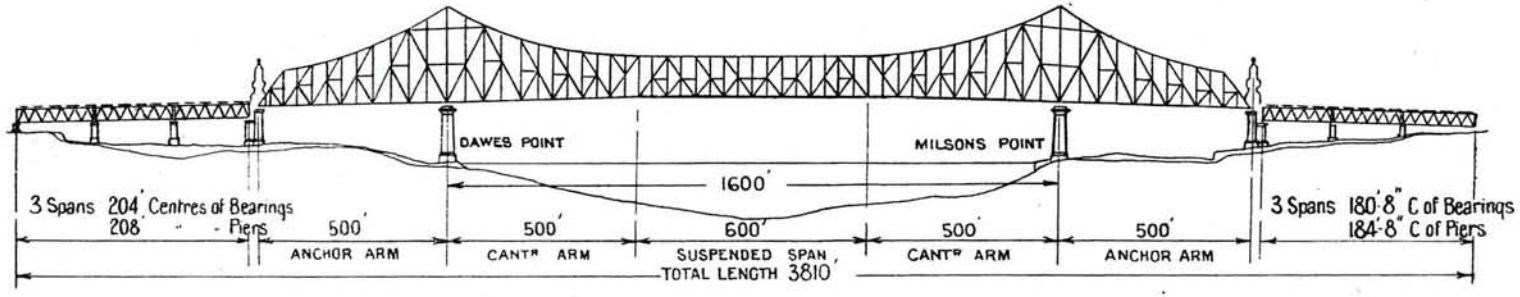
The bridge, though a sound engineering proposition, is unhandsome, its appearance is too utilitarian, whilst its tendered cost, £5,958,356, is too high for acceptance.

As in tender A, all eyebars are of heat-treated carbon steel, the built-up members of the trusses of silicon steel, and the deck system of carbon steel. The deflections are not given.

Mc CLINTIC MARSHALL PRODUCTS Co.

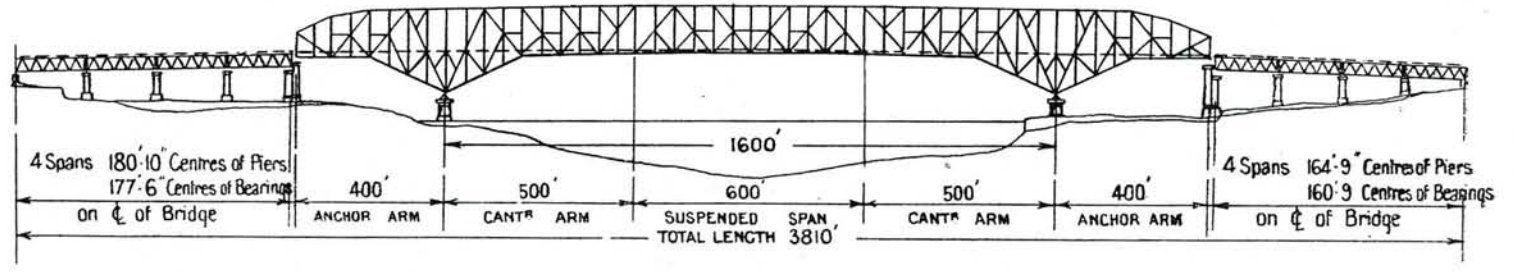
TENDERS FOR A CANTILEVER BRIDGE

Tender A



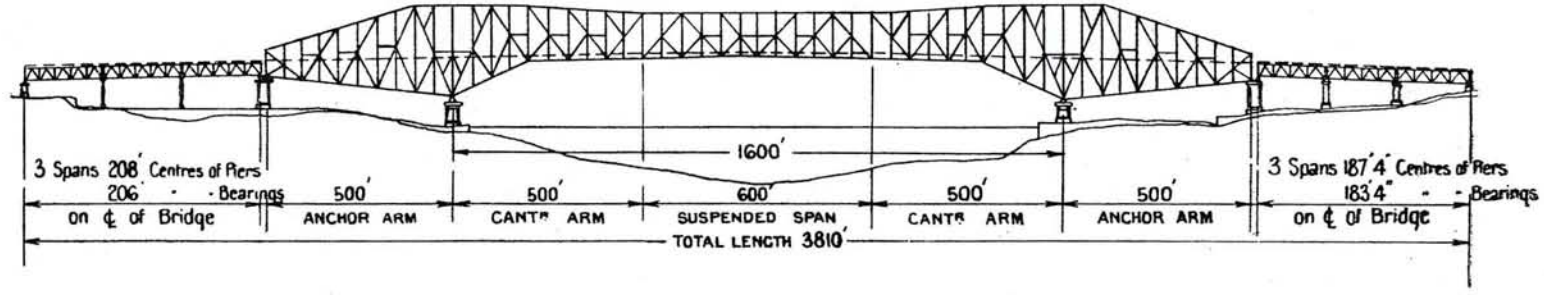
Granite facing throughout ... ... **£6,499,377 : 0 : 0**

Tender B

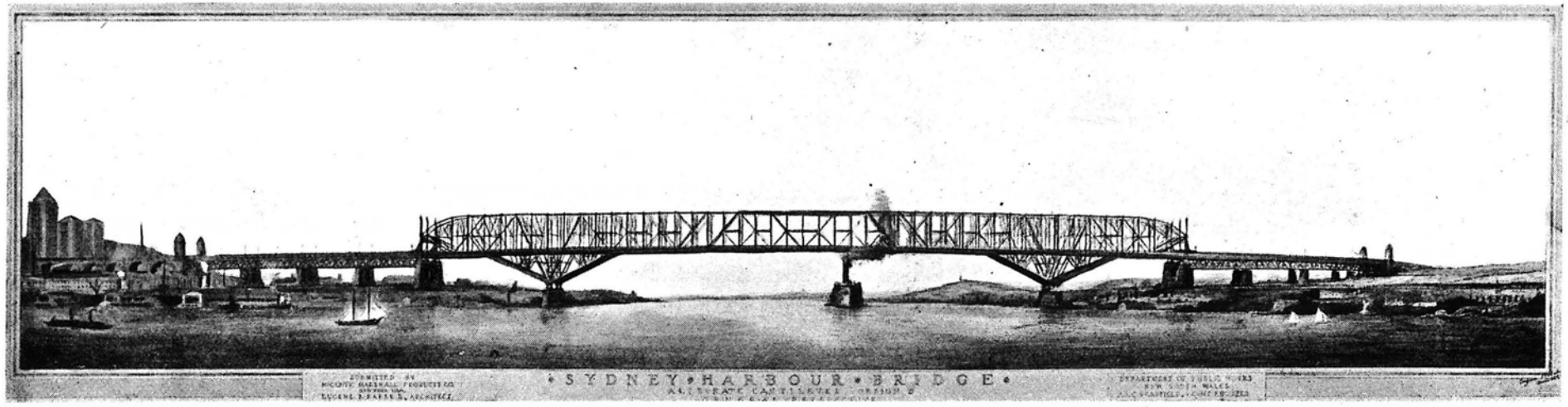


Granite facing throughout ... ... **£5,958,356 : 0 : 0**

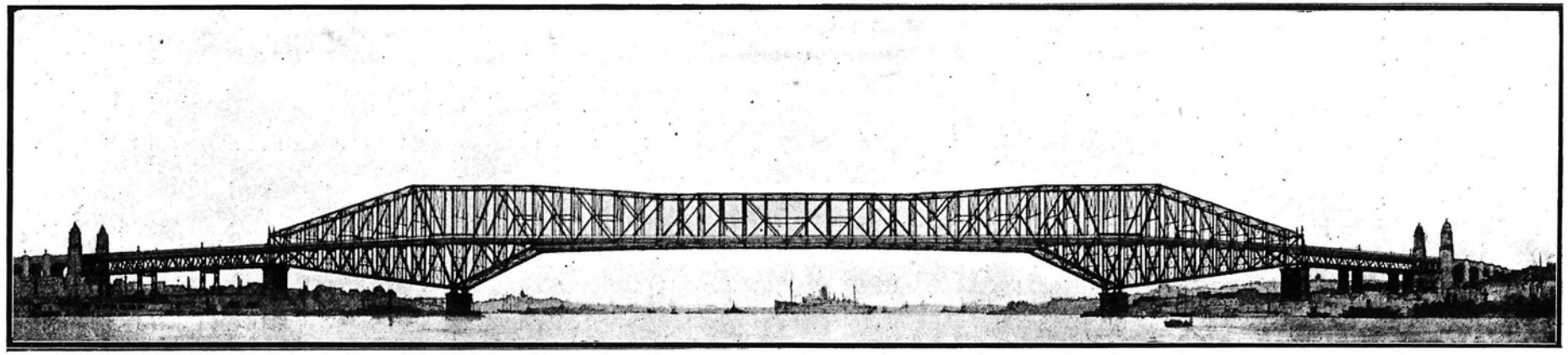
Tender C



Granite facing throughout ... ... **£5,654,531 : 10 : 0**



Photograph No. 2.—McClintic Marshall Products Company. Tender B.



Photograph No. 3.—McClintic Marshall Products Company. Tender C.

Tender C.—This tender, Plan No. 3, is developed from Tender B, which it resembles, the line of development being also economy in masonry for the anchor and approach piers.

With this object in view, the low main piers have been retained, but the anchor arm has been lengthened to 500 feet as in the official design; the approaches on the southern side consist of three truss spans 206 feet, and on the northern side of three spans of 183 feet centres of bearings, The general outline of the trusses is similar to those in Tender B, with modifications, however, which improve the appearance of the structure. [*Photograph* 3.]

The tender substitutes steel bents for the masonry piers of the southern approach spans, but the northern approach spans, being on a curve, the masonry piers are retained.

The bridge is an improvement on that proposed in Tender B, but it cannot be said to altogether harmonise with its surroundings. Tender B and Tender C are similar in design and the same remarks apply to both. The structure is statically sound. All stresses are determinate and have been carefully worked out. The deflections are not given.

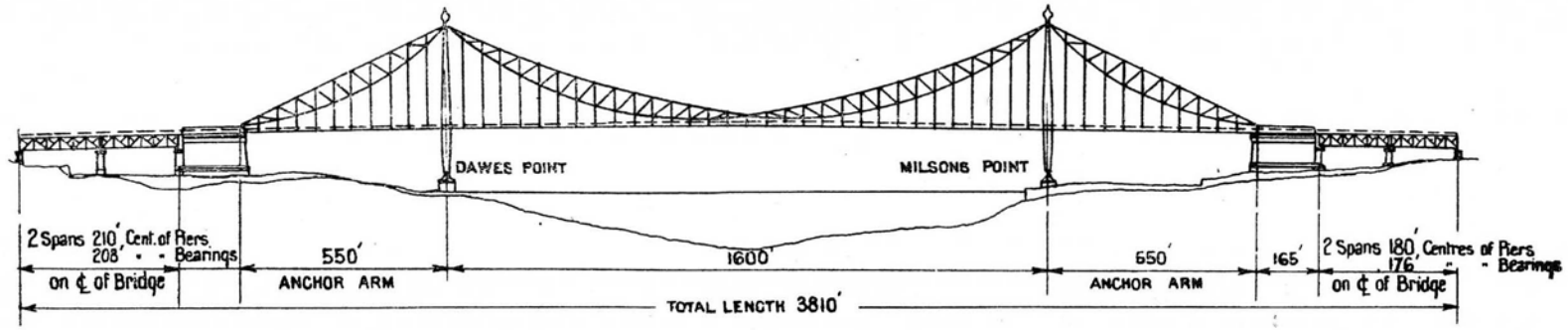
The modifications in the shore arm and in the amount of masonry have enabled a tender of £5,654,531 10s. to be submitted—a reduction of over £300,000 on Tender B, and the appearance of the bridge is improved.

PLAN No. 4.

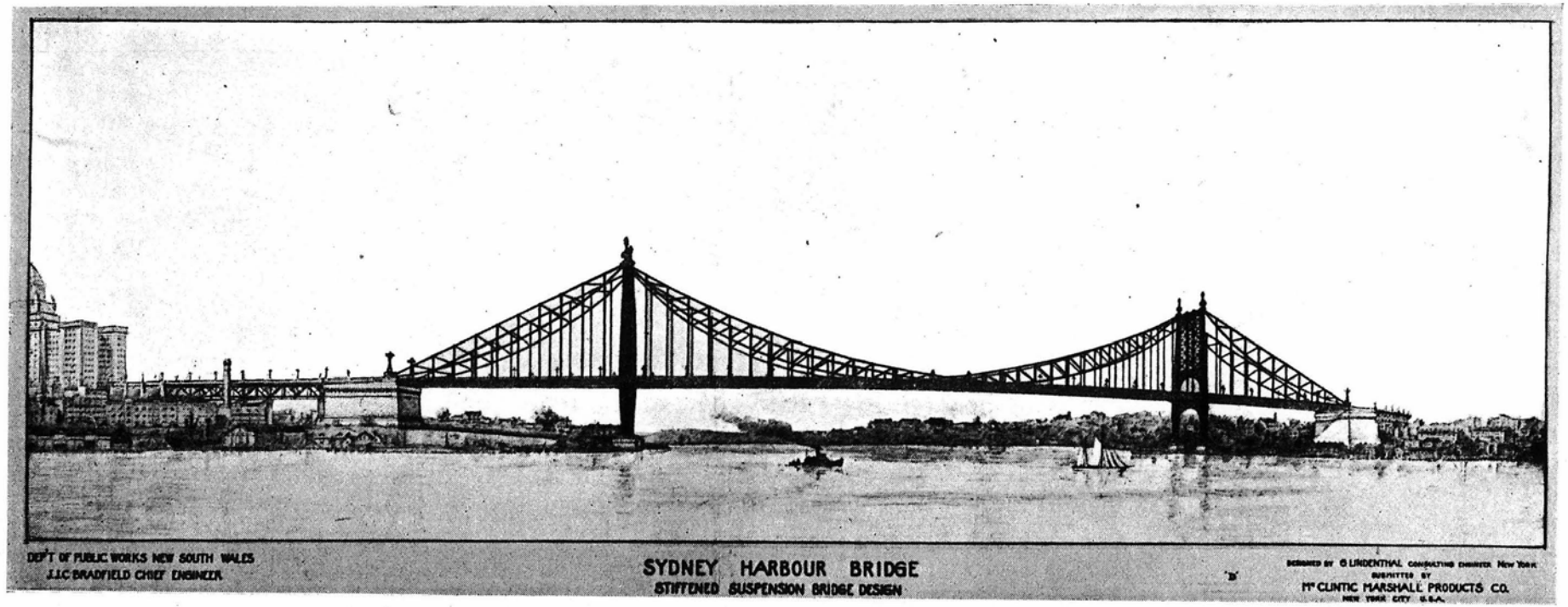
Mc CLINTIC MARSHALL PRODUCTS Co.

TENDER FOR A SUSPENSION BRIDGE

Tender D



Granite facing throughout ... ... £6,047,547 : 0 : 0



Photograph No. 4.—McClintic Marshall Products Company. Tender D.

Tender D.—Plan No. 4 provides for a three-hinged braced eyebar cable suspension bridge with main span of 1,600 feet, and side spans of 550 feet each suspended from the cables; all main panels are 50 feet in length. The two approach spans on the southern side are 208 feet centres, and the two approach spans on the northern side about 176 feet each centres of bearings. The massive anchorages of the main structure are 165 feet long and 110 feet high to take the tension of the cables.

A suspension bridge, similar to the above, designed by the same engineer—Mr. Gustav Lindenthal, of New York City—for the Quebec bridge, was discarded by the Board of Engineers in favour of the cantilever bridge erected at Quebec in 1917. Again, a similar suspension bridge was under consideration for the Hell Gate bridge, but was discarded in favour of a two-hinged braced arch structure, also designed by Mr. Gustav Lindenthal, partly because the arch bridge permitted of much better curves in approach than the suspension bridge could on account of its back span, and it was also the more rigid bridge.

The Sydney Harbour Bridge is a parallel case; the suspension bridge, Tender D, provides for anchor arms 550 feet long, and the railway on the northern side cannot commence to curve away before it passes the anchorage abutments another 165 feet distant, necessitating the use of reverse curves of 500 feet radius; whereas, with the official arch bridge, a curve of 18 chains radius can be obtained, and with the official cantilever bridge a curve of 8 chains radius without reverse curves.

The principal statical element in the design is the braced chain system, which is statically determinate, and is so arranged that no reversal of stress can occur in the chords of the braced trusses. These chords are accordingly constructed of heat-treated carbon steel eyebars, as are also all hangers, whilst all built-up members are of silicon steel plates and shapes. The adoption of heat-treated carbon steel eyebars as the main carrying member is open to doubt; there is no guarantee that every individual eyebar received or can withstand its correct stress.

The main towers, 445 feet above high water, are slender, graceful structures of silicon steel very strongly braced in the transverse direction and hinged at the base in the longitudinal direction. No other transverse bracing is employed in the main trusses, as it is claimed that the structure is inherently stable, and that the appearance is thereby enhanced.

The floor system is provided with a wind truss 156 feet 6 inches between chords, which is hinged at mid-span, continuous over the towers and anchored at the main cable anchorages.

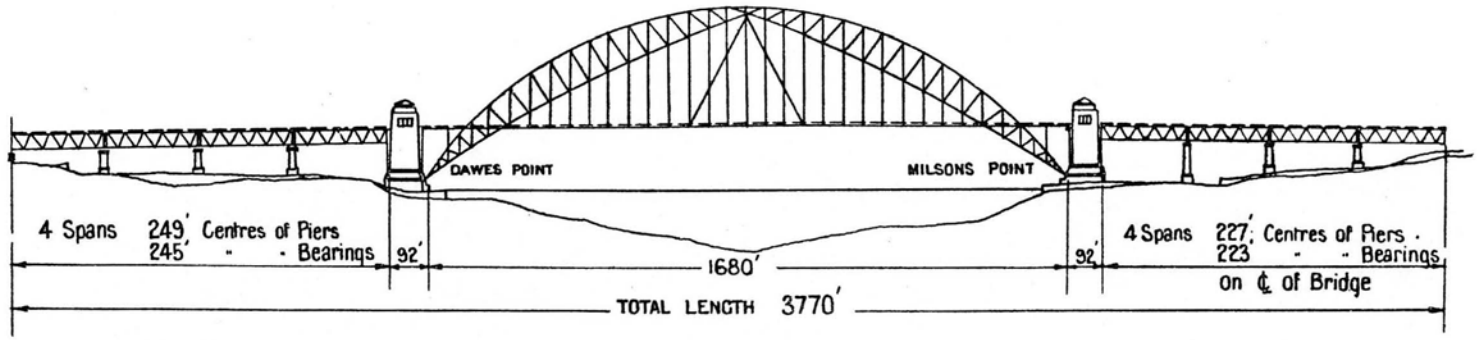
As was to be expected in the design of a suspension bridge submitted by Mr. Gustav Lindenthal, all stress work has been accurately laid down. The maximum deflection at mid-span, under live load, is 3 feet 3·6 inches, and for temperature, 1 foot 6·6 inches, a total of 4 feet 10·2 inches. The claim of Mr. Lindenthal, that this is the most rigid type of suspension bridge, is not borne out, as the design by Dr. Steinman for the suspension bridge submitted by the English Electric Company of Australia, Limited, has a deflection under live load and temperature of less than 3 feet 2 inches.

Aesthetically, this suspension bridge is handsome in outline because of the grace of the loaded backstays, and the clear definition of the loaded elements which remain visible from any distant point of view, but its tendered cost, £6,047,547, militates against its adoption, even if it were as satisfactory as an arch or cantilever bridge under the traffic conditions to be met. [*Photograph* No. 4.]

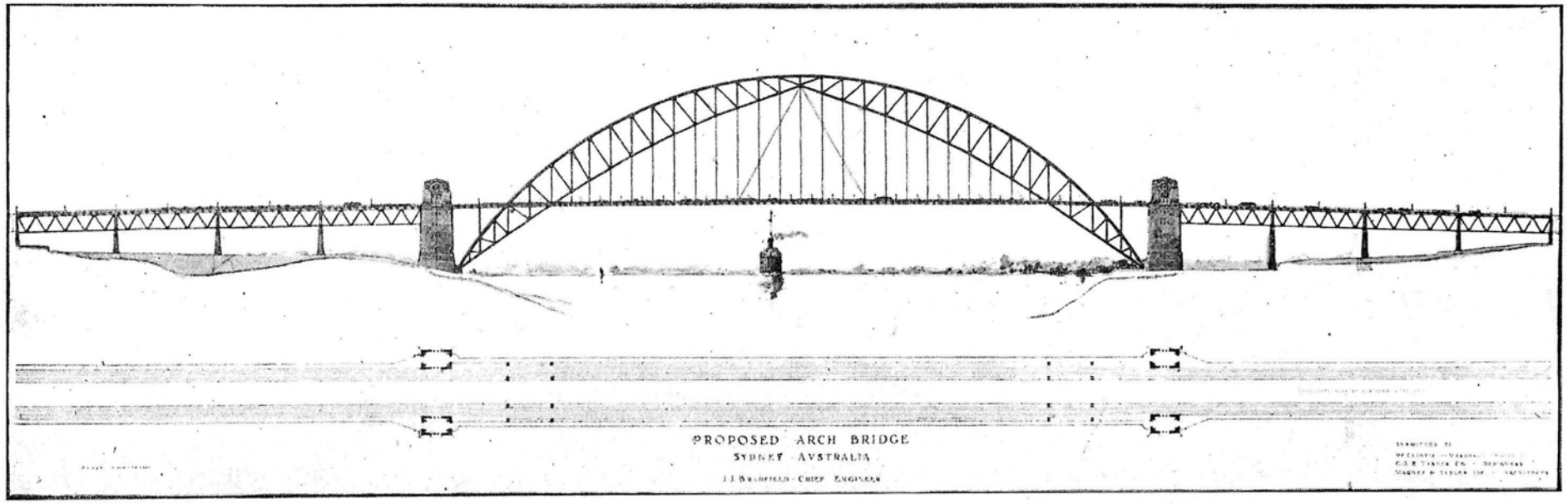
Mc Clintic Marshall Products Co.

Tender for an Arch Bridge

Tender E



Granite facing throughout ... ... £6,053,565 : 0 : 0



Photograph No. 5.—McClintic Marshall Products Company. Tender E.

Tender E.—Plan No. 5, submitted in conjunction with Mr. C. A. P. Turner, of Minneapolis, U.S.A., is for a three-hinged braced arch of 1,680 feet span to centres of hinges, bearing against abutment towers on either shore. The rise to the crown hinge is 445 feet. The southern approach consists of four truss spans, each about 245 feet long, and the northern approach of four spans each 223 feet long centres of bearings. There are four trusses in the main span with the roadway between the inner trusses which are spaced 64 feet apart; each pair of railway tracks is between each outer pair of trusses spaced 34 feet apart centres, a total width of 132 feet between outer trusses, the footways being cantilevered outside the outer trusses.

All main panels are 50 feet in length, the floor being suspended from the main trusses by galvanised steel wire ropes. The floor system, however, provides for subdividing this panel length into three equal stringer spans, intermediate cross-girder loads being taken by longitudinal girders in the planes of the trusses and applied to the main panel points. The whole floor with its bracing forms a rigid riveted truss from abutment to abutment capable of taking up wind and traction stresses. Expansion of the floor system is equalised by diagonal stays from the crown hinge.

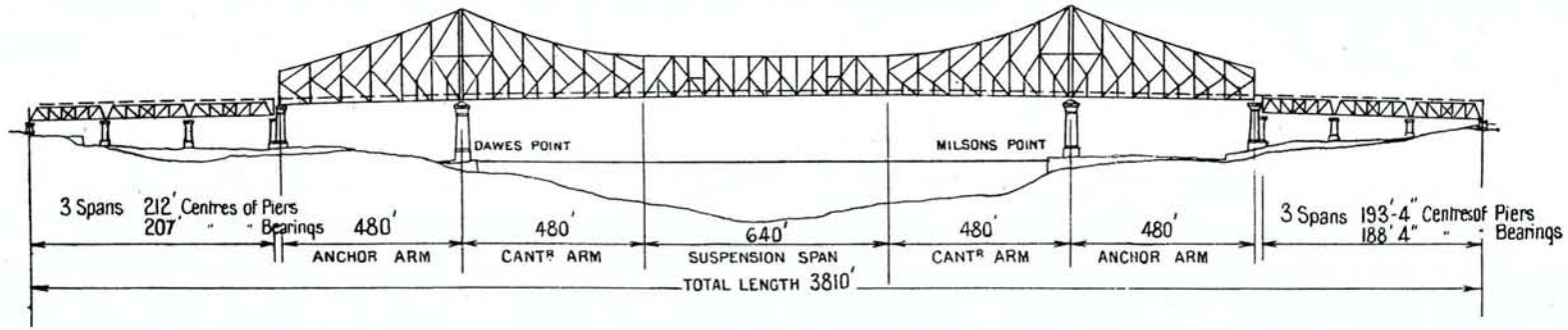
The bridge is of the three-hinged type for dead load, but by means of an ingenious friction clamp in the top chord above the crown hinge, the structure is made two-hinged for live loads. This clamp does not come into operation under the relatively slow action of temperature change, and thus the bridge is three-hinged for temperature stresses also. The deflections are not stated, but they will be somewhat greater than those of the two-hinged arch. The appearance of the structure is not in its favour; the crown pin is 485 feet above high-water level and the outline of the arch ribs, deepest at the quarter points, though in conformity with statical principles, does not add to the appearance, and the defined crescent shape of each half-arch does not produce a satisfactory optical explanation of the transference of the enormous stress from the crown of the arch to the abutments at the springings.

The tendered cost is £6,053,565, much greater than a lower tender for a more beautiful and efficient arch bridge. [*Photograph No.* 5.]

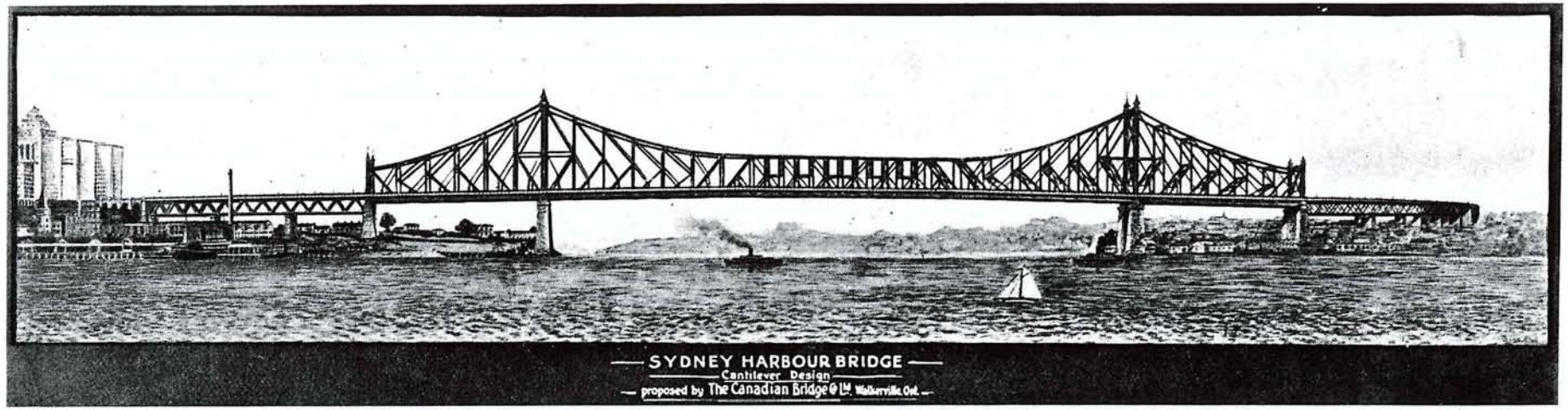
PLAN No. 6.

THE CANADIAN BRIDGE CO., LTD.

TENDER FOR A CANTILEVER BRIDGE



Granite facing throughout ... ... **£5,313,404 : 9 : 4**



Photograph No. 6.—Canadian Bridge Company. Tender A.

3. A Review of the Tenders Submitted—*continued.*

Canadian Bridge Company.

Tender A.—In general form, Plan No. 6, this bridge follows the official cantilever design except that a "K" system of web bracing has been adopted as in the Quebec bridge. The main bridge consists of two cantilevers with shore and anchor arms each 480 feet long supporting a suspended span 640 feet long and 100 feet deep. The southern approaches consist of three truss spans 207 feet, and the northern approaches consist of three spans 188 feet centre of bearings—a total length of 3,810 feet of bridge as specified. [*Photograph No.* 6.]

To simplify the details of the erection traveller and to make the erection problems less difficult, the depth over the main pier has been reduced by 30 feet, making the depth 240 feet. This increases the chord stresses.

As was to be expected from a firm of the high standing of the Canadian Bridge Company, the stress calculations and design of members and details have been most carefully performed, the latter being of a particularly high standard and similar in type to those of the Quebec bridge. The methods of stress analysis are beyond criticism, and full and accurate details of deflections, secondary stress problems, and intricate connection layouts are submitted. Detailed information is supplied of weights of all truss members and bracing, with allowance for details which are ample.

On account of the adoption of the "K" system of bracing, ample opportunity is afforded for the use of eyebars in the lower chords and tension diagonals of the suspended span, and in the upper chords of main cantilevers. The tension diagonals and verticals of the main cantilevers, which in the Quebec bridge consist of built-up members, are also to be eyebars. All eyebars are of heat-treated carbon steel, the built-up members mostly of silicon steel, sub-members and decking of carbon steel. The eyebars have been largely used to take advantage of the Tariff Board's decision *re* duty.

In the tender it is a stipulation that the guaranteed percentage of elongation for the heat-treated steel eyebars is to be 5 per cent., not 6 per cent. as specified, as the firm making these eyebars will not guarantee 6 per cent. Otherwise the material to be used is in accordance with that specified.

On the suspended plan, lateral bracing is provided along the lower chords with sway frames at each main vertical, and the portals at each end post. Upper lateral bracing is not used on account of the heavy torsional action on the suspended span inherent in a cantilever bridge when it is unequally loaded. A somewhat similar system of bracing is used for the main cantilevers.

Ample provision is made in this tender for floor expansion joints and traction trusses in the main structure. The method of erection has been thoroughly investigated, and is to be carried out in a manner similar to that of the Quebec bridge, using a shorter traveller with a revolving jib crane which can reach to any portion of the structure to be erected as it traverses the bridge. It is proposed to erect the anchor arm on false-work and to cantilever out from the main piers, finally lifting the suspended span into position.

Owing to the extensive use of heat-treated carbon steel eyebars, and silicon steel built-up members, and to the decrease in depth over the main piers, the deflection due to live load is 25 inches. Discussion of many intricate secondary phenomena is given in the calculations submitted with this tender. These calculations show a masterful knowledge of statical principles and practice of bridge design. The tendered cost is £5,313,404 9s. 4d., which is the only factor, except fabrication in Australia, militating against its recommendation.

The firm have written stating that they are prepared to supply and erect the superstructure only of the cantilever bridge at a cost of £4,081,099 9s. 4d. These two quotations are subject to exchange, the pound sterling being taken as the equivalent of 4·50 gold dollars.

This tender is much higher than British tenders for a similar cantilever bridge.

Tender B.—This tender, Plan No. 7, is for a so-called "inverted arch," but which, in reality, is a stiffened eyebar cable suspension bridge, with a three-hinged stiffening truss of novel outline, in that the stiffening truss fills the complete space between the cable and the suspended floor, the top chord of the stiffening truss being coincident with the cable itself. The cable is continuous from anchorage to anchorage, but the main span stiffening truss is hinged at the centre of the span, and at the main piers, whilst side span trusses are supported on main piers and on end approach piers, which take the place of the anchor pier of a cantilever bridge. The anchorages themselves are provided at the base of the next approach pier, which then resists uplift and becomes the anchor pier. [*Photograph No.* 7.]

The main panel subdivision of the stiffening truss is variable from 259 feet 3 inches near main post to 86 feet 5 inches at mid-span; these panels are further subdivided by the use of subsidiary trusses near the main post which transfer the loading to the main panel points. The resulting division produces floor panels of 40 feet, 43 feet 2½ inches, and 56 feet in length. This design is unique in using a trussed floor girder with simple triangular bracing and verticals, pin connected to the main trusses.

The bridge consists of a main span of 1,600 feet with two shore spans each 500 feet, the three southern approch spans are 204 feet each, and the three northern approach spans 180 feet each, centres of bearings.

The depth of bridge over the main pier is 270 feet, this depth decreasing to 40 feet at mid-span and at the ends.

The design was made by Mr. C. G. Emil Larsson, of the American Bridge Company, well known in American engineering circles.

The alterations to the pier necessitated by the design have been fully investigated, and revised quantities have been supplied by tenderer.

The stress analysis follows approved lines on the method of influence lines; the structure is quite determinate. Lower lateral bracing systems complete with traction trusses are introduced along lower chords and strong sway bracing at main posts, and along the planes of the main compression members of the stiffening truss.

Joint details and the design of members have been schemed out in a most efficient manner, and the information and plans submitted are of the same high standard as supplied with the tender for the cantilever bridge. The main cables are to be heat-treated carbon steel eyebars, except the four mid-span panels where, on account of reversal of stress, built-up silicon steel members are employed. Main built-up members are of silicon steel, details of carbon steel.

In the tender it is a stipulation that the guaranteed percentage of elongation for the heat-treated steel eyebars is to be 5 per cent., not 6 per cent. as specified, as the firm making these eyebars will not guarantee 6 per cent. Otherwise the material to be used is in accordance with that specified.

The calculated deflection at mid-span under live load amounts to 2 feet 9·58 inches; whilst the deflection at the same point due to temperature, is 1 foot 7·96 inches, a total of 4 feet 5·54 inches.

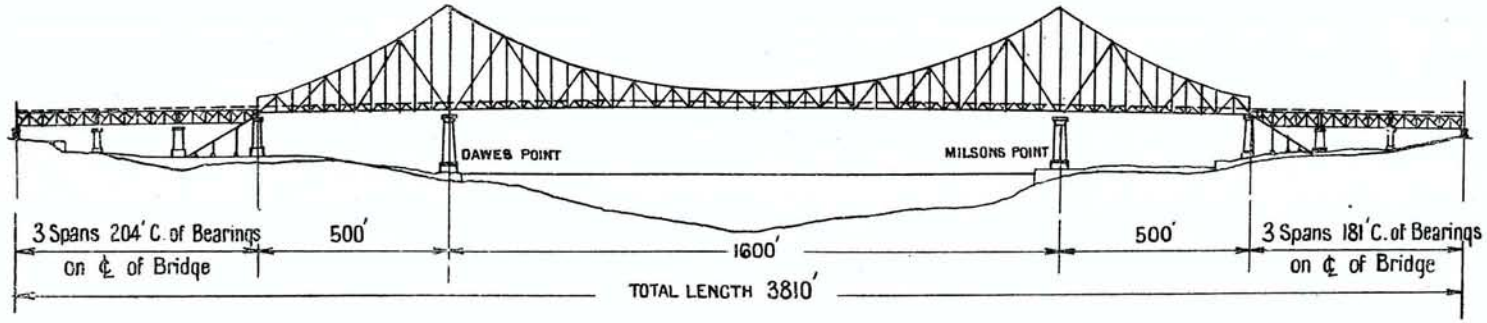
The appearance of the bridge generally is pleasing, but somewhat marred by the inclined anchorage eyebars beneath the approach spans, adjacent to the main structure, and by the large open panel spaces near the main posts and the long unwieldy diagonal members at these places.

The tendered cost is £5,091,202 18s. 4d.; it is the lowest of all the tenders received for suspension bridges.

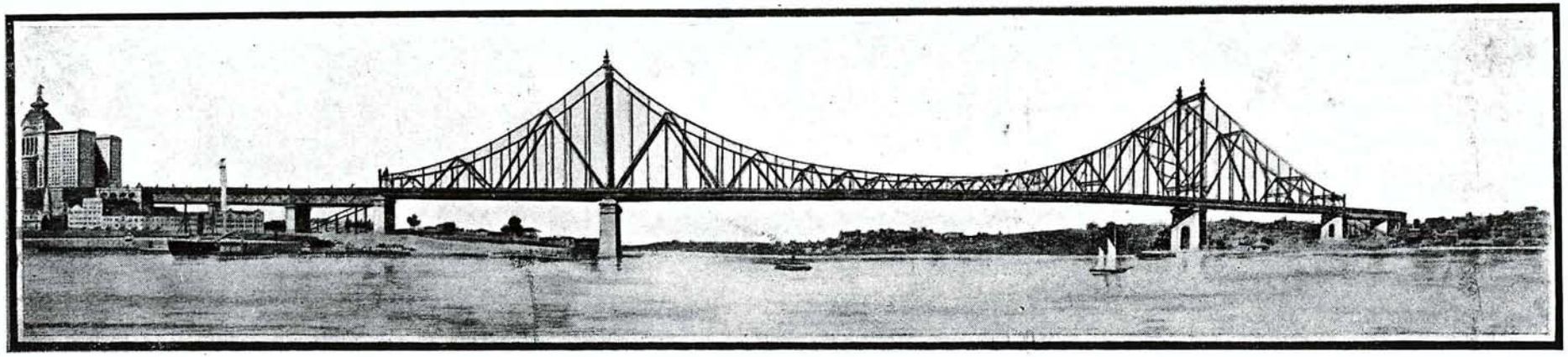
PLAN No. 7.

THE CANADIAN BRIDGE CO., LTD.

TENDER FOR A SUSPENSION BRIDGE



Granite facing throughout ... ... £5,091,202 : 18 : 4



Photograph No. 7.

3. A Review of the Tenders Submitted—*continued.*

Sir William Arrol & Co.

In submitting their tenders for the cantilever and arch bridges, Sir Wm. Arrol & Co. state, "We can suggest nothing better than Mr. Bradfield has put before us." The special high-grade steel it is proposed to use would be supplied by William Beardmore & Co., of Glasgow. It was produced during the war for the British Admiralty to permit the scantlings of new battleships being reduced in weight. It has been fully tested by the Admiralty; its special qualities are high limit of proportionality and toughness.

Minimum ultimate tensile strength 38 tons (85,120 lb.) per square inch.

Minimum limit of proportionality, 17 tons (38,080 lb.) per square inch.

Minimum elongation in a length of 8 inches, 17 per cent.

Cold-bend test. Through an angle of 180 degrees round a curve whose inner radius is $1\frac{1}{2}$ times the thickness of the piece being tested, without cracking.

This steel appears to be quite satisfactory, but the working stresses have been taken as those allowable under the specification for nickel steel, which must have a minimum yield point of 50,000 lb. per square inch, and are too great for the material proposed.

Cantilever Bridge.—This bridge, Plan No. 8, follows closely the official design, except that, to allow for simpler erection, the bracing system adopted is of the "K" type. The main span is 1,600 feet centres of piers, the anchor and cantilever arms are each 500 feet long, the suspended span 600 feet long; the depth of the suspended span is 90 feet. The three southern approach spans are 204 feet, and the northern approach spans about 180 feet centres of bearings. The total length of bridge is 3,810 feet.

The main cantilevers are provided with strong sway bracing at main posts and in the planes of compression verticals and diagonals; these sway frames transfer the loads to the lower lateral systems, which themselves are formed of K-braced frames. The suspended span is provided with complete sets of upper and lower lateral and portal bracing and intermediate sway bracing.

The calculated deflection at the centre under live load and impact is 16·56 inches, or 15·05 inches for live load only, neglecting the effect of details. Allowing for details, the calculated live-load deflection at centre of span is 12·04 inches.

Extreme care has been devoted to the preparation of this tender. The stress analysis, design, and layout of truss members and details have been excellently performed, as would be expected from firms with the high reputation of Sir Wm. Arrol & Co. and Sir John Wolfe Barry & Co. It is to be noted that members built-up of plates and shapes are used exclusively throughout the structure; no eyebars, which are exclusively an American product, are used. All main truss members are of the high-grade steel before mentioned, as are also the outer trusses of the approach spans.

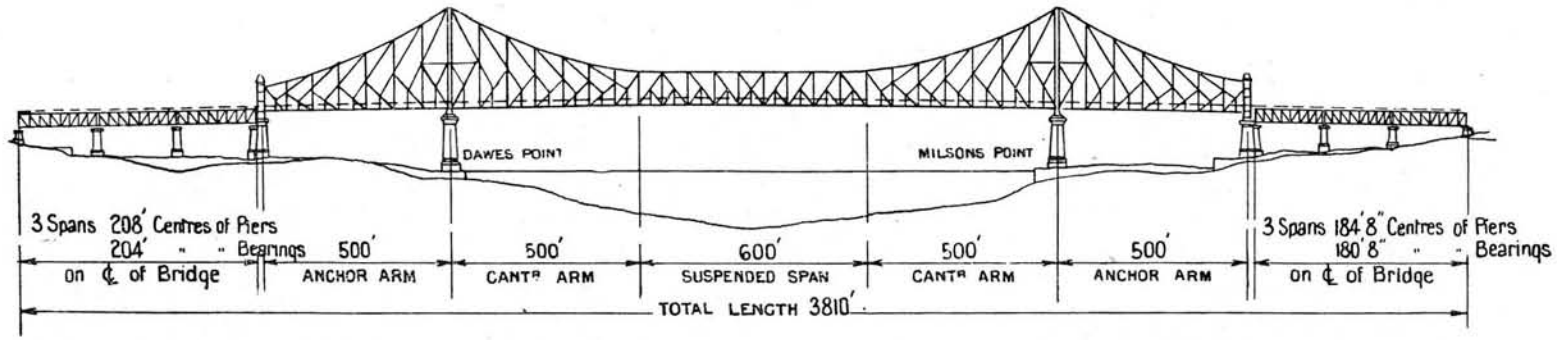
The bridge is to be erected by constructing the anchor arms on staging and then building out the main cantilevers by means of a large traveller which supports a revolving jib crane, the traveller running on tracks at floor level. The suspended span is to be lifted into place.

The tendered price is £4,978,488 7s. 8d.

PLAN No. 8.

SIR Wm ARROL & CO., LTD

TENDER FOR A CANTILEVER BRIDGE



Granite facing throughout ... ... £4,978,488 : 7 : 8

3. A Review of the Tenders Submitted—*continued.*

Sir William Arrol & Co.

Arch Bridge.—This bridge, Plan No. 9, also follows closely the official design. It is, however, a three-hinged arch of main span of 1,650 feet, divided into 34 panels of 48 feet $6\frac{11}{32}$ inches, with four southern approach spans of 244 feet and four northern approach spans about 219 feet centres of bearings, a total length of 3,770 feet. The lower chord of the main arch is parabolic with a rise of 375 feet to the crown hinge. The arch rib is 60 feet deep at crown, 80 feet deep at quarter points and 192 feet deep at end posts. The details and stress analysis of this bridge have been investigated by tenderer with the same care as evidenced in the cantilever bridge, and the structure represents one of the highest forms of expression of modern engineering practice. The main truss members, lateral bracing, floor girders, outer girders of approach spans, and main span railway stringers are of the special high-grade steel, the deck bracing details, the deck and the inner girders of approach spans are of carbon steel.

The crown hinges consist of 24-inch diameter pins with 36-inch diameter sleeves, the hinges at the springing are 26 inches in diameter with 38-inches diameter sleeves and are made of forged steel.

The figures for rigidity clearly prove that the arch is by far the most rigid and efficient structure of all three types submitted by tenderers. The deflection at mid-span under live load is given by tenderer at $6\frac{3}{4}$ inches, which is correct; the temperature deflection at the same point I have calculated to be 9·6 inches, a total of 16·035 inches.

The question of distortion of the sway frames under symmetrical live load does not therefore occur to such a degree as in a cantilever bridge. According to the deformation diagrams supplied by the tenderer, the maximum relative horizontal motion of the two upper chord points in the same sway frame under unsymmetrical live load is $1\frac{5}{32}$ inches, which will produce only small secondary stresses in the sway frames and the members of the main trusses.

The method of erection proposed is to cantilever out from each shore until each half meets at the crown hinge, the top chords being taken in a straight line to a firm rock anchorage. On these straight back stays, a creeper traveller is to be built, which constructs the bridge panel by panel until both halves meet in the middle and by means of adjusting jacks the two halves are lowered to bear on the crown pin. The top chord traveller needed to perform this operation will only be light in comparison with the large traveller needed for the cantilever bridge.

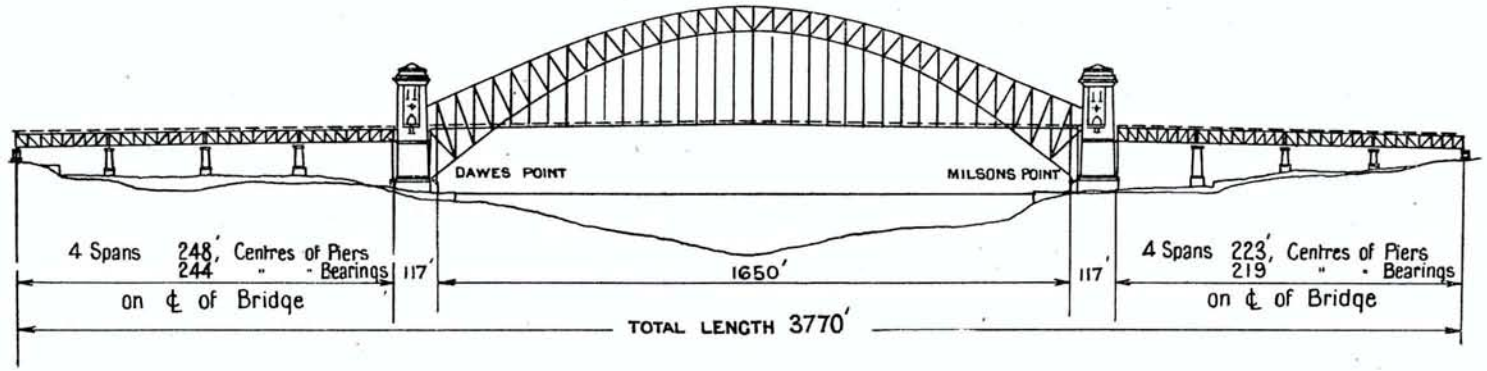
The working stresses have been taken as those allowable under the specification for nickel steel and are too great for the material proposed.

The tendered price is £4,645,351 7s. 8d.

PLAN No. 9.

SIR Wm ARROL & Co., LTD.

TENDER FOR AN ARCH BRIDGE



Granite facing throughout ... ... **£4,645,351 : 7 : 8**