Sydney Harbour Bridge

Report on Tenders

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1924.

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

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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.	Imported. 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 36·7 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.

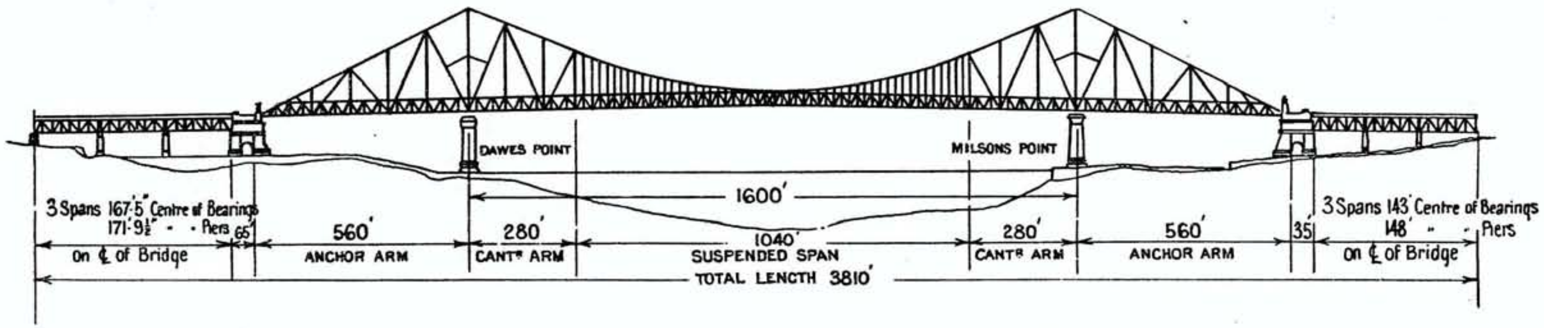
The appearance of the bridge does not commend itself; the wide open panel subdivision of the cantilever arms does not harmonise with the closely spaced hangers of the suspended span, whilst the long straight upper chords of the anchor arms, where they junction with the lower chords at the anchorage, 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.

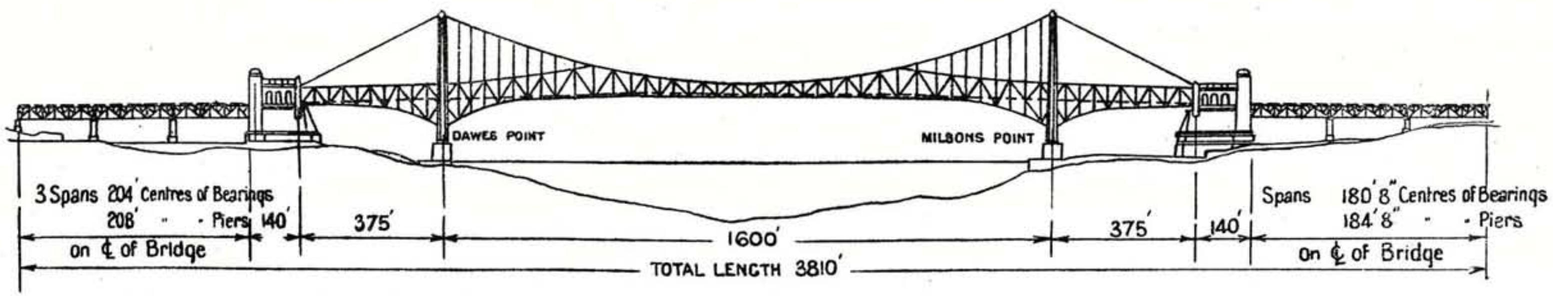
The stress analysis has been carried out by means of a particularly brilliant graphic analysis following on preliminary analytical calculations on the approximate method. The structure is indeterminate, the stiffening truss itself being indeterminate before the addition of the cable.

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

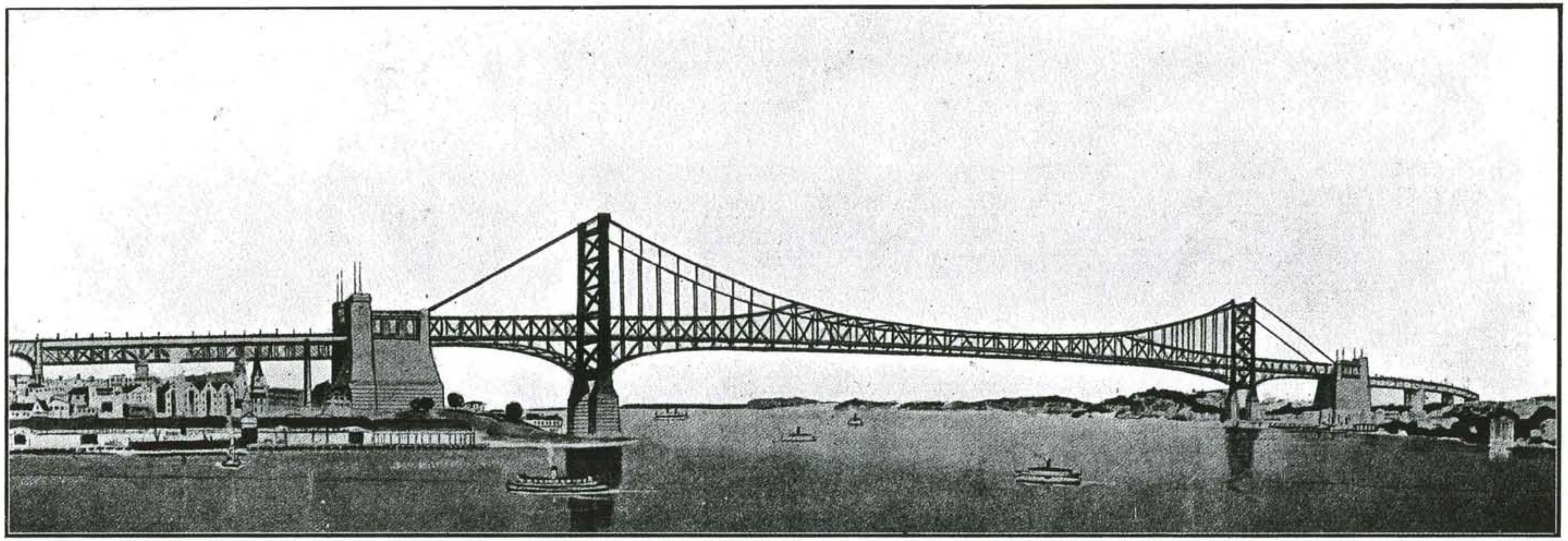
PLAN No. 2.

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.

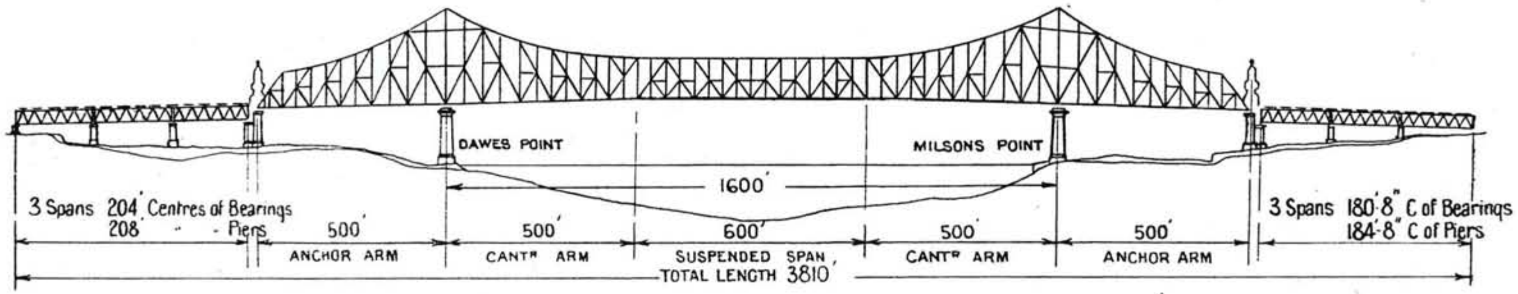
As in tender A, all eyebars are of heat-treated carbon steel, the built-up members of the trusses of silicon steel, and the deck system of carbon steel. The deflections are not given.

PLAN No. 3.

Mc CLINTIC MARSHALL PRODUCTS Co.

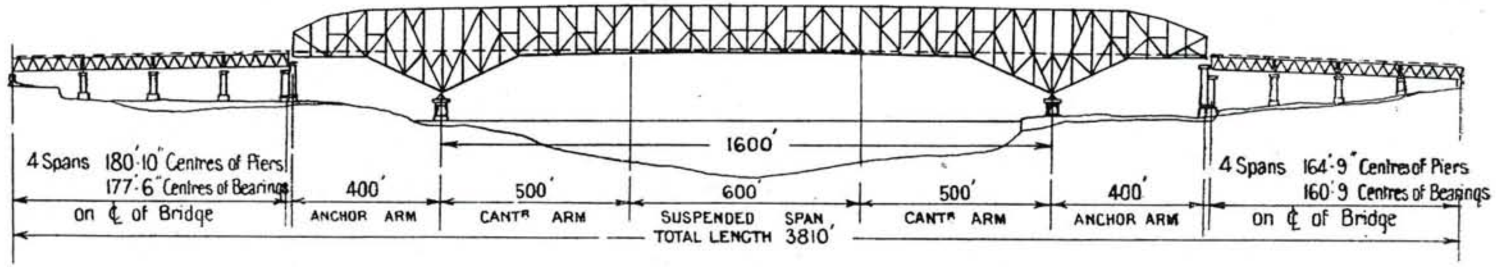
TENDERS FOR A CANTILEVER BRIDGE

Tender A



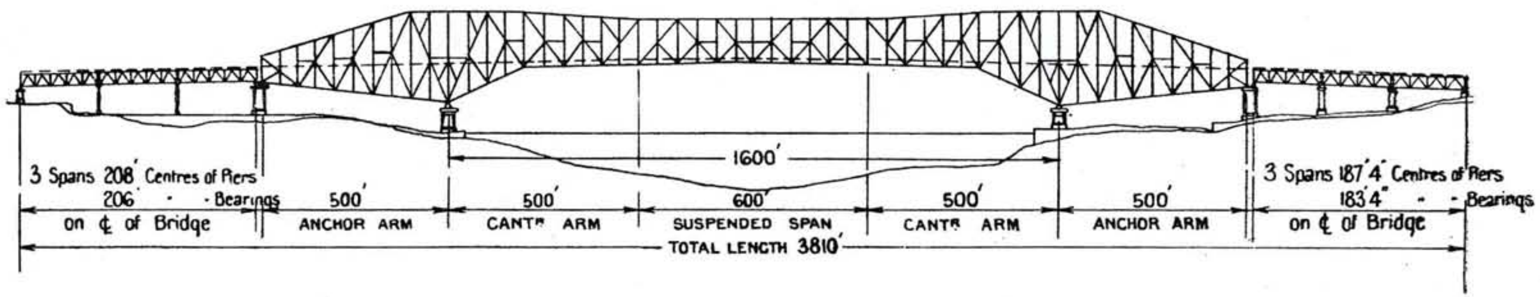
Granite facing throughout ... ... **£6,499,377 : 0 : 0**

Tender B

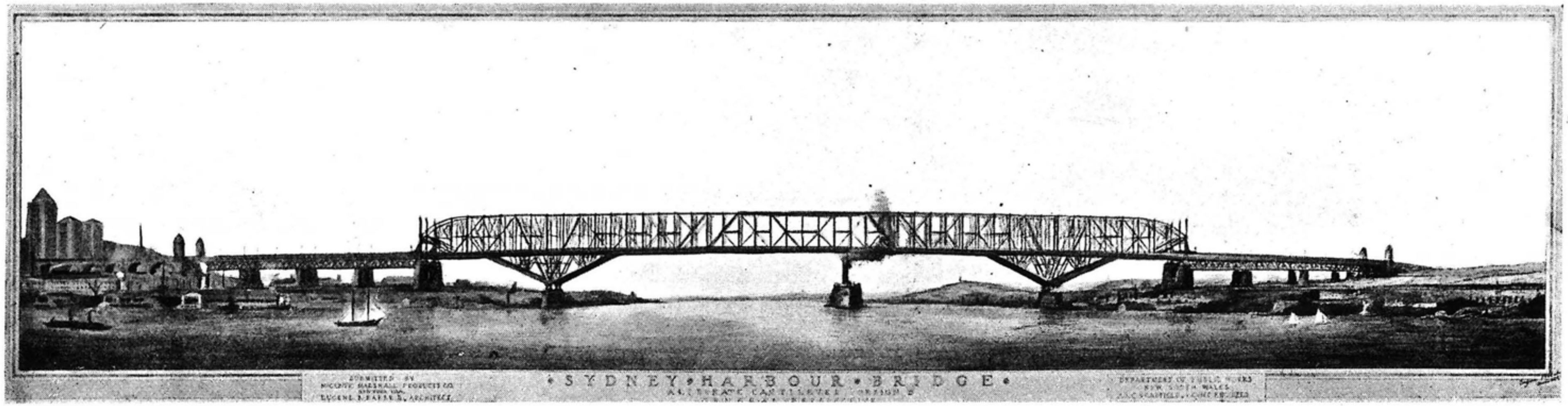


Granite facing throughout ... ... **£5,958,356 : 0 : 0**

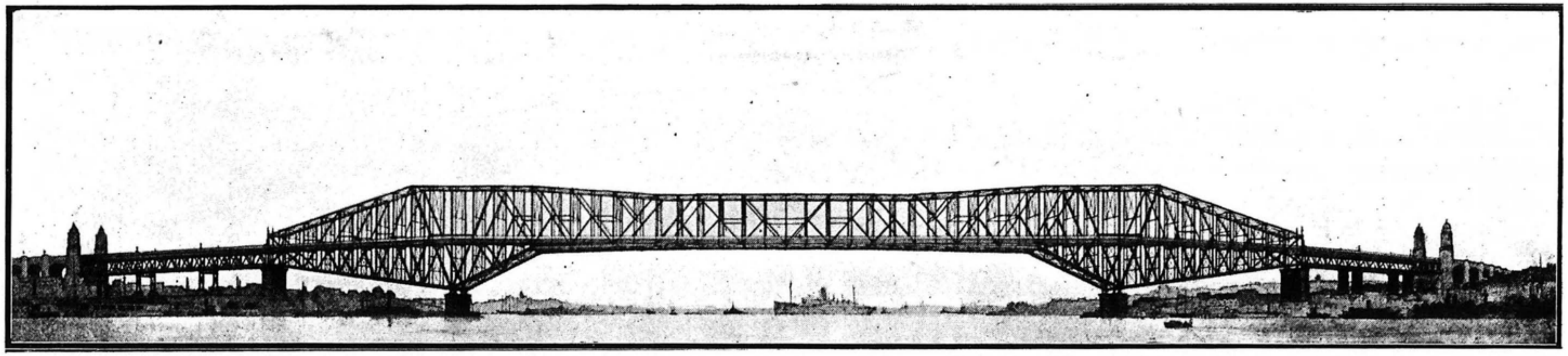
Tender C



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.

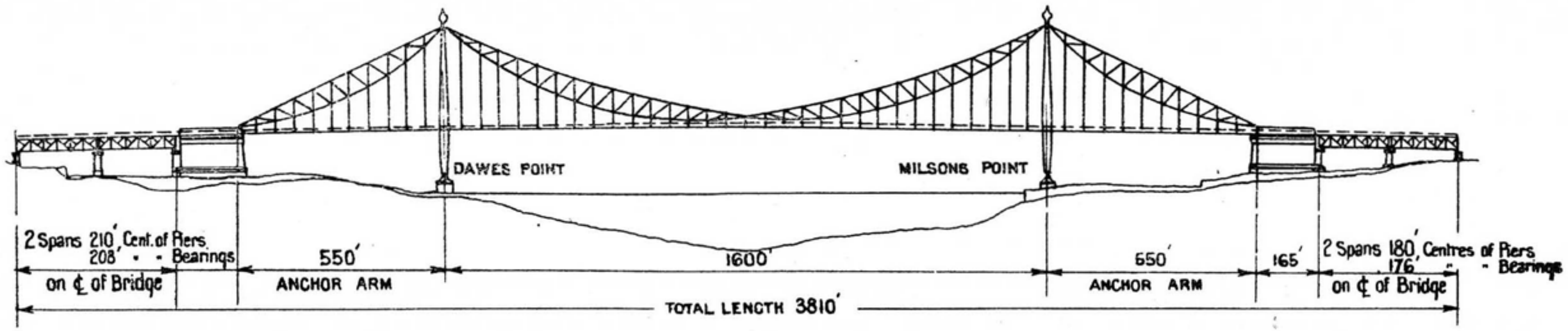
The modifications in the shore arm and in the amount of masonry have enabled a tender of £5,654,531 10s. to be submitted—a reduction of over £300,000 on Tender B, and the appearance of the bridge is improved.

PLAN No. 4.

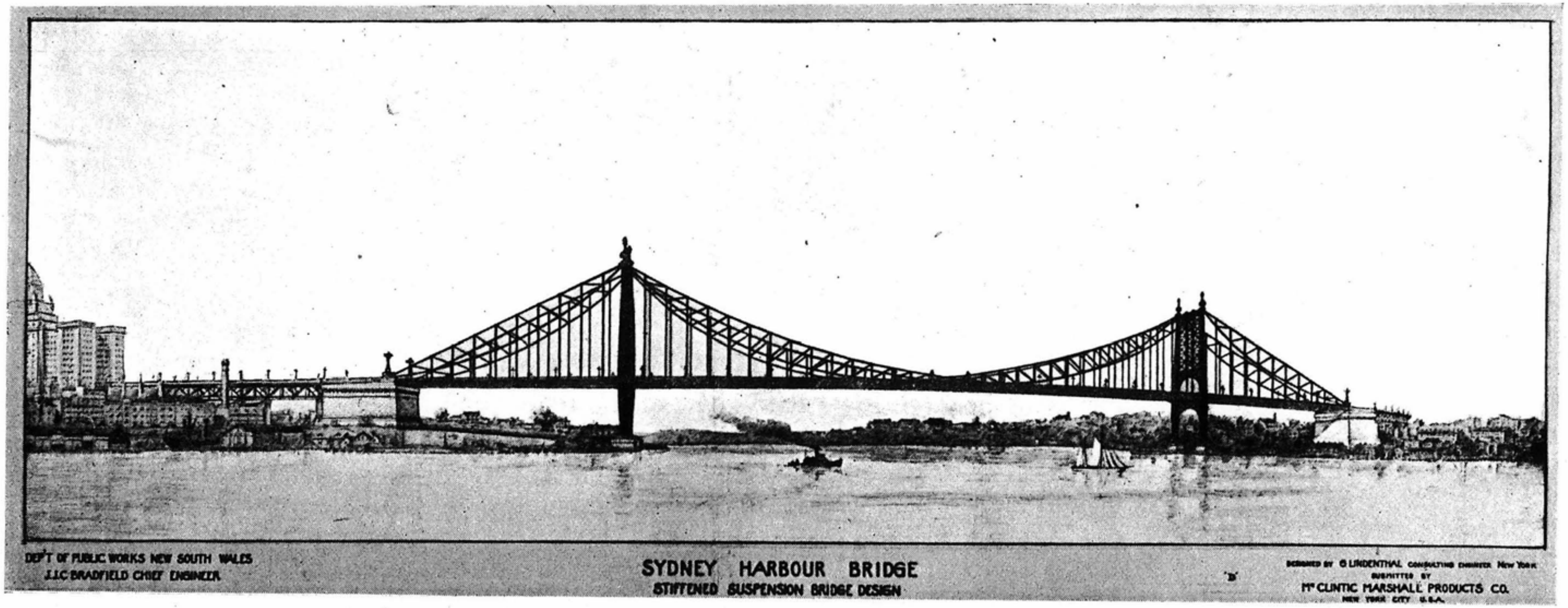
Mc CLINTIC MARSHALL PRODUCTS Co.

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.

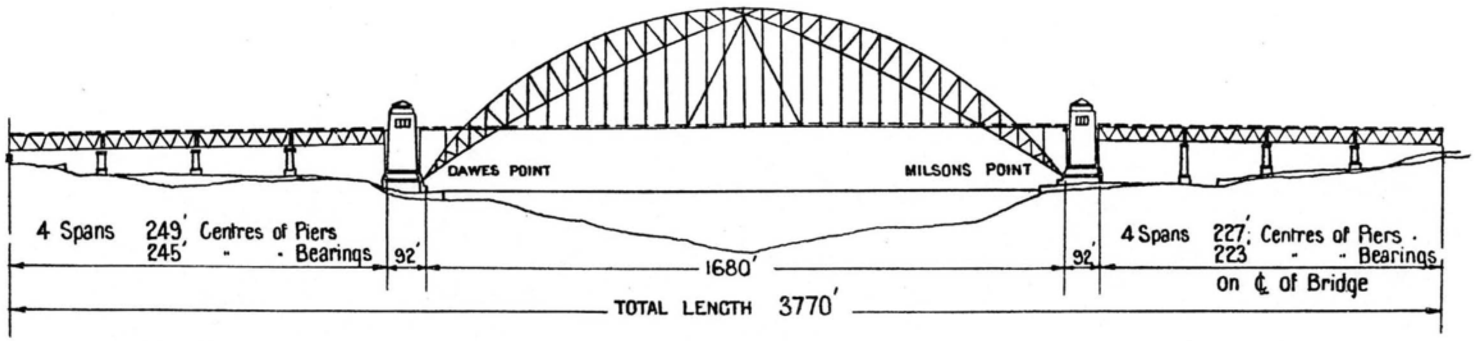
Aesthetically, this suspension bridge is handsome in outline because of the grace of the loaded backstays, and the clear definition of the loaded elements which remain visible from any distant point of view, but its tendered cost, £6,047,547, militates against its adoption, even if it were as satisfactory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

PLAN No. 5.

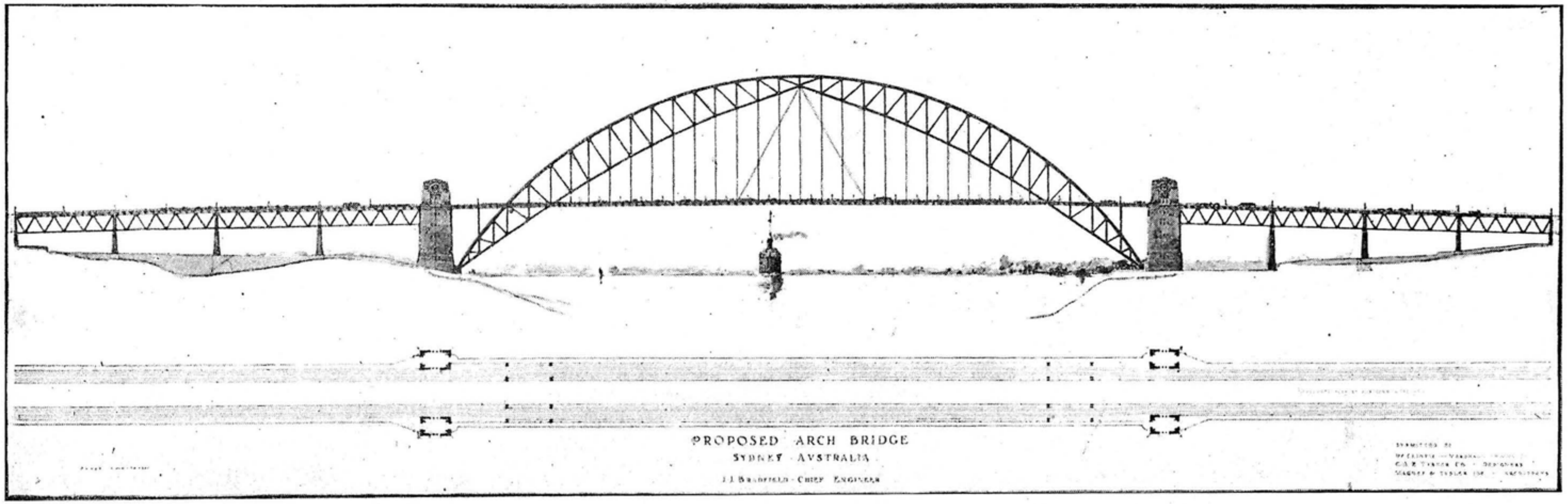
Mc CLINTIC MARSHALL PRODUCTS Co.

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.

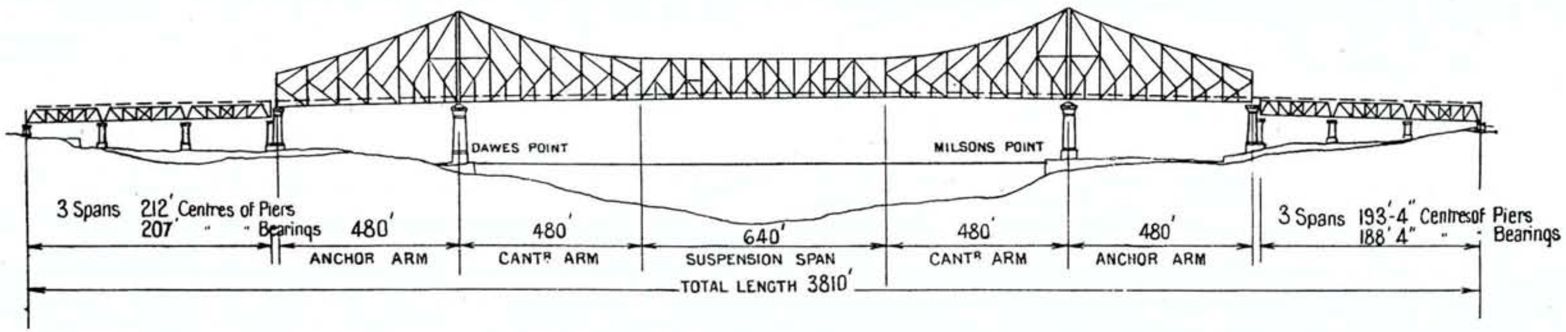
The bridge is of the three-hinged type for dead load, but by means of an ingenious friction clamp in the top chord above the crown hinge, the structure is made two-hinged for live loads. This clamp does not come into operation under the relatively slow action of temperature change, and thus the bridge 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.]

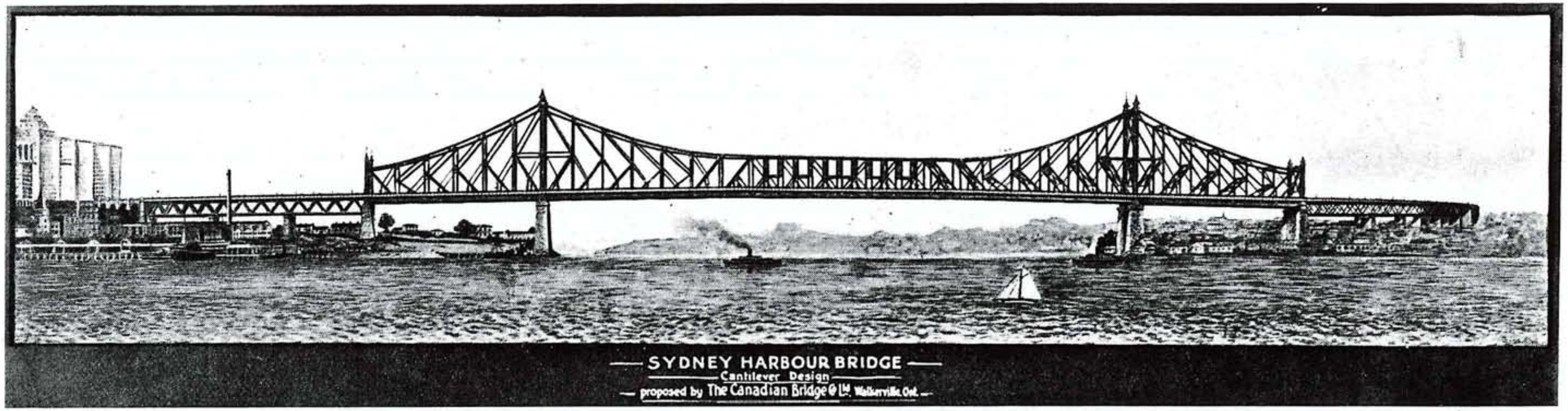
PLAN No. 6.

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 falsework 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.

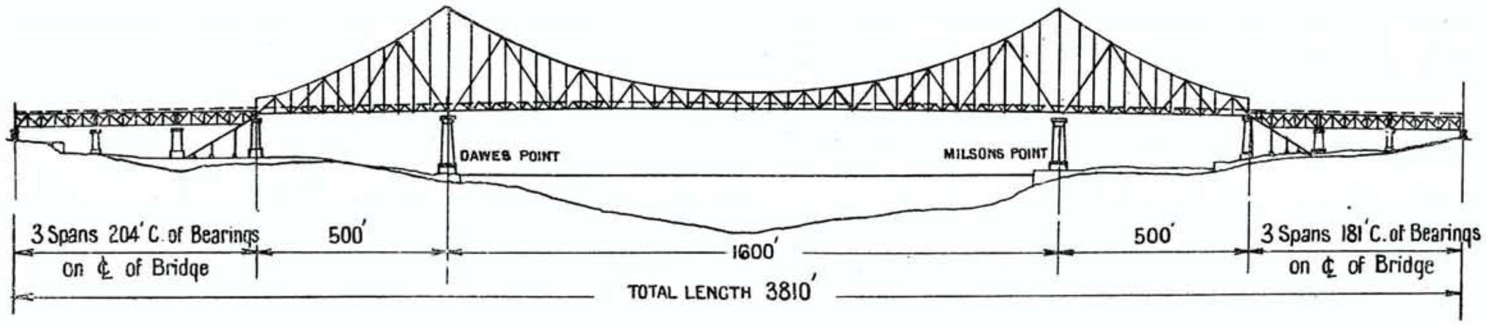
The appearance of the bridge generally is pleasing, but somewhat marred by the inclined anchorage eyebars beneath the approach spans, adjacent to the main structure, and by the large open panel spaces near the main posts and the long unwieldy diagonal members at these places.

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

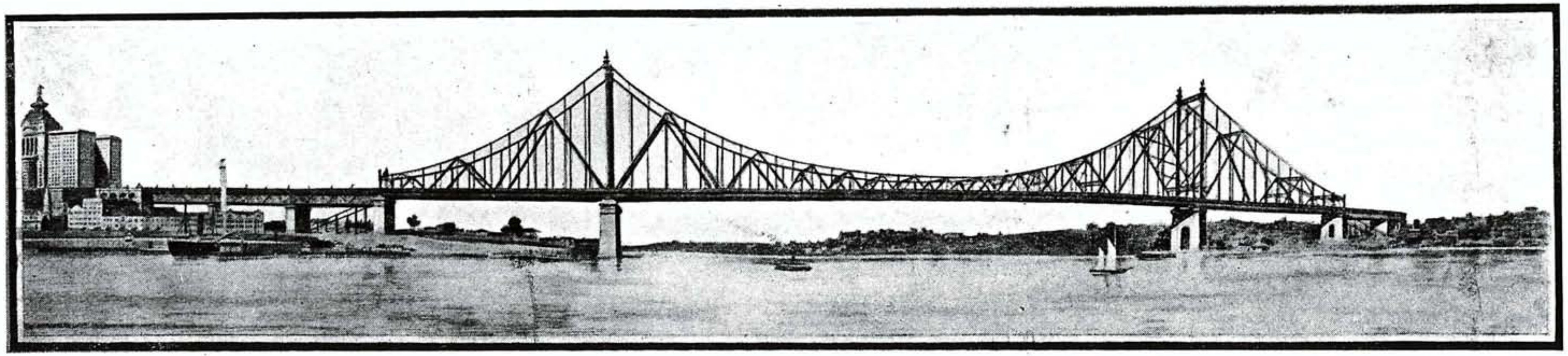
PLAN No. 7.

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 1½ 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.

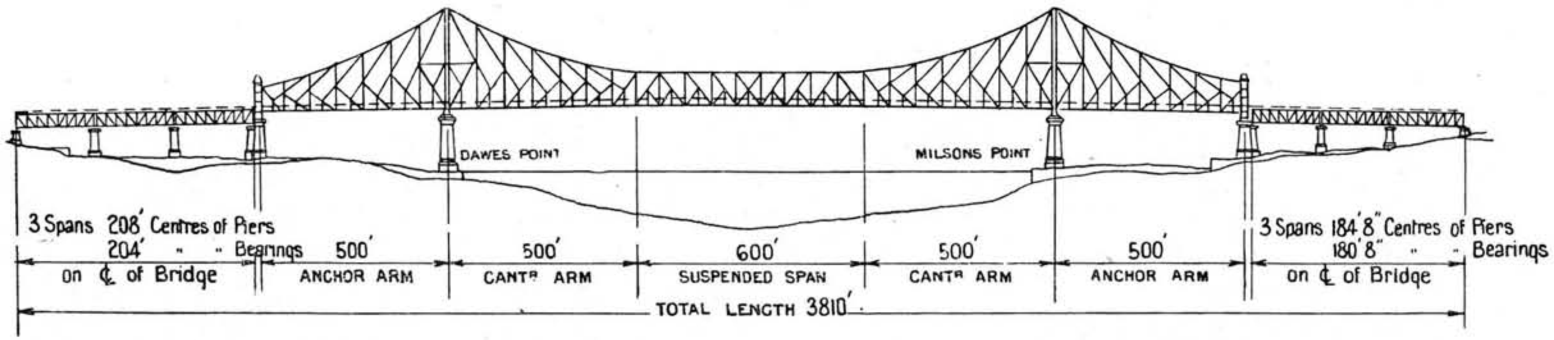
The bridge is to be erected by constructing the anchor arms on staging and then building out the main cantilevers by means of a large traveller which supports a revolving jib crane, the traveller running on tracks at floor level. The suspended span is to be lifted into place.

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

PLAN No. 8.

SIR W^M^ 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.

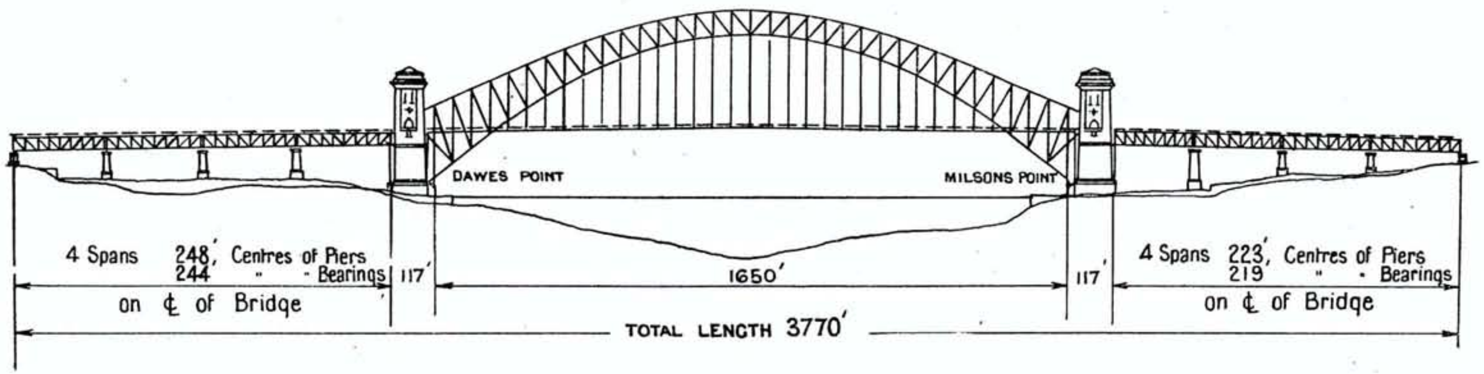
The method of erection proposed is to cantilever out from each shore until each half meets at the crown hinge, the top chords being taken in a straight line to a firm rock anchorage. On these straight back stays, a creeper traveller is to be built, which constructs the bridge panel by panel until both 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.

SIR W^M. ARROL & CO., LTD.

TENDER FOR AN ARCH BRIDGE



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

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

Messrs. Dorman Long & Co., of Middlesbrough, England, and Sydney and Melbourne, Australia.

This firm has submitted seven tenders based on the official specifications and plans, and are to be complimented on the excellence of the plans, calculations, and material submitted. The calculations submitted with tenders are of the highest order of perfection in soundness, thoroughness, and detail, even more so than the excellent calculation work of Sir Wm. Arrol & Co. and the Canadian Bridge Company. Messrs. Dorman Long & Co. have supplied full and accurate details of secondary stresses, which have been investigated on approved lines.

Arch and cantilever-arch calculations follow most modern practice, while cantilever bridge calculations make reference, amongst other matters, to the torsional action on the suspended span, and are unique in that in these calculations only is a complete discussion given of the distortion of sway and lateral frames of the main cantilevers due to differential deflections under unsymmetrical live load.

Associated as architects with Dorman Long & Co. is the eminent firm of Sir John Burnet and Partners, and as engineers, Mr. R. Freeman, M.Inst.C.E., M.Am.Soc.C.E., of Sir Douglas Fox and Partners, and Mr. G. Imbault, formerly chief engineer of the Cleveland Bridge and Engineering Company, of Darlington, England.

Messrs. Dorman Long & Co. propose to use silicon and carbon steel throughout in accordance with the specifications. Main members are of silicon steel, whilst lateral bracing, approach trusses, and most of the deck system are of carbon steel. There are no special alloy steels to be used.

Tender A1.—This tender, Plan No. 10, is for a two-hinged arch bridge of 1,650 feet span, with essential masonry piers and skewbacks only, *i.e.*, without the abutment towers included in the official design. The length of main bridge and approaches is 3,770 feet. The southern approach spans consist of five deck spans, 209 feet centres of bearings, whilst the northern approach spans, five in number, are about 190 feet centres of bearings. All piers and abutments are granite faced as specified. Tendered cost, £3,499,815 15s. This bridge is simple and elegant, but aesthetically too severe for its setting.

Messrs. Dorman Long & Co. propose to erect the arch bridge by cantilevering out from each shore, using wire cable backstays anchored in tunnels in solid rock. When the arch is connected at the centre, initial stress is put in the centre top chord to bring the structure to the two-hinged condition. [*Photograph No.* 8.]

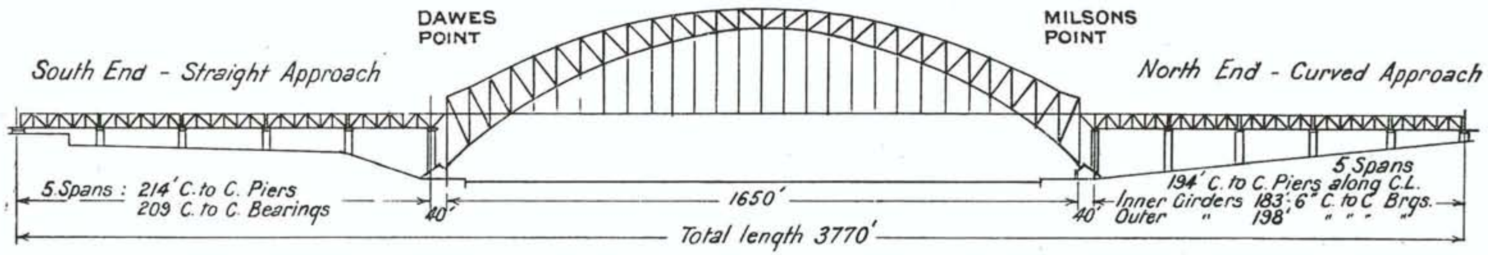
Tender A2.—This tender, Plan No. 10, is also for a two-hinged arch bridge of 1,650 feet span, but with alternative masonry abutment towers faced with pre-cast concrete blocks above plinth level in lieu of granite facing. The length of main bridge and approach spans is 3,770 feet. Owing to the design of the abutment towers, which are much longer than those provided in the official design, four steel approach spans of 193 feet 9 inches are required on the southern side, and on the northern side four spans of 166 feet 6 inches centre to centre of bearings. Tendered cost, £4,233,105 4s. 7d.

The bridge is attractive in appearance, but the abutment towers are too massive. [*Photograph No.* 9.]

Dorman Long & Co. Ltd.

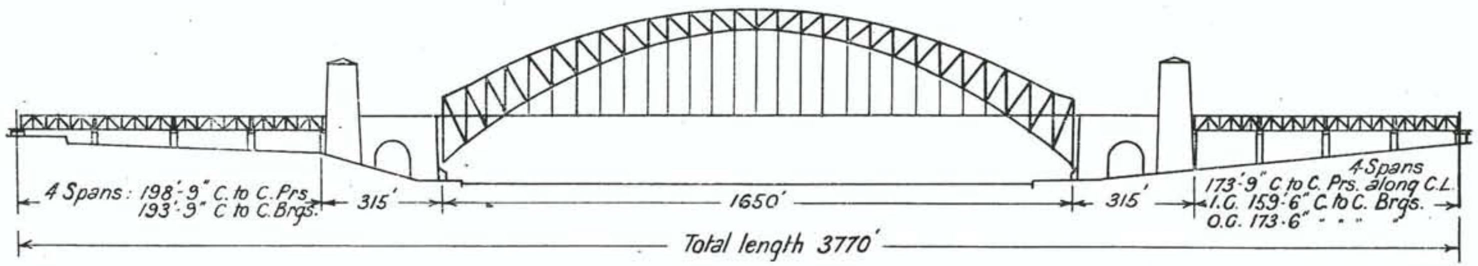
Tenders for an Arch Bridge

Tender A1



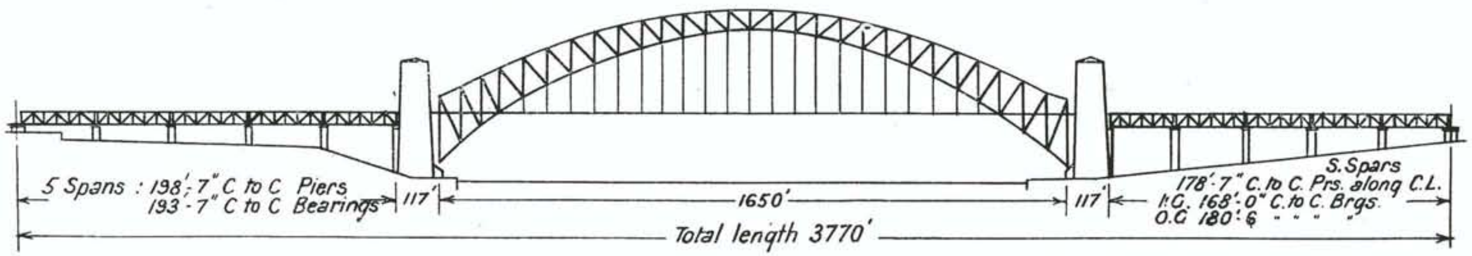
Alternative (A1). Without abutment towers, granite masonry facing ... ... £3,499,815 : 15 : 0

Tender A2



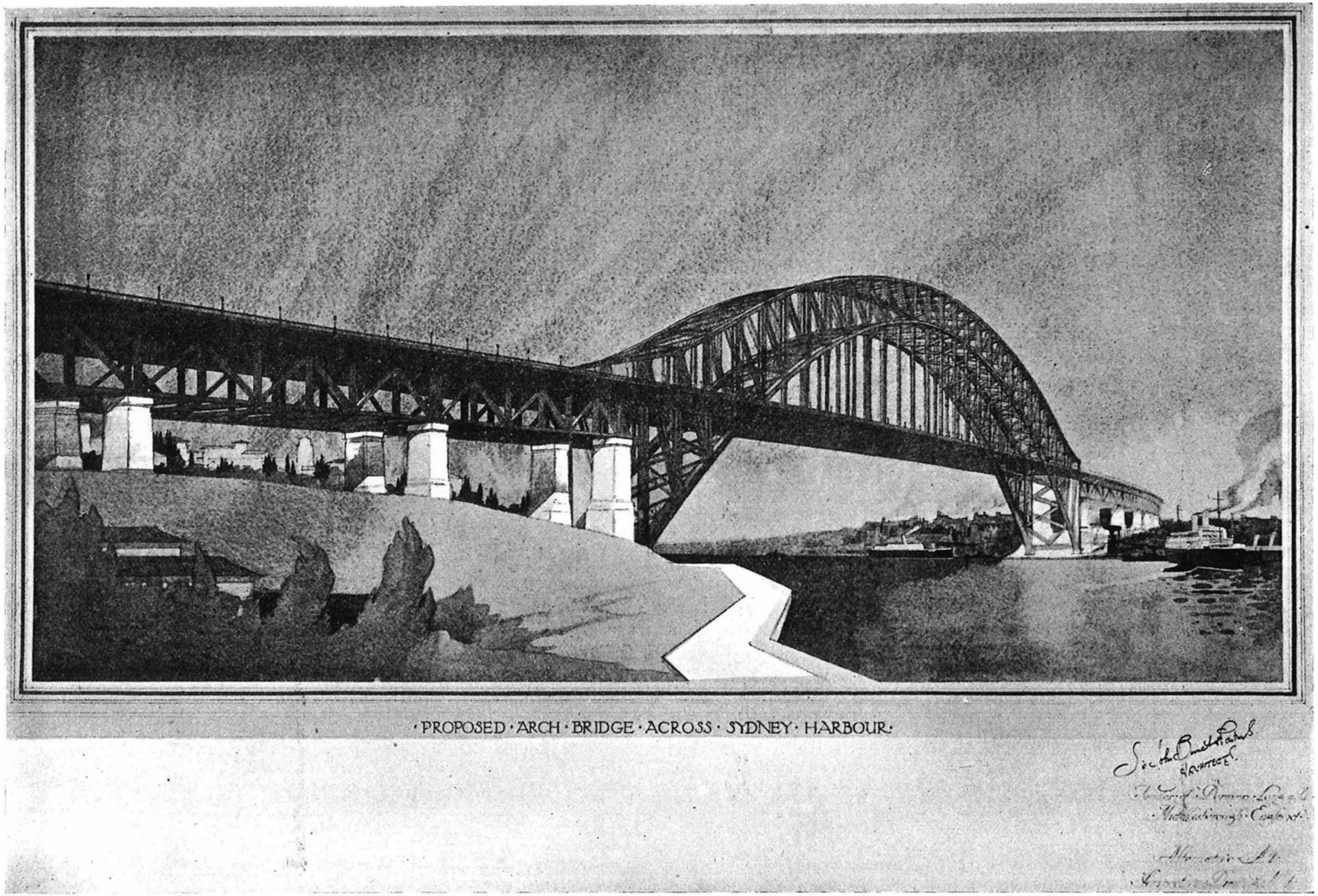
Alternative (A2). Abutment towers, Tenderer's own design, granite facing to plinth level, precast concrete blocks above plinth level ... ... £4,233,105 : 4 : 7

Tender A3

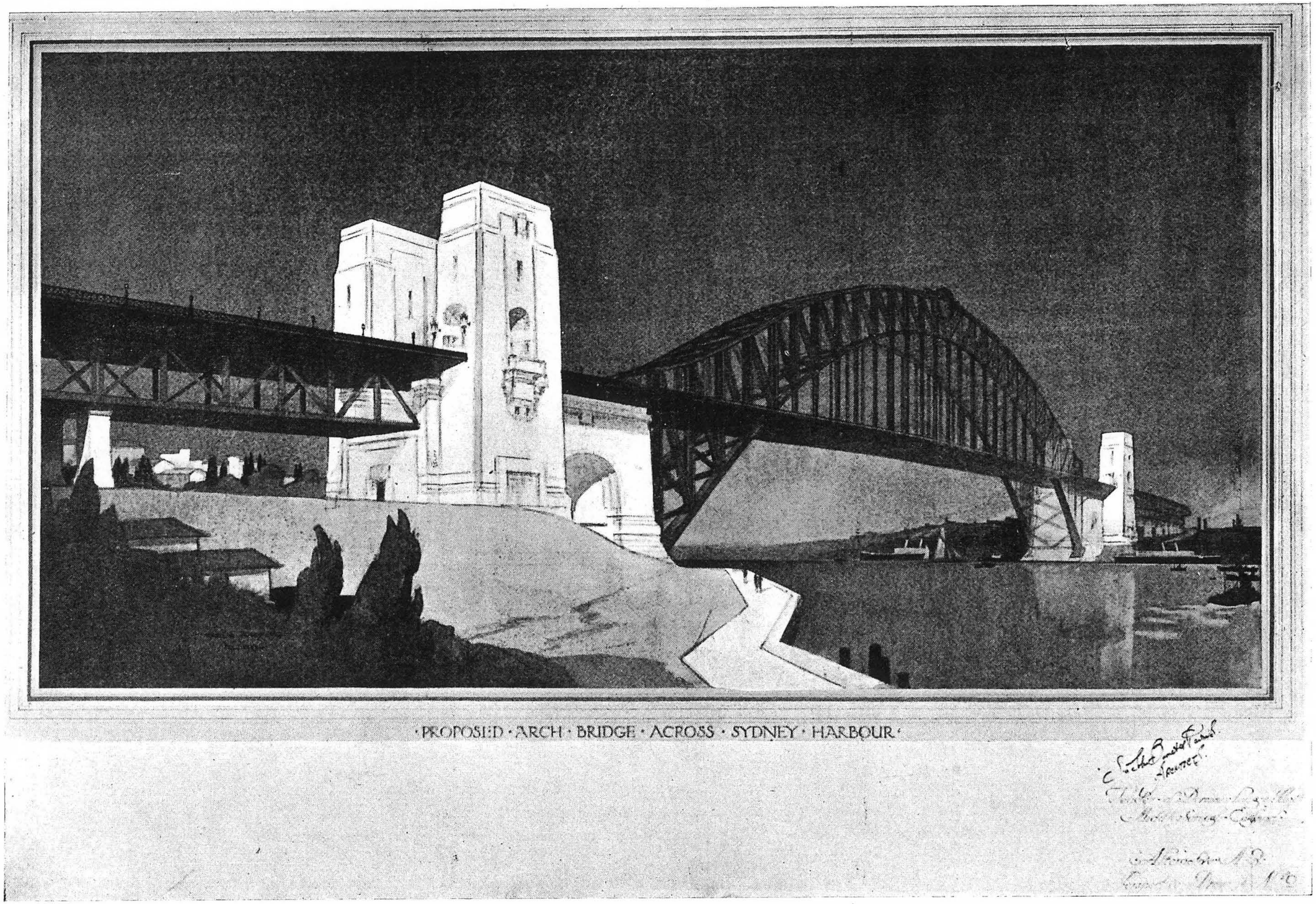


(A3) In accordance with Official Design, granite facing throughout ... ... £4,217,721 : 11 : 10

(A3) Alternative. In accordance with Official Design, but with towers of precast concrete blocks above plinth level ... ... £3,977,721 : 11 : 10



Photograph No. 8.—Dorman Long and Co. Tender A1.



Photograph No. 9.—Dorman Long and Co. Tender A2.

Tender A3.—This tender, Plan No. 10, in accordance with the specification and the official design, is also for a two-hinged arch bridge of 1,650 feet span, with the abutment towers faced with granite masonry as specified. The southern approach spans consist of five deck spans of 193 feet 7 inches, and on the northern side of five spans of 174 feet 3 inches centre to centre of bearings. The total length of the main bridge and approach spans included in the tender is 3,770 feet.

Tendered cost, £4,217,721 11s. 10d. This is the tender recommended for acceptance.

I have had perspective drawings prepared to compare with the perspective drawings of the alternatives submitted by Sir John Burnet and Partners, and consider this bridge has the best appearance and is the most attractive proposition of the seven tenders submitted.

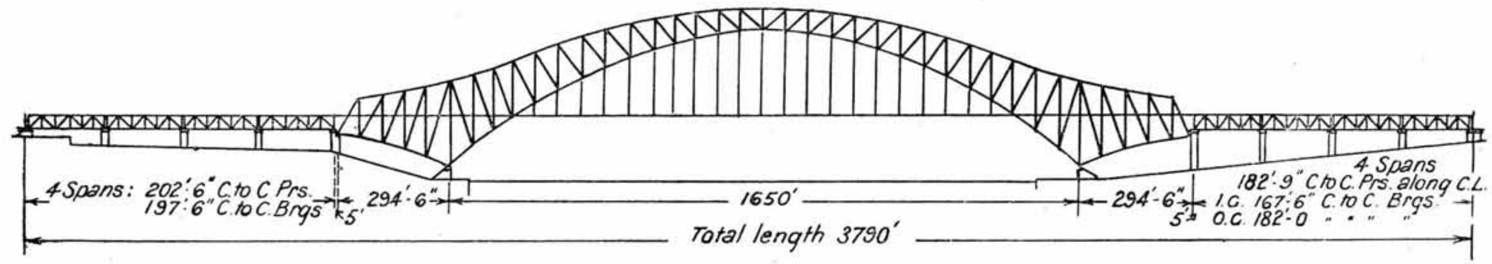
The calculated deflection at the centre of the steel arches included in the foregoing tenders, under full live load and impact, is 3·9 inches, or 3·55 inches for live load, whilst due to a rise or fall in temperature of 60 degrees, the up or down movement would be 7½ inches—a maximum movement under live load and temperature of 11·05 inches.

PLAN No. 11.

DORMAN LONG & CO. LTD.

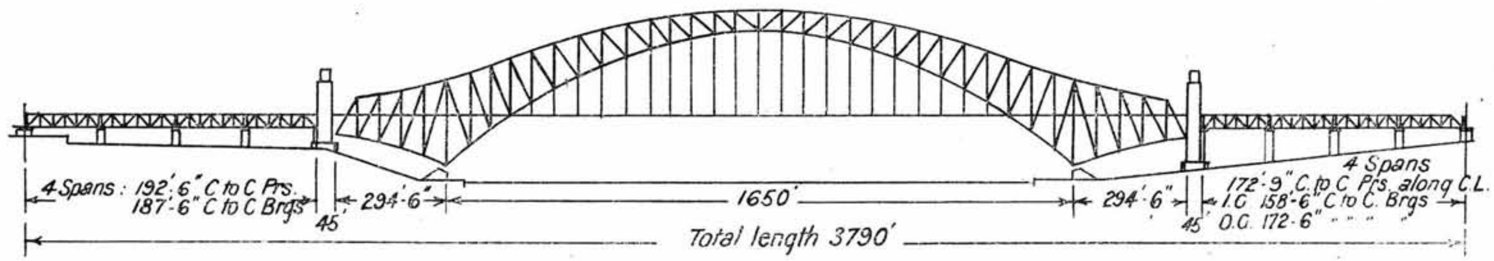
TENDERS FOR A CANTILEVER BRIDGE

Tender B1



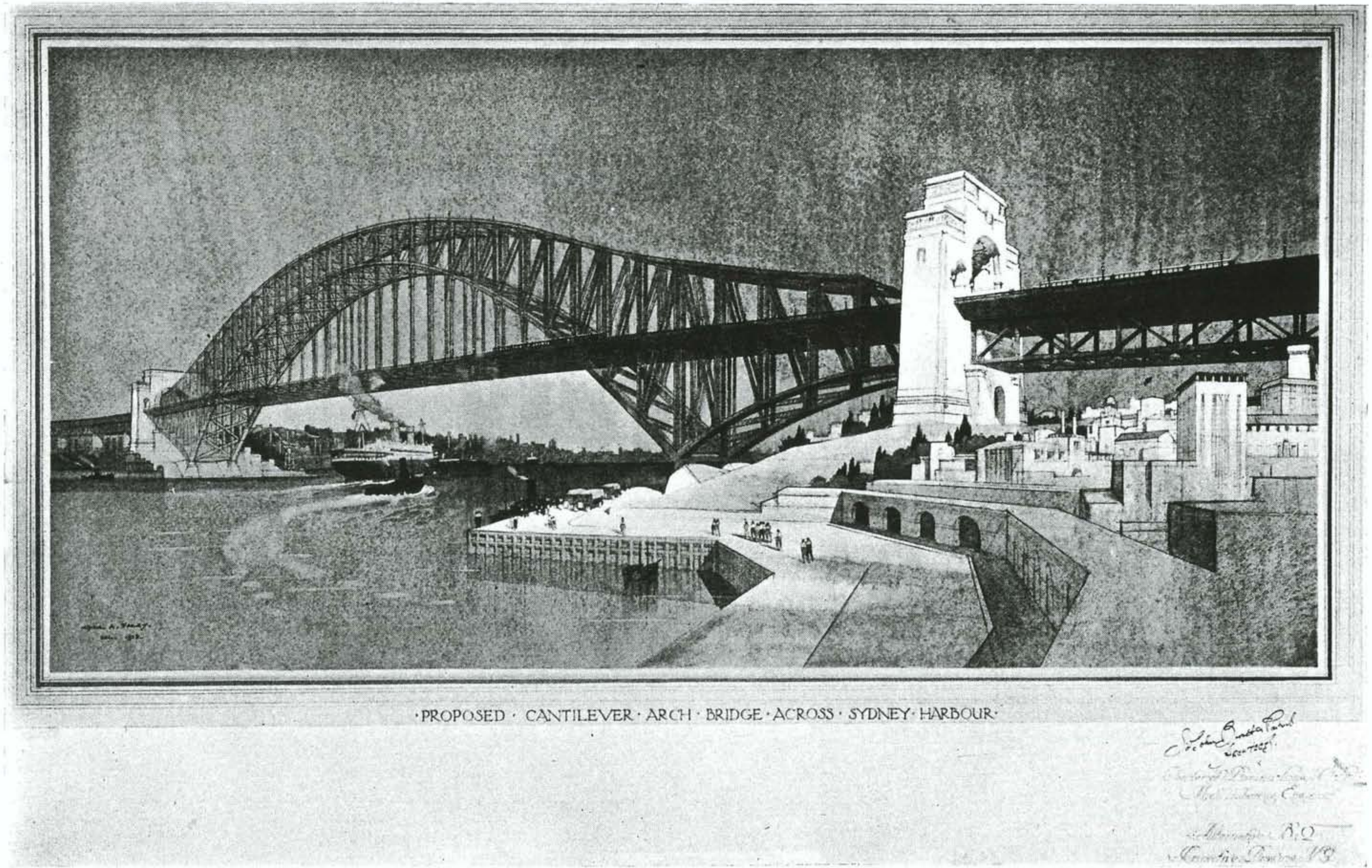
Alternative (B1). Granite facing throughout ... ... £3,709,686 : 2 : 6

Tender B2



(B2). Ornamental towers, granite facing up to plinth level, precast concrete blocks above plinth level ... ... £3,941,728 : 6 : 3

(B2). Alternative Granite facing throughout ... ... £4,175,523 : 0 : 0



Photograph No. 10.—Dorman Long and Co. Tender B2.

Tender B1.—This tender, Plan No. 11, is for a cantilever-arch bridge, the centre span of which is 1,650 feet and the anchor arms each 294 feet 6 inches long, or a total length of 2,239 feet overall, for the cantilever-arch trusses. The tender provides for the facing of the piers and abutments to be of granite as specified, but no ornamental towers are provided. The total length of the bridge tendered for is 3,790 feet. The approach spans on the southern side consist of four spans 197 feet 6 inches, on the northern side of four spans 174 feet 9 inches centre to centre of bearings. Tendered cost, £3,709,686 2s. 6d. This bridge, in architectural treatment, is on all-fours with tender A1. It is simple, elegant, but too severe for its setting. Of the two bridges, the simpler arch is the more attractive.

The cantilever-arch bridge would be erected by first constructing the shore arms on falsework, and then building out on each side, panel by panel, using wire cable backstays anchored in solid rock. Both halves of the bridge will then be adjusted to meet, and initial stress will be induced in the centre panel top chord by means of hydraulic rams before this member is riveted up.

Tender B2.—This tender, Plan No. 11, is for a cantilever-arch bridge, the centre span of which is 1,650 feet and the anchor arms each 294 feet 6 inches, or a total length of 2,239 feet for the cantilever-arch trusses. [*Photograph No.* 10.]

This tender provides for granite up to the plinth level and pre-cast concrete blocks above plinth level; ornamental towers are provided at the ends of the anchor arms. The total length of bridge tendered for is 3,790 feet. The approach spans on the southern side consist of four spans of 187 feet 6 inches, and on the northern side, four spans of 165 feet 6 inches centres of bearings.

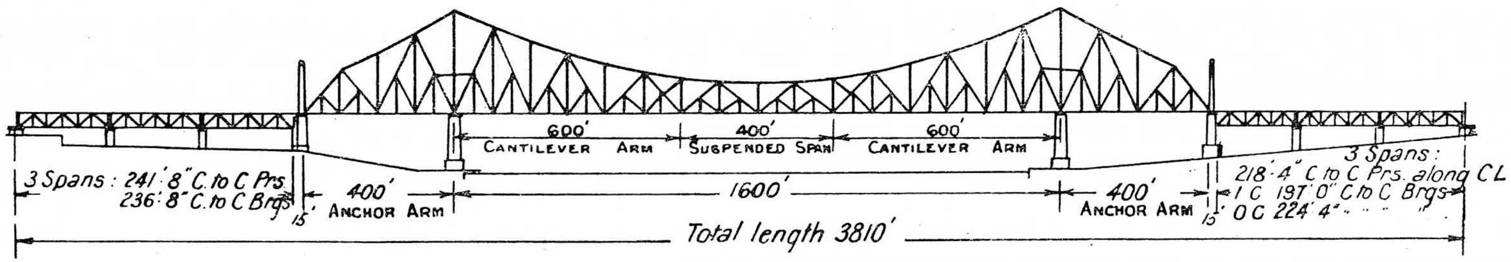
Under live load and impact the calculated deflection at the centre of the cantilever-arch is 4·4 inches, or 4 inches for live load, and due to temperature, 8 inches, or a maximum vertical movement of 12 inches under live load and temperature.

The tendered cost is £3,941,728 6s. 3d., with granite up to plinth level and pre-cast concrete blocks above plinth level, and with granite facing throughout, £4,175,523. This bridge is a simple composite structure harmonious in its conception, but it is not as elegant a structure as the arch bridge with abutment towers, tender A3.

DORMAN LONG & CO. LTD.

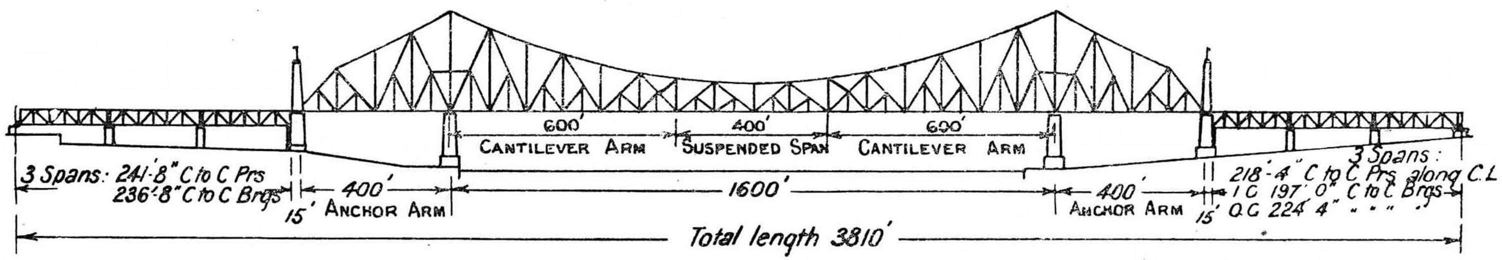
TENDERS FOR A CANTILEVER ARCH BRIDGE

Tender C1

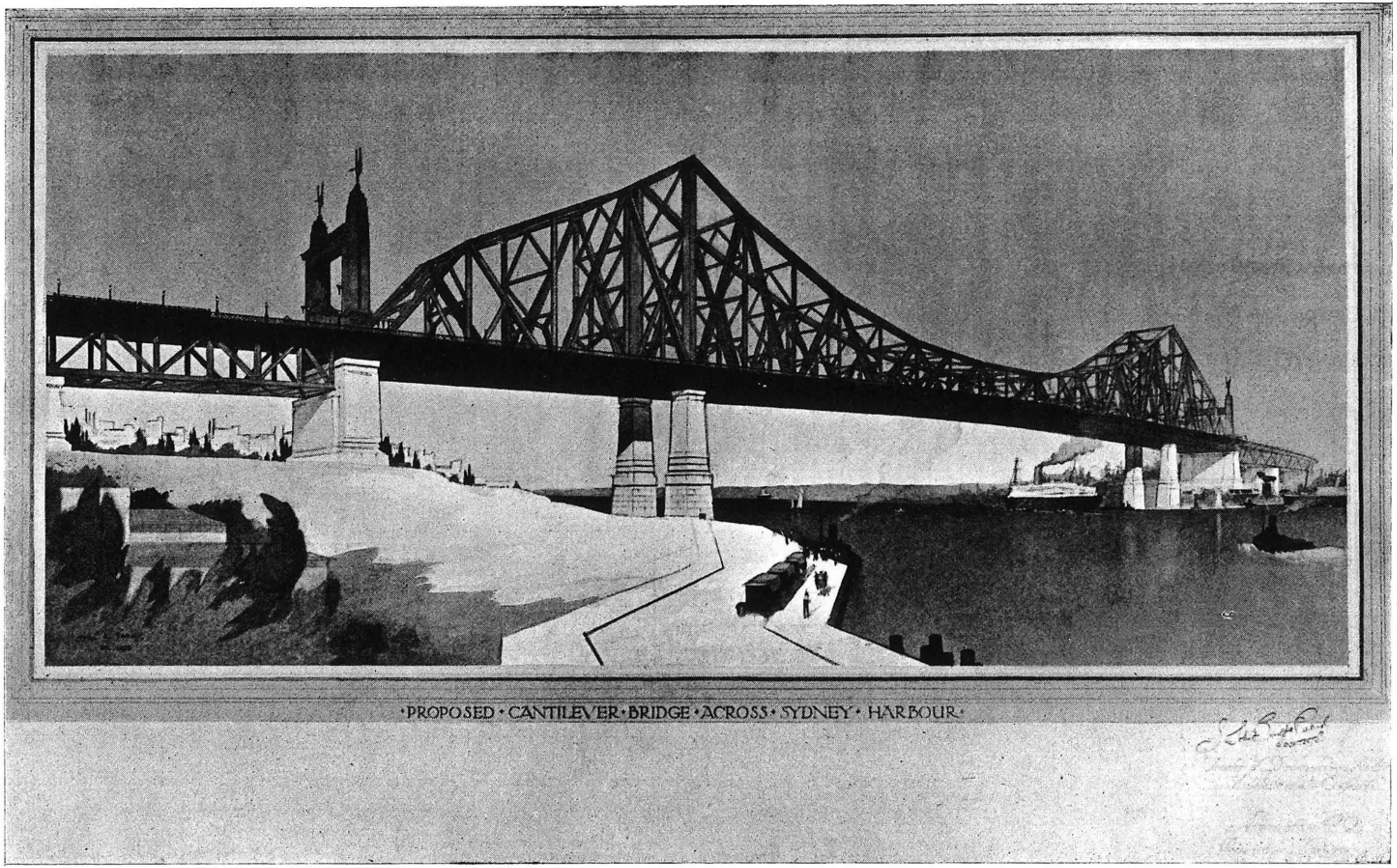


Alternative (C1). Granite facing throughout ... ... £4,551,758 : 13 : 3

Tender C2



Alternative (C2). Facing with precast concrete blocks ... ... £4,310,812 : 1 : 0



Photograph No. 11.—Dorman Long and Co. Tender C2.

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

Messrs. Dorman Long & Co.

Tender C1.—This tender, Plan No. 12, is for a cantilever bridge the centre span of which is 1,600 feet centres of main piers, the anchor arms being 400 feet long or 100 feet shorter than in the official cantilever bridge. There are three approach spans of 236 feet 8 inches centres of bearings on the southern side, and three approach spans on the northern side 210 feet 8 inches centres of bearings. The total length of bridge tendered for is 3,810 feet. The bridge is in accordance with the specification and provides for piers and abutments faced with granite masonry, and with the ornamental metal portals as specified. The amount of tender is £4,551,758 13s. 3d.

For erection, the anchor arms are first built on falsework, and the cantilever arms constructed by means of travellers running on deck level. The suspended span is to be cantilevered out from both sides, using two smaller travellers until both halves meet in the centre of the span.

Special attention has been paid by Sir John Burnet and Partners to the outline of the bridge. Its appearance is not as harmonious as the two-hinged arch bridge with abutment towers, while its cost is some £334,000 greater.

Tender C2.—This tender, Plan No. 12, is for a cantilever bridge, the centre span of which is 1,600 feet centres of main piers, the anchor arms being 400 feet long or 100 feet shorter than in the official cantilever bridge. There are three approach spans of 236 feet 8 inches centres of piers on the southern side, and three on the northern side 210 feet 8 inches centres of bearings. The total length of bridge is 3,810 feet. The bridge is in accordance with the specification, except that the piers and abutments are faced with precast concrete blocks in lieu of the granite specified. [*Photograph No.* 11.]

Under live load and impact the deflection at the centre of the suspended span is 12·5 inches, or 11·36 inches for live load, whilst temperature would cause an up or down movement of ·4 inches for a range of 60 degrees on either side of normal, making a maximum deflection of 11·76 inches for live load and temperature.

Tendered price is £4,310,812 1s., or £240,946 12s. 3d. less than the same bridge with granite masonry facing.

4.—Tendered Cost and Type of Bridge.

From the summary of tenders it will be seen that of the twenty tenders submitted by the six firms, five tenders are for arch bridges, two for cantilever-arch bridges, seven for cantilever bridges, five for suspension bridges, and one for a cantilever-suspension bridge.

Arch Bridges.

Of the five tenders submitted for the arch type, the lowest providing for granite facing for the piers and abutment towers as specified, is tender A3 of Messrs. Dorman Long & Co., at £4,217,721 11s. 10d. The second lowest tender is that of Sir Wm. Arrol & Co., at £4,645,351 7s. 8d., whilst the third lowest tender, providing for granite facing as specified, submitted by the McClintic Marshall Products Company, in conjunction with Mr. C. A. P. Turner, of Minneapolis, is for an amount of £6,053,565.

Of the twenty tenders received, the lowest is tender A1 of Messrs. Dorman Long & Co., for an arch bridge. This tender includes granite masonry facing for the piers, but does not provide for the abutment towers required by the official specification and plans. The amount of tender is £3,499,815 15s.

Messrs. Dorman Long & Co. also submit a third tender, A2, for an arch bridge with abutment towers of a somewhat different design to that shown on the official plans. This tender, amounting to £4,233,105 4s. 7d., provides for granite masonry facing up the plinth level with pre-cast white concrete blocks above plinth level.

The official estimate for the arch bridge based on British-Australian material in terms of the specification and on complete fabrication at Milson's Point is £4,339,530, all piers being masonry faced with granite.

Cantilever-arch Bridges.

The two tenders for cantilever-arch bridges were both submitted by Messrs. Dorman Long & Co.—tender B1 at £3,709,686 2s. 6d., and tender B2 at £3,941,728 6s. 3d. The first tender provides for granite masonry facing but does not provide for abutment towers, the second tender includes abutment towers designed by Sir John Burnet and Partners faced with granite masonry up to plinth level, pre-cast white concrete blocks being used above that level. Messrs. Dorman Long & Co. were asked on the 26th January to submit a price substituting granite masonry facing for the pre-cast stone in their tender B2, and as stated in their letter dated 8th January last this price is £4,175,523.

The cantilever-arch follows closely the official arch outline; the shore arms have been added in an attempt to improve the appearance and for economy. The tender for the simple arch bridge unadorned with towers, tender A1 of Messrs. Dorman Long & Co., is £3,499,815 15s., whilst the tendered cost of the cantilever-arch unadorned with towers, tender B1 of the same firm, is £3,709,686 2s. 6d.—a difference in favour of the simple arch of £209,870 7s. 6d., but the simple arch either with or without abutment towers is the more elegant bridge. If the cost of towers of the same design is added to the amount of tender for either the simple arch or the cantilever-arch bridge, the relative difference of £209,870 will still obtain. A simple arch is less costly than a cantilever-arch bridge and is more elegant.

Cantilever Bridges.

Of the seven tenders submitted for the cantilever type, the lowest tender providing for granite facing for the piers and abutments as specified is tender C1 of Dorman Long & Co., at £4,551,758 13s. 3d., whilst the second lowest tender is that of Sir Wm. Arrol & Co., at £4,978,488 7s. 8d., the third lowest tender providing for granite facing as specified is that of the Canadian Bridge Company, at £5,313,404 9s. 4d., whilst the comparable tender of the McClintic Marshall Products Company, is £6,499,377.

Of the tenders received for cantilever bridges, the lowest tender is that of Messrs. Dorman Long & Co., at £4,310,812 1s.; this tender provides for the substitution of pre-cast white concrete blocks for the granite masonry specified.

The McClintic Marshall Products Company also submitted two other tenders, the amount of masonry in the main and anchor piers being reduced on account of the type of cantilever adopted. These tenders are £5,958,356 and £5,654,531 10s. respectively, both of which are much higher in price than the tenders of either Messrs. Dorman Long & Co. or Sir Wm. Arrol & Co., but had they been lower in price they could not have been recommended as their appearance does not commend them.

The official estimate for the cantilever bridge based on British and Australian material in terms of the specification, and complete fabrication at Milson's Point is £4,704,840, all piers being masonry faced with granite.

Suspension Bridges.

The lowest tender for a suspension bridge providing for granite masonry facing as specified is that submitted by the Canadian Bridge Company for an " inverted arch " at a tendered cost of £5,091,202 18s. 4d. The second lowest tender is that of the English Electric Company of Australia Limited, at a tendered cost of £5,609,125 2s. 1d., and the third lowest tender providing for piers similarly faced with granite masonry is that of the McClintic Marshall Products Company, at £6,047,547.

The English Electric Company of Australia, Limited, submit two alternatives; the steel superstructure of the bridge is the same in all three tenders, but in one alternative it is proposed to substitute concrete for the granite facing, the tender being £4,943,763 0s. 5d., and in the other alternative to substitute brickwork facing with granite quoins, the price being £5,109,333 12s. 11d.

Cantilever-suspension Bridge.

A tender has been submitted by the Goninan Bridge Corporation of Newcastle, in conjunction with Messrs. Baume Marpent, of Haine St. Pierre, Belgium, for a cantilever-suspension bridge, the tendered amount being £10,712,015 19s. 8d. Of all the tenders received, this is the highest.

The above six tenders for suspension bridges were all prepared by American engineers, Mr. Gustav Lindenthal, of New York, designing the braced eyebar cable suspension bridge tendered for by the McClintic Marshall Company; Mr. Emil Larsson, of New York, the eyebar cable stiffened suspension bridge submitted by the Canadian Bridge Company;

Dr. Steinman and Mr. H. D. Robinson, of New York, the straight wire cable suspension bridge with continuous stiffening truss submitted by the English Electric Company of Australia, in their three tenders, and Mr. J. B. Strauss, of Chicago, in conjunction with Monsarrat and Pratley, designing the cantilever-suspension bridge submitted by the Goninan Bridge Corporation of Newcastle.

The lowest tender received for a suspension bridge with granite masonry facing is £873,000 higher than the best tender received for the official two-hinged arch bridge, and this suspension bridge tender is £539,000 higher than the lowest tender for the cantilever bridge. The tenders received certainly do not show the economy claimed for the suspension bridge.

Summary.

The lowest tendered prices for the various types of bridges, each faced with granite masonry, are as follow :—

Type.	Amount. £ s. d.	Tenderer.
1. Cantilever-arch	4,175,523 0 0	Dorman Long & Co.
2. Arch with abutment towers ...	4,217,721 11 10	Dorman Long & Co.
3. Cantilever	4,551,758 13 3	Dorman Long & Co.
4. Suspension	5,091,202 18 4	Canadian Bridge Company.
5. Cantilever-suspension	10,712,015 19 8	Goninan Bridge Corporation.

In all submissions to and interviews with the Minister my advice has been that the arch type of bridge would cost less than any other type, possibly £350,000 less than a cantilever bridge, that the cantilever bridge would be the next lowest in price, and the suspension type of bridge, whilst less efficient than either the arch or the cantilever, would be the highest in cost. The result of the tenders confirms my advice.

In the summary above, the cantilever-arch has less costly abutment towers than the arch bridge, but with the same abutment towers it would cost £209,870 7s. 6d. more than the simple arch bridge.

The tender of Messrs Dorman Long & Co. for the arch bridge with abutment towers, tender A3, at £4,217,721 11s. 10d., is the most favourable, and is in accord with the plans and specification issued when tenders were called.

5.—Engineering Aspects Governing the Choice of Type.

The choice of type for the Sydney Harbour bridge, quite apart from all question of cost, should be governed by certain engineering aspects which will now be considered.

Erection.

Of the three types of long-span bridges, the suspension bridge is the easiest to erect. The erection of the main towers on either side involves no special difficulty, and when these are completed, the main cables are strung across from anchorage to anchorage, one wire at a time if the cables are composed of straight wire strands, or hung from auxiliary cables if composed of eyebars. The main cables then form a supporting agent for the rest of the structure, which is assembled and riveted up.

The cantilever bridge again offers little difficulty. In the first place the shore or anchor arms are built upon falsework, and are anchored to the anchor piers. Starting from the main piers, a special erection traveller then builds out the cantilever arms. The suspended span may be cantilevered out as a continuation of this method, as proposed by the McClintic Marshall Products Company for their tenders B and C, and by Dorman Long & Co., or lifted bodily into position as proposed by all other tenderers submitting cantilever bridges. All these operations, though not as simple as the erection of a suspension bridge, present no real difficulty.

The erection of an arch bridge of large span has, in the past, been regarded as more difficult. It is, however, but an extension of the method by which the cantilever bridge is built, in that the anchors to tie the main structure back to the solid rock on either shore must be temporarily created by the use of backstays. The arch is then erected panel by panel as a cantilever until both sides meet in the middle.

Each of the three types of bridge can be satisfactorily and safely erected.

Rigidity.

All structures under the action of the rolling load deform as the load passes from one end of the bridge to the other. The relative amount of deflection under live load at the centre of the span is a criterion of the rigidity of the structure, and its suitability for the heavy railway traffic. Dealing first with bridges of the suspension type, the deflection under live load of the braced chain suspension bridge designed by Mr. Gustav Lindenthal is 3 feet 3·6 inches at mid-span, the deflection of the stiffened eyebar suspension bridge submitted by the Canadian Bridge Company is 2 feet 9·58 inches at the centre, and of the English Electric Company 1 foot 3·4 inches, my check figure on which gave 1 foot 6 inches, this suspension bridge being a remarkably rigid structure.

The deflection of the cantilever bridge submitted by the Canadian Bridge Company under live load is 2 feet 1 inch. This is due to heat-treated eyebars being used largely in its design. The cantilever bridges submitted by the firms of Messrs. Dorman Long & Co., and Sir Wm. Arrol & Co., fabricated wholly of built-up plates and shapes, are much more rigid under full live load; in the former, the deflection would be

11·36 inches, whilst Sir Wm. Arrol & Co's cantilever bridge, built of special carbon steel plates and shapes, would have a deflection of 12·04 inches at centre of the suspended span. The calculations for the official cantilever bridge using built-up members and eyebars gave a calculated centre deflection of 1 foot 1¼ inches.

The arch type of bridge is the most rigid; the three-hinged arch bridge submitted by Sir Wm. Arrol & Co., has a calculated deflection of 6·75 inches at the centre, whilst the two-hinged official arch bridge tendered for by Messrs. Dorman Long & Co., has a deflection of 3·55 inches at the centre under full live load. This tender provides for silicon and carbon steel built-up members throughout. My calculations made for a three-hinged arch bridge under full live load gave a centre deflection of 7 inches, and for the two-hinged arch, the official design as submitted for tenders, 4 inches under full live load.

It will thus be seen that a two-hinged arch bridge is more rigid than any of the other types, be it cantilever, suspension, or three-hinged arch. The two-hinged arch has only one-quarter the live load deflection that the most rigid suspension bridge yet designed has, one-third the deflection of a rigid cantilever bridge built up of plates and shapes, and 50 per cent. of the deflection of a three-hinged arch bridge.

Distortion under Unsymmetrical Live Load.

Inseparable from the question of rigidity is the question of distortion of the structure under an unsymmetrical live load. The symmetrical arrangement of the railway tracks on the bridge is a conspicuous feature of the layout of the structure as a whole, and its effect is to confine the forces due to live load on one side of the bridge entirely to one truss, so that when the two tracks on one side are simultaneously loaded, one truss sustains maximum distortion and the other is unaffected. In a suspension bridge the deflections produced are of considerable magnitude and give rise to serious problems in the design of the lateral and transverse bracing. In a cantilever bridge and the very rigid suspension bridge submitted by the English Electric Company the deflections are much less than in a suspension bridge of ordinary type; but, nevertheless, there is sufficient distortion produced to render the use of upper lateral bracing on the main trusses impossible, and in a cantilever bridge to set up heavy twisting and shearing on the rigid sway frames, with consequent large secondary stresses.

The same causes produce the effect of torsion on the suspended span of a cantilever bridge, when diagonally opposite portions of the channel span are loaded, causing the two corresponding supports of the suspended span to fall. The result is a twisting effect on the suspended span, which renders the use of the top lateral bracing on the span doubtful, and if the deflections are heavy, impossible. Consequently, also, sway frames of the suspended span are subject to heavy bending stresses.

In the case of an arch bridge, the tendency of one truss to distort under unsymmetrical loading can be restrained by means of lateral bracing of the same type as that required to resist lateral wind force, the relative distortion is reduced to a relatively small amount, and produces no special difficulty in the design of bracing, with very small secondary stresses in main strusses.

It is not an unlikely condition that the two railway tracks on one side of the bridge will be loaded simultaneously whilst the tracks on the other side are unloaded. The deck of the bridge would then have a lateral cross-fall under live load, governed in magnitude by the deflections of the various bridges under consideration, which could be immediately reversed in direction if the other pair of tracks were loaded. This tendency to see-saw under the action of the railway trains would produce a racking and straining of the rigid connections of the deck, which is more pronounced the less rigid the structure is. This see-sawing would be greater with a suspension bridge than with a cantilever bridge built up of plates and shapes, whilst with the arch bridge the deflection is so small that this tendency to dance would not be noticeable.

The two-hinged arch bridge is least affected by unsymmetrical loading, *i.e.*, when one truss takes the full railway load and the other is unloaded. It is, therefore, to be preferred to either the cantilever or the suspension bridge.

The Approaches.

It is interesting to note in connection with the Hell Gate arch bridge that a suspension bridge was found to be impracticable on account of the sharp curves it would necessitate on the approaches. Curiously, a parallel condition exists with the Sydney Harbour Bridge. With all the suspension and cantilever bridges, including the official cantilever bridge, the best curve in approach which can be obtained is 500 feet radius; with an arch bridge a curve of 1,200 feet radius can be obtained, the reason being that cantilever and suspension bridges have straight shore spans, and the railway cannot begin to curve away until it passes the ends of the anchor arms or the anchorage of the suspension bridge, in the case of the Sydney Harbour Bridge a distance of 500 feet, whereas with the arch bridge, the railway can begin to curve away at a point 500 feet nearer the water.

As the approaches are, in places, on a grade of 1 in 40, with an arch bridge there will be an appreciable saving in maintenance and running costs over either a cantilever or a suspension bridge, whilst a greater average running speed can be maintained.

Appearance.

The suspension bridge with centre and side spans suspended from the main cables is generally considered the most graceful type of bridge on account of its light appearance and the sweep of its cables. Stiffened suspension bridges, however, suffer from the disability that, when viewed from a distance, the light cables and suspenders vanish, with the result that the sweep of the cables is lost and the eye is left unsatisfied, only the shallow stiffening trusses remaining visible.

The most graceful suspension bridge submitted is that of McClintic Marshall Products Company, designed by Mr. Gustav Lindenthal, of New York, a braced cable bridge with loaded backstays. In this case the sweep of the cables is well marked by the cable bracing, and would be the striking feature when viewed from any distance. The towers are slender and elegant, and the anchorages are in proportion. The suspension bridge submitted by the Canadian Bridge Company also will not suffer in appearance due to this vanishing of the cables, for the cables and top chords of the stiffening trusses are coincident. In appearance this bridge resembles a cantilever bridge without its massiveness.

The appearance of the stiffened suspension bridge submitted by the English Electric Company lacks balance, and is not pleasing on account of the short shore arms and straight backstays. Further, when this bridge is viewed from a moderate distance, the cables will be almost invisible and the hangers completely invisible, leaving the towers gaunt sentinels against the skyline and the stiffening truss alone visible over the harbour. There would then be no apparent reason for the existence of the towers and massive anchorages, some 200 feet high and long, and more particularly for the unusual shape of the stiffening truss. The increase in depth at the quarter points and over the towers, while structurally a most important and unique feature of this bridge, would then, from the aesthetic point of view, further detract from its appearance on account of the "angularity" produced at these points.

A more solid appearance is afforded by the cantilever bridge, which offers greater mass to the eye than the suspension bridge. If built on strictly utilitarian lines the cantilever bridge is not beautiful, but, as in the Forth bridge, the cantilever type can show harmony of proportion, truth, strength, and dignity.

All these desirable features are possessed by the cantilever bridges submitted by the Canadian Bridge Company and Sir Wm. Arrol & Co., which closely follow the outline of the official cantilever bridge. The sweep of the upper chords in the main span, the towers over the main piers, and the falling curves of the anchor arm top chords produce a graceful effect similar to that of the suspension bridge, and express harmony with the rising foreshores on either side.

The appearance of the two-hinged arch, in the opinion of many people, is to be preferred to a cantilever bridge, and its appearance is superior to two of the suspension bridges submitted and not inferior to that submitted by the McClintic Marshall Products Company. The two-hinged arch is a handsome structure, the abutment towers are in keeping with the graceful outline of the arch, which conforms to the principles of truth, for "beauty is truth and truth is beauty." The arch, graceful at the crown, has depth where it is wanted, the floor line is well marked from end to end of the structure, and the rib, beautiful in its strength and its simplicity, demonstrates clearly its purpose, taking the eye down to the abutments on either side without camouflage or interruption.

6.—Supply of Australian Steel.

The specification, clause 16, requires that "The contractor must provide in his tender to utilise as far as is reasonably practicable all materials called for by this specification which are being manufactured in New South Wales at the date of the closing of tenders." Carbon steel, silicon steel, and the various alloy steels are included in the specification; the tenders indicate that only carbon and silicon steel will be required for the bridge.

The Broken Hill Proprietary Company is making carbon steel with approximately the chemical and physical properties required by the specification; there is little doubt but that the Broken Hill Proprietary Company will be able to produce the carbon steel flats and shapes required. Last year the company made a test ingot of silicon steel endeavouring to meet the requirements of the specification. Test specimens were sent by the Department to the University and were tested by Professor Warren. The chemical tests were not altogether in accord with the specification, and the physical tests fell just below the specification. The steel was particularly free from sulphur and phosphorus, but the percentage of silicon was too high and the percentage of manganese was too low to enable the steel to meet the tensile and bending tests.

I have little doubt that the Broken Hill Proprietary Company can produce the ingots of silicon steel, but the rolling of these ingots into angles up to 10 in. x 10 in. x $1\frac{1}{4}$ in., and flats up to 30 in. wide able to withstand the tests specified is another matter. The company will not undertake to produce the plates required for the bridge, so the plates cannot be obtained in Australia. The material for the Sydney Harbour Bridge must be the best that can be produced and above suspicion. Specimens cut both lengthwise and crosswise from the rolled material must fulfil the physical tests, and more especially the bend tests. In making silicon steel material there will, without doubt, be reject material, and as there is no outlet for such material in New South Wales, the making of silicon steel shapes and flats up to 30 in. wide, which must meet the requirements of the specification, may probably prove financially unattractive to the company.

To roll the plates required for the Sydney Harbour Bridge, slabbing and plate mills equal to the largest in existence, costing approximately £2,000,000 sterling, would have to be established. Open-hearth plant necessary to maintain these plate mills in continuous operation would cost another £1,000,000 sterling. Such a plant would require at least three years to erect and could give an output of 3,000 tons per week of plates $\frac{3}{16}$ inch or over in thickness, or allowing for contingencies, repairs, holidays, &c., about 120,000 tons per annum.

A return furnished me by the Acting-Collector of Customs, Sydney, states that particulars of imports of steel plates over $\frac{3}{16}$ in. in thickness are not separately recorded in the statistics of that Department, but these imports are included under the general heading of "Iron and Steel, Plate and Sheet (plain), not galvanised." The total tonnages of iron and steel plate and sheet imported, for the years 1919-20, 1920-21, 1921-22, and 1922-23, are :—

	Tons.
1919-20	30,602
1920-21	74,171
1921-22	26,048
1922-23	37,056

Of this tonnage, probably not more than 40 per cent. would be plates $\frac{3}{16}$ in. thick and upwards, and during each of the last two years the tonnage of these plates imported would not exceed 15,000 tons.

It is clear that the requirements of Australia do not, at the present time, justify the establishment of plate mills and open-hearth plant at a cost of £3,000,000 sterling, which would meet present requirements if in operation less than two months of the year.

It is impossible to obtain all the steel in Australia for a bridge of this magnitude, but all firms tendering desire to purchase portion of their metalwork in New South Wales as under :—

The English Electric Company of Australia.—Out of a total of 47,028 tons, this firm is willing to purchase 24,298 tons of sections from the Broken Hill Proprietary Company and 4,722 tons of galvanised steel wire and cable wrapping from Ryland's (Australia) Limited, about 60 per cent. of the total.

The company states in their tender that the amount of money to be spent abroad is 12½ per cent. of their amount of tender, *i.e.*, approximately £700,000.

The McClintic Marshall Products Company.—This company is prepared to purchase material up to 12,135 tons from the Broken Hill Proprietary Company if it can be obtained.

Sir Wm. Arrol & Co. — This firm has asked the Broken Hill Proprietary Company to supply 14,500 tons of shapes and plates up to 30 in. wide. The Broken Hill Proprietary Company does not guarantee to supply the above, but is prepared to cut rolls provided the tonnage is sufficient to warrant it in doing so.

Out of a tendered cost of £4,978,488 for the cantilever bridge, the firm estimates that the net cost c.i.f. excluding duty of material imported is £1,767,000, or 35 per cent. of the total, or with duty £2,210,000, which is 44 per cent. of the total tender, 56 per cent. of the tendered price being for work executed in New South Wales, profit, &c.

For the arch bridge, including duty, the value of the work to be imported is £1,746,000, the total tendered cost being £4,645,351, *i.e.*, 62·4 per cent. of the tendered price is for work executed in New South Wales, profit, &c.

The Canadian Bridge Company.—This company proposes to purchase from the Broken Hill Proprietary Company 5,400 tons of plates and shapes for the "inverted arch" bridge, and 4,230 tons for the cantilever bridge.

The Goninan Bridge Corporation, Newcastle.—This company states it proposes to obtain 24,236 tons of material purchased from the Broken Hill Proprietary Company, Newcastle.

Messrs. Dorman Long & Co. — Under their tenders, Messrs. Dorman Long & Co. propose to purchase in New South Wales materials up to the capacity of the New South Wales mills (subject to the same being to specification requirements) as under :—

Tender.	Total tonnage.	From New South Wales. Sections.	From England. Plates.
A 1	50,893	24,444	26,449
A 2	50,515	24,713	25,802
A 3	51,095	24,837	26,258
B 1	57,020	27,977	29,043
B 2	57,119	28,174	28,945
C 1	65,162	33,564	31,598
C 2	65,047	33,506	31,541

The Broken Hill Proprietary Company has been asked to supply 25,000 tons of steel, is able to supply 18,000 tons, and if the balance can be obtained from the Broken Hill Proprietary Company or other local mills, it will be obtained.

In tender A3, the value of the material to be imported is £343,800, which represents but 8·1 per cent. of the total amount of tender.

Dorman Long & Co. are also willing to take from the Broken Hill Proprietary Company any suitable material they may roll during the continuance of the contract, providing same is delivered so as not to impede fabrication requirements.

Summary.

From the foregoing it is evident that all the tenderers would obtain a proportion of their material from the Broken Hill Proprietary Company. The English Electric Company of Australia and Messrs. Dorman Long & Co. propose to purchase as much material, subject to specification requirements, as can be obtained in New South Wales. Sir Wm. Arrol & Co. and the McClintic Marshall Products Company have also fairly endeavoured to meet the specification in this respect.

Clause 68 of the specification stipulates : " All steel for any purpose in this bridge shall be made by manufacturers of established reputation for the kind and character of the steel specified."

At the date of the closing of tenders, the silicon steel which will be required in the construction of the bridge as plates and heavy angles, had not been manufactured in Australia, nor are there rolling mills in Australia capable of rolling such plates. Likewise, high-grade galvanised steel wire suitable for bridge construction was not being made in Australia.

It is evident that as much Australian steel as the rolling mills in Australia can produce to comply with the requirements of the specification and of the accepted tender, will be used in the bridge. Indications are that 50 per cent. or more will be manufactured in Australia.

7.—Fabrication of Metalwork in New South Wales.

The summary, page 3, also gives the tonnages of metalwork which the various firms propose to fabricate in New South Wales and to import from abroad. These tonnages do not include ornamental gunmetal castings or the steel rails for the railway tracks.

Of the six firms tendering, two firms, viz., Messrs. Dorman Long & Co. and the English Electric Company of Australia, tender to fabricate the whole of the metalwork in New South Wales. Messrs. Dorman Long & Co., under their tender for a cantilever bridge, would fabricate the whole of the metalwork, some 65,453 tons, at Milson's Point, whilst under their tender for an arch bridge, 50,288 tons would be fabricated there.

The tender of the English Electric Company of Australia includes some 46,108 tons of steel to be fabricated in Sydney.

The Goninan Bridge Corporation of Newcastle, out of 43,939 tons, proposes to fabricate 24,236 tons at Newcastle, the balance, 19,703 tons, comprising the heavy steel cantilevers, would be fabricated of British steel in Belgium by Messrs. Baume, Marpent, the firm with which the Goninan Bridge Corporation is associated.

The other three firms propose to fabricate the major portion of the metalwork outside New South Wales.

Sir Wm. Arrol & Co. propose to fabricate the bridge in Sydney and Glasgow. For their cantilever bridge there is a tendered tonnage of 57,653 tons, about 13,495 tons of which would be fabricated locally, whilst for their arch bridge, of tendered tonnage 40,228, about 13,682 tons would be fabricated locally. In addition, Sir Wm. Arrol & Co. propose to fabricate the necessary falsework in Sydney, or, including the main bridge, a total of 21,670 tons for the cantilever bridge and 15,740 tons for the arch bridge.

The McClintic Marshall Products Company proposes to fabricate the metalwork in Sydney and in the United States. Under their most favourable offer for a cantilever bridge, out of a total of 50,191 tons, some 17,000 tons, or about 30 per cent., would be fabricated in Sydney, and the balance imported from the United States.

The Canadian Bridge Company proposes to fabricate the steelwork in New South Wales, the United States, and Canada. Out of a tonnage of 38,064 for their cantilever tender, the amount to be fabricated in New South Wales is 4,230 tons, or about 11·1 per cent. of the total, whilst for their suspension bridge or "inverted arch," out of 38,015 tons, it is proposed to fabricate 5,400 tons, or about 14·2 per cent. of the total, in New South Wales.

Considering the most favourable tender from each firm, on the basis of the tonnage to be fabricated in New South Wales, the relative order of the firms tendering is :—

Messrs. Dorman Long & Co.	Cantilever bridge	65,453 tons.
	Arch bridge	50,288 ,,
The English Electric Company of Australia	Suspension bridge	46,108 ,,
Goninan Bridge Corporation	Cantilever-suspension bridge	24,236 ,,
McClintic Marshall Products Company ...	Cantilever bridge	17,000 ,,
Sir Wm. Arrol & Co.	Arch bridge	13,682 ,,
The Canadian Bridge Company	Suspension bridge	5,400 ,,

Although the tonnage to be fabricated in New South Wales by Messrs. Dorman Long & Co. for either a cantilever or an arch bridge is greater than the tonnage proposed by the English Electric Company, yet as each firm tenders to fabricate 100 per cent. of the steel in New South Wales, they are equally satisfactory proposals in this respect.

The other four firms will fabricate portion of the steelwork abroad, and the amount of duty included in their respective tenders is as under :—

Name of Firm.	Type.	Tonnage imported.	Amount of duty stated in Tender.
			£ s. d.
The Goninan Bridge Corporation ...	Cantilever-suspension ...	19,703	1,268,536 16 0
The McClintic Marshall Products Company.	Cantilever	33,191	691,140 0 0
The Canadian Bridge Company ...	Suspension	32,615	517,400 0 0
Sir Wm. Arrol & Co.	Arch	26,546	368,928 16 10

The tender of Sir Wm. Arrol & Co. for the official arch bridge is the lowest tender received for any type of bridge which provides for fabricating the main members abroad, and is, therefore, comparable with tender A3 of Messrs. Dorman Long & Co., which is also for the official arch bridge, but which tender provides for fabricating wholly in New South Wales. The duty payable on fabricated steelwork is given by Sir Wm. Arrol & Co. in their tender as £368,928 16s. 10d. The tenders of the English Electric Company of Australia and of Messrs. Dorman Long & Co. include plates which cannot be manufactured in Australia, the former firm stating that 60 per cent. of the steelwork required will be obtained in Australia, and Messrs. Dorman Long & Co. have asked the Broken Hill Proprietary Company to supply at least 50 per cent., and will obtain from the Broken Hill Proprietary Company all steel which that firm can manufacture to comply with the specification.

At a meeting of the Tariff Board, held in Melbourne on 13th August last, at which representatives of Australian steel producers and myself were present—there were no representatives of the English Electric Company of Australia, the Goninan Bridge Corporation, or Messrs. Dorman Long & Co., of Sydney, present at that meeting, or, if there were, I did not recognise their representatives—the meeting was unanimously of the opinion that all material necessary for the construction of the bridge which could not be produced in Australia should be admitted under tariff item 404 free (British preferential tariff), and 10 per cent. (general tariff).

The meeting also decided that corrugated and buckled plates, also eyebars and eyebar pins could not be produced in Australia, and considered these items should be admitted under item 404. Under the Customs tariff, 1921, it appeared as if on and after 1st January, 1922, there was a duty of 48s. per ton on plates imported from Great Britain and 85s. per ton foreign. It was pointed out that under a by-law already in operation, plain plates of 30 inches or over in width, and over 10 guage, were already admissible under item 404; but in order to make the position perfectly clear, a subsequent by-law was issued extending the provisions of the original by-law to cover plates planed on ends but not cut to size in cases where they might be too thick to be cut by shearing and therefore had to be cut by planing.

I had been asked by tenderers to obtain the Tariff Board's ruling in this matter, also to get their ruling on eyebars, eyebar pins, and on buckled and corrugated plates. There had been correspondence with the Tariff Board in March, 1922 and subsequently, in reference to these matters, and in response to a telegram from the Acting-Chairman, I attended the Melbourne meeting. I was not sent by the Government of New South Wales, nor did I, on behalf of the Government, ask for any amendment in duty. I pointed out to the Tariff Board that, by imposing a duty on material for the bridge which could not be manufactured in Australia, it was simply taking money out of His Majesty's State pocket and putting it into His Majesty's Federal pocket; that the property-owners paying the tax and the railway passengers would have to provide this money if the duty were imposed, unduly penalising this section of the community, as they alone, and not the people of Australia or of New South Wales, are paying for the bridge, without benefiting any industrial enterprise.

Following this meeting the Tariff Board recommended, and the Minister for Trade and Customs, on 4th September last, approved that steel for the bridge as under, which could not be manufactured in Australia, should be admitted under item 404, free (British preferential tariff) and 10 per cent. (general tariff) :—

(1) Plates and buckled or corrugated plates, over 30 inches in width sheared or planed but not finished to size, of any specification or alloy, if undrilled or otherwise unmanufactured—Item 404.

(2) Eyebars and eyebar pins as specified, of any steel or specification—Item 404.

(3) Non-fabricated structural steel shapes being rolled steel beams, channels, joists, girders, columns, trough and bridge steel not drilled or further manufactured, including such shapes of carbon or alloy steels will be dutiable under tariff item 155 at 48s. per ton (British preferential tariff), 90s. per ton (general tariff).

This decision gave firms, wishing to fabricate the bridge in Australia, an advantage over firms importing the bridgework already fabricated, in that it was now clear to the former that no duty would have to be paid on the rolled plates, plain, buckled, or corrugated, but otherwise unmanufactured, whilst the importing firms would have to pay duty on the value of the rolled material plus the cost of fabrication. Therefore, this decision of the Minister for Trade and Customs helped to make it possible to fabricate the bridge wholly in Australia in admitting plates duty free which the Australian steel rolling mills could not and did not propose to roll.

On 18th December last, the Acting-Chairman of the Tariff Board informed me by letter as under :—

> It has been found necessary to alter the wording of the decision of 4th September last regarding plain and buckled or corrugated plates for the Sydney Harbour Bridge, as the original wording raised a doubt as to whether certain plates would be dutiable or admissible under by-law.
>
> The amended decision reads as follows :—
>
> (*a*) " Iron and steel plates and sheets, plain, of greater thickness than 10 gauge and over 30 inches in width, to be used in width of over 30 inches, sheared or planed edges, cut to size or otherwise, if undrilled or otherwise unmanufactured, for use in the construction of bridges ... Item 404.
>
> (*b*) " Iron and steel plates, buckled or corrugated, sheared or planed edges, of any specification or alloy, if undrilled or otherwise unmanufactured, for use in the construction of bridges ... ... Item 404.

It will be noticed that the words " not finished to size " have been left out, and the words " cut to size or otherwise " have been substituted. Also, that in the case of plain plates, a stipulation is made that they must be used in widths over 30 inches.

So far as buckled or corrugated plates are concerned, no restrictions are now imposed regarding gauge or width.

One firm tendering for wholly Australian fabrication has, I understand, objected to the words, " cut to size or otherwise." I have no knowledge why these words were inserted, and I never, at any time, made representations to that effect. However, if the plates cut to finished size could be transported from abroad to Sydney without damage to the finished surfaces, this ruling would not be detrimental to firms wishing to fabricate the material locally, as they would obtain the plates duty free Britain or 10 per cent. foreign, with a certain amount of work already done abroad, whereas firms importing the bridgework fabricated would have to pay 35 per cent. (British preferential tariff) and 45 per cent. (general tariff) duty on the value of these plates plus fabrication.

These decisions of the Tariff Board in regard to plates, while not in any way prejudicial to the interests of any Australian manufacturer of steel, have assisted the English Electric of Australia and Messrs. Dorman Long & Co. to tender for fabrication wholly in New South Wales. This latter firm intends to erect shops which will be an asset to the firm on the completion of the bridge, and these shops are not charged against the bridge in Messrs. Dorman Long & Co.'s tender.

On this account, and because of the saving of shipping, freight, and handling charges on the very heavy fabricated members, if imported, Messrs. Dorman Long & Co. have submitted a most attractive tender.

The tender recommended does not contain any eyebars. The plates, which cannot be produced in New South Wales to comply with the specification, will be imported from Middlesbrough, England, just as they leave the rolling mills, and will be fabricated wholly in New South Wales; there will be no planing or cutting to sizes before they leave England.

8.—The Most Acceptable Tender.

In deciding which is the most acceptable tender, engineering and economic aspects must be considered in conjunction with the financial aspect.

The engineering considerations are :—

(*a*) The bridge must be the best that engineering skill can devise. It must be of unquestionable strength and stability. It should have the maximum rigidity vertically under the rolling load and laterally under wind pressure so that by its freedom from vibration it may have the reputation of being the strongest and the most rigid bridge in the world.

The arch bridge fulfils these conditions much better than any other type, and of the tenders submitted a cantilever bridge is next best. The tender of Dorman Long & Co. is the most acceptable for an arch bridge, and for a cantilever bridge the most acceptable tenders are those of the Canadian Bridge Company and of Sir Wm. Arrol & Co.

(*b*) The bridge should be simple to erect and safe at all stages of erection.

A bridge of the suspension type would be the easiest bridge to erect, the cantilever bridge, necessitating the lifting of the suspended span into place, would be more difficult, whilst the erection of an arch bridge across Sydney Harbour would be more difficult still, but with our solid rock foreshores is well within the range of present-day knowledge and appliances.

Sir Douglas Fox and Partners designed the arch bridge of 500 feet span across the Zambesi River near the Victoria Falls; the Cleveland Bridge Company, of Darlington, England, fabricated and erected this bridge. The former firm is associated with Dorman, Long & Co. in their tender, as is also Mr. Imbault, at one time chief engineer of the Cleveland Bridge Company.

I have carefully studied the methods of erection of the arch bridges proposed by Dorman Long & Co., and by Sir Wm. Arrol & Co., and I have no hesitation in advising that a two-hinged arch bridge can be erected by the methods proposed, and that the bridge will be safe at all stages of erection.

(*c*) No untried material, or material of which there is the slightest doubt as to quality, must be used in the bridge.

Dorman Long & Co. propose to use ordinary steel only, viz., carbon and silicon steel.

Sir Wm. Arrol & Co. propose to use a special high-grade steel, developed for the Admiralty during the war.

The English Electric Company of Australia proposes to use carbon steel only.

The Goninan Bridge Corporation proposes to use carbon, silicon, and nickel steels, and heat-treated carbon steel eyebars.

The Canadian Bridge Company proposes to use heat-treated carbon steel eyebars, and carbon and silicon steels.

The McClintic Marshall Products Company proposes to use heat-treated carbon steel eyebars, and carbon and silicon steels.

The Canadian Bridge Company and the McClintic Marshall Products Company have a reservation in their tenders that the guaranteed elongation of heat-treated carbon steel eyebars is to be 5 per cent., instead of 6 per cent. as specified.

All the steels submitted are satisfactory.

The tender of Dorman Long & Co. is the most favourable, as this firm is the only firm among those tendering who manufacture plates and shapes, and are able to supply all the steel required from their own mills. Dorman Long & Co.'s plate-rolling mill is admitted to be equal to any in the world, and as steel manufacturers they have a world-wide reputation. All other firms tendering have to purchase the rolled material in the open market.

(*d*) Suitability for railway traffic.

The two-hinged arch bridge meets all railway requirements much more efficiently than any of the other bridges submitted.

(*e*) Appearance.

If appearance alone had to be considered, the most handsome bridge of each type is as given below, although all five are handsome structures :—

			Amount of tender,		
Suspension	(McClintic Marshall Products Company)—		£6,047,547	0	0
Cantilever	(Canadian Bridge Company)	...	5,313,404	9	4
	(Sir Wm. Arrol & Co.)	... ...	4,978,488	7	8
Arch	(Dorman Long & Co.)	... ...	4,217,721	11	10
	(Sir Wm. Arrol & Co.)	... ...	4,645,351	7	8

Of these five bridges, it is difficult to choose which is the most suitable for its setting, but making every allowance for appearance, common-sense selects the arch bridge. It will be a handsome structure of which any community might well be proud.

On engineering considerations the tender of Dorman Long & Co., for the two-hinged arch bridge is undoubtedly the most acceptable tender.

The economic considerations are :—

(*a*) It was a condition of tendering that materials suitable for use in the bridge which were being manufactured in New South Wales at the date of closing of tenders should be used as far as practicable.

Two firms, the English Electric Company of Australia and Dorman Long & Co., of Sydney, undertake to obtain as much steel from the Broken Hill Proprietary Company, suitable for the bridge, as that firm is able to supply.

These two firms stand out in this respect above all other tenderers, and as a minimum about 50 per cent. of the total tonnage of steelwork in the bridge would be so obtained. The balance of the material required, the plates, are not being rolled in Australia, nor would the demand for plates in Australia at present justify the erection of plate-rolling mills which could meet the present demand in less than two months each year.

The Broken Hill Proprietary Company has informed the Department that it cannot roll the plates required for the bridge; all the carbon steel sections, however, will probably be obtained in Newcastle.

The value of the plates imported by Dorman Long & Co. would represent 8·1 per cent. of their tendered price.

(*b*) As far as practicable the bridge should be fabricated in New South Wales.

The English Electric Company of Australia and Dorman Long & Co. each undertakes to fabricate the bridge wholly in New South Wales.

Judged on economic conditions, the tenders of the English Electric Company and Dorman Long & Co. are equally satisfactory and stand out beyond all other tenders.

The financial considerations are :—

The cost should be reasonable, consistent with the engineering and economic aspects.

The tender of Dorman Long & Co. is not affected in any way by questions of rate of exchange; all fabrication is to be done in New South Wales. It is specified that advances will be made on material only when delivered duty paid at the fabricating shops which will be in Sydney. As the whole of the work of fabrication and erection is to be done in New South Wales, the contractor (if Dorman Long & Co.'s tender is accepted) will be paid in Australian currency in Sydney free of all transmission charges as specified.

The tender A3 of Dorman Long & Co. for a two-hinged arch bridge with abutment towers and piers faced with granite masonry in accordance with the official design at a cost of £4,217,721 11s. 10d.. is undoubtedly the most acceptable tender.

This firm submits the lowest of all tenders, viz., tender A1 for an arch bridge without abutment towers but with granite facing on piers and abutments at £3,499,815 15s.; but on account of the improved appearance with abutment towers, which were specified, I consider that tender A3 at £4,217,721 11s. 10d. is the best. If pre-cast concrete block facing is used in lieu of Moruya granite in tender A3, the tender would be reduced to £3,977,721 11s. 10d., or £240,000 less than the price which includes granite masonry facing.

Moruya granite is a medium coarse-grained material, pale in colour, and consists of an irregular admixture of potash felspar, quartz, and biotite (magnesium mica.) In the sunshine the dark mica sparkles and throws up the whitish grey colour of the felspar and quartz. Tests made by the Public Works Department give it an average crushing strength of 7·8 tons per square inch, or 1,123 tons per square foot.

The difference in appearance between the two bridges, one with granite facing and the other with white artificial stone facing, more than offsets the difference in price. Furthermore, the granite spalls, obtained when quarrying the blocks, will be crushed, and used as aggregate for the concrete, so that a better and stronger substructure will result than if it is constructed with artificial stone blocks backed with bluestone concrete.

Of all the tenders received for part fabrication abroad, the lowest is that of Sir Wm. Arrol & Co., for an arch bridge at £4,645,351 7s. 8d. About 66 per cent. of the steelwork would be fabricated in Scotland, the balance in New South Wales, but the price is £427,629 15s. 10d. higher than Dorman Long & Co.'s tender for all Australian fabrication.

The lowest tender for a cantilever bridge, providing for granite masonry faced piers and abutments is that of Dorman, Long & Co., at £4,551,758 13s. 3d., which provides for fabrication wholly in New South Wales. Sir Wm. Arrol & Co.'s tender for a cantilever bridge is £4,978,488 7s. 8d. and is for about 75 per cent. fabrication abroad. It will thus be seen that Dorman Long & Co.'s tender for a cantilever bridge is £334,037 higher than tender A3 of the same firm for an arch bridge, while Sir Wm. Arrol & Co.'s tender for a cantilever bridge is £760,766 15s. 10d. higher than Dorman Long & Co.'s tender A3 for an arch bridge, both tenders providing for granite masonry facing of piers and abutments. Of the two cantilever bridges, that of Sir Wm. Arrol & Co., which closely follows the official design, is preferable to that of Dorman Long & Co., which has a shorter anchor arm of 400 feet and a less pleasing appearance.

The tender of the English Electric Company of Australia for a suspension bridge is equally favourable with the tender of Dorman, Long & Co. as regards fabrication in Australia and the use of Australian steel. It would be simpler to erect than the arch bridge, but it has four times the deflection under live load that the arch bridge has, whilst the arch bridge also has better railway approaches and a better appearance. The tendered price of the suspension bridge with granite facing is £5,609,125 2s. 1d., or £1,391,403 10s. 3d. more than the arch bridge, whilst the lowest tender of the English Electric Company for this suspension bridge with concrete facing for the piers and abutments is £4,943,763 0s. 5d., or £966,041 8s. 7d. higher than Dorman, Long & Co.'s tender for an arch bridge also with concrete facing. In either tender the arch is the more efficient bridge.

After a thorough examination of all tenders submitted, I consider the most acceptable tender is that of Messrs. Dorman Long & Co., tender A3 for a two-hinged arch bridge with piers and abutment towers faced with granite masonry, at a cost of £4,217,721 11s. 10d., and I recommend that this tender be accepted.

The estimated cost of the main bridge and approaches as included in the Sydney Harbour Bridge Act of 1922, excluding land resumptions, is £5,500,000, or with land resumptions £5,750,000, which sum is not to be exceeded by more than 10 per cent.

My estimated cost of the northern and southern approaches to the bridge, including the alterations to Lavender Bay station, the escalators, and the diversion of the tramway along Dind-street, is £1,275,000; the northern approaches up to date are being carried out at 23 per cent. below this estimate.

If the tender of Dorman, Long & Co. is accepted, the financial position will be as follows:—

Main bridge—Dorman Long & Co.'s tender ...	£4,217,721	11	10
Approaches (Estimated cost)	1,275,000	0	0
	£5,492,721	11	10

Assuming that the contract is let forthwith, the money will be required somewhat as under :—

Year.	Main Contract.	Approaches.	Total.
	£	£	£
1924 ...	Nil.	175,000	175,000
1925 ...	217,721	....	217,721
1926 ...	600,000	....	600,000
1927 ...	800,000	250,000	1,050,000
1928 ...	1,250,000	250,000	1,500,000
1929 ...	850,000	300,000	1,150,000
1930 ...	500,000	300,000	800,000
	£4,217,721	£1,275,000	£5,492,721

Last year the land tax returned £114,000, and the years 1924, 1925 should return £133,000 each, a total of £380,000 up to the end of 1925. The expenditure up to the same date is estimated to be £392,721, so that the land tax will practically pay for construction but not for land resumption. From the year 1926 onwards the money as set out will have to be found, less the amount of land tax derived during the year.

The bridge recommended is the most suitable and the best that engineering skill can at present devise. It will be handsome in appearance and will be the longest span arch bridge in the world. As much Australian steel as Australian manufacturers are prepared to produce to meet the requirements of the specification and to roll into plates and shapes will be used in its fabrication. Plates only, valued at 8·1 per cent. of the amount of the tender, need be imported from Middlesbrough, England. These plates cannot be manufactured in Australia at the present time. All other steel and all workmanship will be Australian. The bridge will be fabricated wholly at Milson's Point, Sydney, by Australian workmen; the piers and abutments will be constructed of Moruya granite, Nepean River sand, and New South Wales cement, and the bridge will be erected by Australian labour.

9.—Description, Fabrication and Erection of the Two-hinged Arch Bridge Recommended.

The two-hinged arch bridge, in accordance with the official specification and plans, comprises a two-hinged main arch span from Dawes' Point to Milson's Point, a distance of 1,650 feet, centre to centre of bearings, with five deck approach spans on either side of the harbour. The overall length of the bridge is 3,770 feet.

On the southern approach the five spans are each 193 feet 7 inches to centres of bearings, with piers 198 feet 7 inches centres, and the approach is straight. The northern approach leaves the main span on a curve of 2,152 feet radius running into a curve of 1,300 feet radius at the northern end of the approach, so that the inner approach trusses are 168 feet span, whilst outer trusses are 180 feet 6 inches span to centres of bearings, and the piers are 178 feet 7 inches centres measured along centre line of the bridge. All approach spans are supported by granite faced concrete piers measuring 17 feet 6 inches by 14 feet at the top and tapering uniformly outwards towards the base, the average height of the piers being 50 feet above ground level.

All approach spans are carried by two main truss girders, which are supported by independent piers. Two cast steel bearings on each pier, bedded on a dressed granite cap, support the main girders of adjacent spans. The spacing of the two main trusses of each approach span is 98 feet 6 inches centre to centre, and the trusses are 34 feet 10 inches deep, braced on a simple triangular system with verticals at each panel point. Cross-girders rest at each panel point on the top chords of the main trusses and support the remainder of the floor system on their top flanges. Lateral bracing is provided in the plane of the top chords with transverse frames in the planes of the end posts; while at each panel point the cross-girders are trussed to form sway bracing to the span. The whole of the approach spans and deck are built of carbon steel.

The main arch trusses are set in vertical planes, and are spaced 98 feet 6 inches centre to centre, with parabolic lower chords of 1,650 feet span and 350 feet rise from centres of bearings. At the crown the depth is 60 feet, which increases by means of a parabolic top chord and a slight reverse at each end to 190 feet over the main bearings. The highest point of the top chord is 445·48 feet above high-water level of the harbour. Each of the bearings is 38 feet to centre above standard datum or 35·48 feet above high-water level, and is designed to carry the inclined thrust of the arch trusses. The abutments are of concrete with granite aggregate and faced with granite above ground level, being built up from a level of 25 feet below top rock level, and the inclined skewbacks are capped with granite accurately dressed to take the heavy silicon steel pedestals which carry the main pins. This pedestal is built in three tiers comprising two grillages each 4 feet deep, with lower base plates $2\frac{3}{4}$ inches thick in six portions, making a total area of 22 feet by 17 feet 6 inches or 385 square feet, supporting an upper pedestal 8 feet 5 inches high, which bears on the main pin. The upper grillage is composed of solid bars of silicon steel, each 6 inches thick and the lower grillage of 12 bars each 5 inches thick. Each main pin is divided longitudinally into halves, and is 10 feet long and

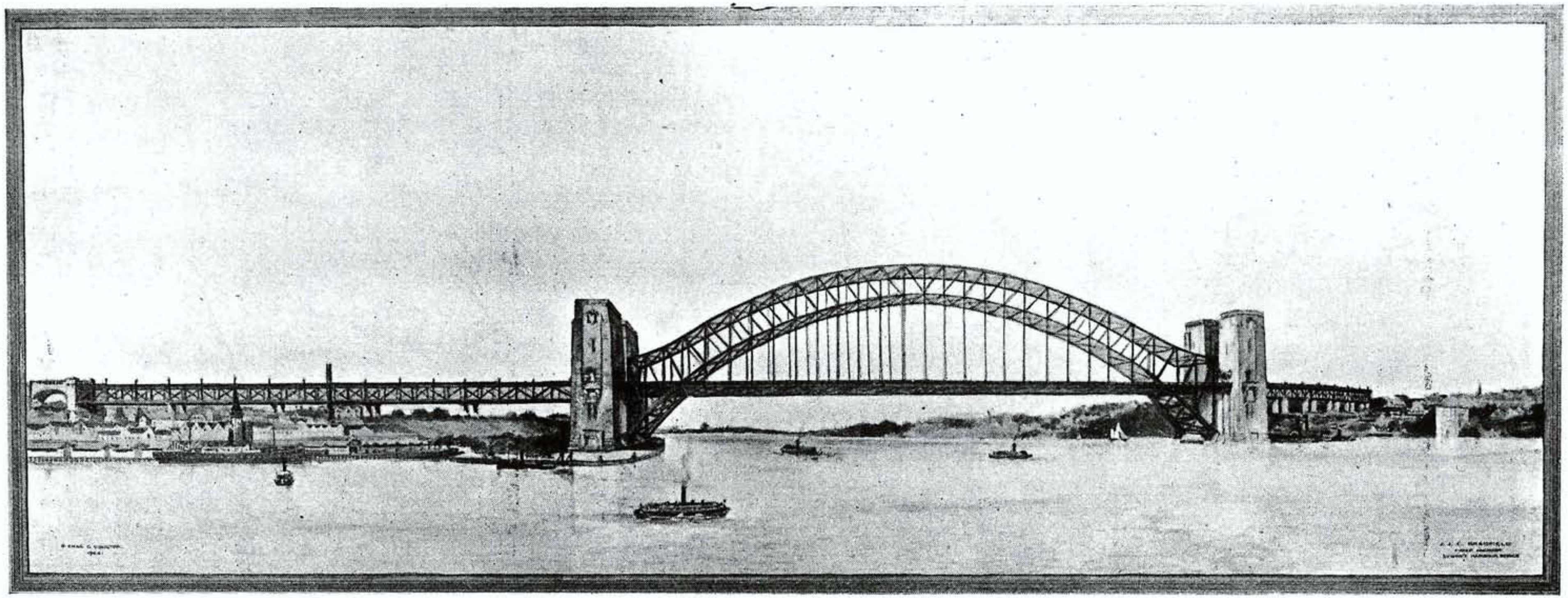
52 inches in diameter, enclosing a solid key pin 14 inches in diameter, divided into four lengths, one for each web of the lower chord. The whole is covered by a thin steel sheet casing and is kept in position during erection by six holding-down bolts each 4 inches in diameter. The weight of each complete pedestal is approximately 260 tons.

Each main truss consists of two main chords divided into 28 panels of 58 feet $11\frac{5}{32}$ inches, by a single system of bracing. Lateral bracing consists of double diagonals and struts on top and bottom chords, with a portal frame between end posts and a portal bay in the lower lateral frame where the floor intersects the plane of the lower chords. From the abutments to near the quarter points, the lateral members in both systems are riveted to the chords, but between these points, where relative deflections of the trusses under unsymmetrical live load are appreciable, pin connections are used at the ends, permitting rotation in a vertical plane parallel to the axis of the member.

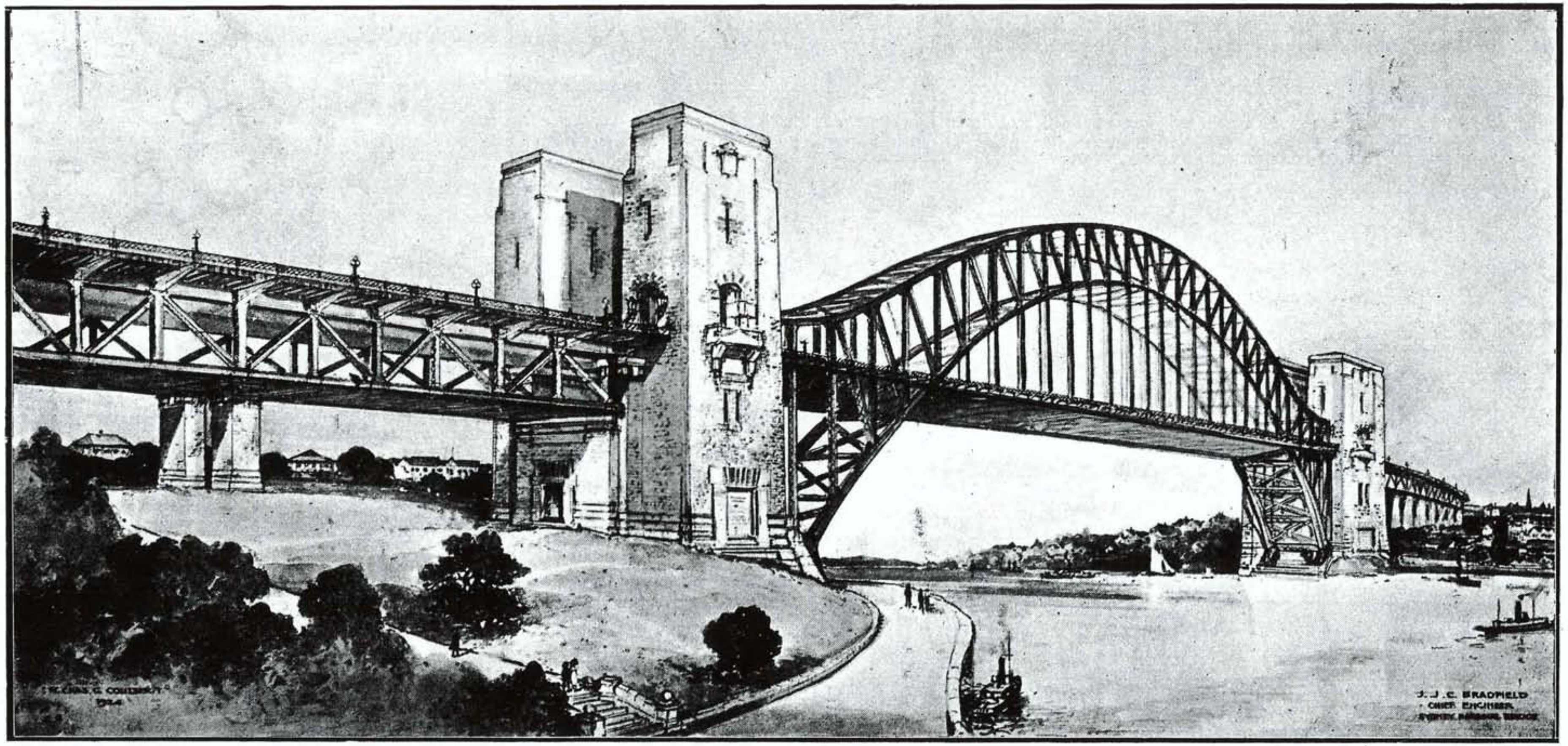
Every main chord member of the trusses consists of a built-up section composed of four web plates and sixteen flange angles 10 inches by 10 inches, together with flange plates forming a rectangular box section. Vertical and diagonal main truss members are composed of four web plates with eight flange angles 8 inches by 8 inches and lattice bracing suitably proportioned. Webs of all members are spaced to allow about 30 inches clear. Main top chord members are 40 inches deep throughout and 10 feet 6 inches wide across the flanges with webs varying from $1\frac{7}{8}$ inches to $1\frac{3}{8}$ inches thick. The depth of bottom chords varies from 48 inches to 108 inches, and the thickness of webs from $2\frac{3}{4}$ inches to $4\frac{1}{2}$ inches, the width being the same as the top chord. The greatest thickness of any individual web plate is $2\frac{1}{2}$ inches with rivets of $1\frac{1}{4}$ inches maximum diameter. All chord sections are stiffened with transverse diaphragm plates on each side of connections and erection joints. Manholes and openings in diaphragms provide access to each compartment of the chords. The weight of each panel section of the bottom chord varies from 112 tons at the crown to 370 tons at the abutment. All main members of the arch trusses, the larger sections of the lower lateral system, hangers and flanges of arch cross-girders are of silicon steel. The remainder of the deck and lateral systems are of carbon steel.

For the extent of three panels next to each main bearing the cross-girders are connected to the truss verticals by pins. Beyond these points, the cross-girders are suspended at each end from the main trusses by silicon steel hangers at each panel point. These hangers are constructed of rectangular, built-up sections, and the connections are made by means of pins. Each cross-girder consists of a double-webbed plate girder 150 feet long and 12 feet deep, into which the stringers are framed. At the point where the floor intersects the lower chord, a special cross-girder is used, hung from the lower panel point. Lateral rigidity of the floor is provided by a complete truss with wind chords and double diagonals fixed to the stringers and connected to the cross-girders. The depth of this truss is 148 feet 6 inches and it forms a cantilever system anchored at the end posts, bearing on the main truss lateral system where it intersects the lower chords, and supporting a central "suspended span" extending through the central 14 panels of the span.

The deck throughout the bridge consists, as specified, of a central roadway 57 feet wide between kerbs; on each side of the road two railway



Photograph No. 12.



Photograph No. 13.

Fabrication.

Messrs. Dorman Long & Co., Limited, already have works at Sydney and Melbourne, and arrangements have been made, apart from the Sydney Harbour Bridge contract, for constructing more extensive shops in Sydney. These shops will be used immediately for the construction of the special shops for fabricating the material for the bridge.

The proposed new workshops will rank among the heaviest shops of the character now in existence, and will be provided with the finest equipment of heavy structural fabricating machinery that it is possible to procure. The shops will be constructed in two portions—one being 600 feet long and 149 feet wide to centres of crane rails consisting of two 73 feet bays, and the other being 600 feet long and 130 feet wide consisting of one bay only. The two-bay shop will be utilised for the preparation of the individual pieces of the bridge members in detail, the processes carried out comprising templating, shearing, planing, drilling, riveting, &c., and all the necessary machinery will be specially designed for the work. The two 73-feet bays in this shop will be equipped with four modern electrically-driven overhead cranes.

The second shop, 130 feet wide in one span, will be devoted to the assembling of the various pieces dealt with in the first shop to form the finished bridge members. After the bridge members are assembled, they will be riveted up and the ends will be machined to the finished lengths ready for erection. In this shop will be located the heavy hydraulic and pneumatic riveting machines and the specially designed end-planing and pin-boring machines. After completion, the various bridge members will be assembled in panels in the position ultimately taken up in the finished structure, and all splices and connections at the junctions of the members will be drilled in position to ensure absolute accuracy of workmanship. In this shop will be mounted two 150-ton electric overhead travelling cranes, and after the bridge members have been finally completed, the cranes will lift the members in their complete finished conditions and lengths, direct to barges designed for the purpose. These barges will be run into a dock which will be constructed within the width of the shop, so that the overhead electric cranes have complete command of the dock area. After the bridge members are on board, the barges will be towed into position in the harbour right under the erection cranes working at the bridge, thus reducing the amount of handling to a minimum.

Photograph No. 14 shows the proposed fabricating shops at Milson's Point.

Erection.

The arch will be erected as two principal cantilevers built out from either shore.

Stage 1.—After the necessary excavation has been performed and approach piers constructed, the first step in the scheme of erection will be the construction of sufficient of the abutment towers to support the decking next the end posts of the main arch, and of the approach trusses, beginning with those adjacent to the main span. These spans will be erected on full timber stages with cranes travelling on special tracks laid on the stage (*Plan No.* 13, *Photograph No.* 15), and the work will proceed until the end of the approach spans is reached.

Stage 2.—On the deck of the bridge so constructed a stage will be built up, the top surface corresponding with the level and plane of the top chord of the arch. On this stage the main erection cranes, shown in Plan No. 14, will be constructed in a position ready for erecting the end post and first panel of the bridge. (*Photograph No.* 16.) These cranes, each weighing 536 tons, have been specially designed for the erection of this bridge, and will be capable of lifting members up to 160 tons weight. In this position the cranes will erect the bearings, end post, and first panel complete. As soon as the end post is in position it will be anchored back to the solid rock by means of steel wire cables.

For anchoring the structure to the rock, tunnels will be driven in a position approximately below the second pier of the approach spans from the main arch bearing. These tunnels will consist of two inclined shafts corresponding to the lines of cables 140 feet apart, but so arranged as to put a definite pressure on the rock where the cable leaves the ground level. (*Plan No.* 15.) These shafts will be approximately 10 feet by 6 feet, and will be connected by two semi-circular cross-tunnels. The cross-tunnels will be sunk to a depth of approximately 120 feet below ground level, depending upon the character of the rock as revealed by the sinking of the shafts. The minimum factor of safety produced on this method is 3½, and will obtain just before the two arms of the arch meet at the crown.

The cables passing into the tunnels will be composed of twisted steel wire terminating just above ground level in U-bolt sockets for connecting to the length of anchor cable from ground line to the bridge structure. This connection serves also for adjustment of length. The lengths of cables from the ground to the point of attachment to the trusses will be composed of parallel wire strands wound round cast steel reels forming the terminals at each end of each length. For the first stage of the erection these lengths of cable will be of twisted wire, attached to the tops of the end posts.

Adjustment of the length of cable is performed by means of the U-bolt shackles shown on Plan No. 15, by means of which equality of stress condition can be verified by eye from the sag of the various cables.

Stage 3.—On completion of the first panel of the bridge the erection crane will be moved forward on the top chords of the bridge, the overturning moment due to the weight of the first panel and of the crane being taken by the anchorage cable.

In this position the crane will erect the second panel, the anchorage cables being increased from time to time to provide the necessary reaction. This process will be continued until the crane reaches the fifth panel.

Immediately behind the fifth panel, a further series of cables will be secured so as to transfer the reaction from the end post to this panel point. (*Plan No.* 16, *Photograph No.* 17.) Special gussets supporting anchorage pins will be constructed at this panel point, to which the straight wire cables will be attached. In order to reduce the stress in this second series of cables they will be carried over struts standing on top of the end posts of the arch, the strut supporting cast steel saddles carrying the cables in two groups superimposed on one another. (*Plan No.* 17). Another strut supported on hydraulic jacks at ground level serves for final adjustment of the completed half-arches.

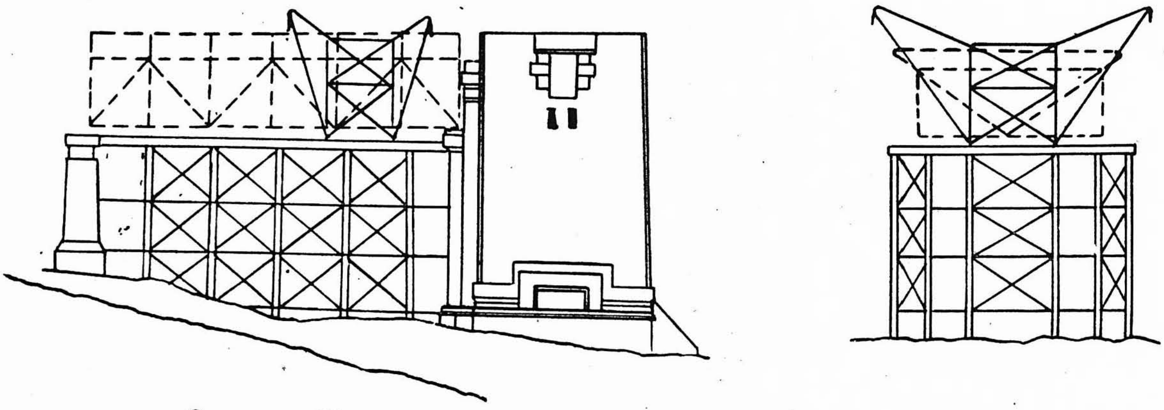
Stage 4.—As soon as sufficient cable is provided to sustain the reaction, the cables secured to the end post will be slacked, and these cables will then be available for augmenting the cables attached to the fifth panel as the reaction increases due to the moving forward of the crane. The crane will continue to erect successive panels until the tenth panel from the end post is reached, leaving four panels on each side of the centre line to be erected. (*Plan No.* 18, *Photograph No.* 18.)

Stage 5.—As in Plan No. 19, Photograph No. 19, the remaining panels will be erected by means of a lighter crane, shown in Plan No. 20, its total weight being only about 180 tons. This crane will be used in the same manner as that already described for erecting the other panels of the bridge. The half-arches will be finally adjusted in level and allowed to come together by means of hydraulic rams on the struts supporting the cables just above ground level. These jacks will be provided with collar packings in short lengths so that the pressure is normally on the collars, and it will be necessary only to exert a pressure sufficient to permit the removal of a section of the collar packing. The jacks will then be used only to lower the cables and allow the two half-arches to meet. As they do, the tension in the cables will be relieved. In this condition the arch will be complete as a three-hinged arch under the dead load of the main trusses and bracing.

Stage 6.—(*Plan No.* 21, *Photograph No.* 20).—Hydraulic rams will then be inserted in the top chord members and an initial stress will be put into the members to correspond with the stress which would arise in these members if the arch were built as a complete elastic two-hinged structure of the correct calculated lengths for all members. The total stress required in the top chord is 4,900,000 lb.

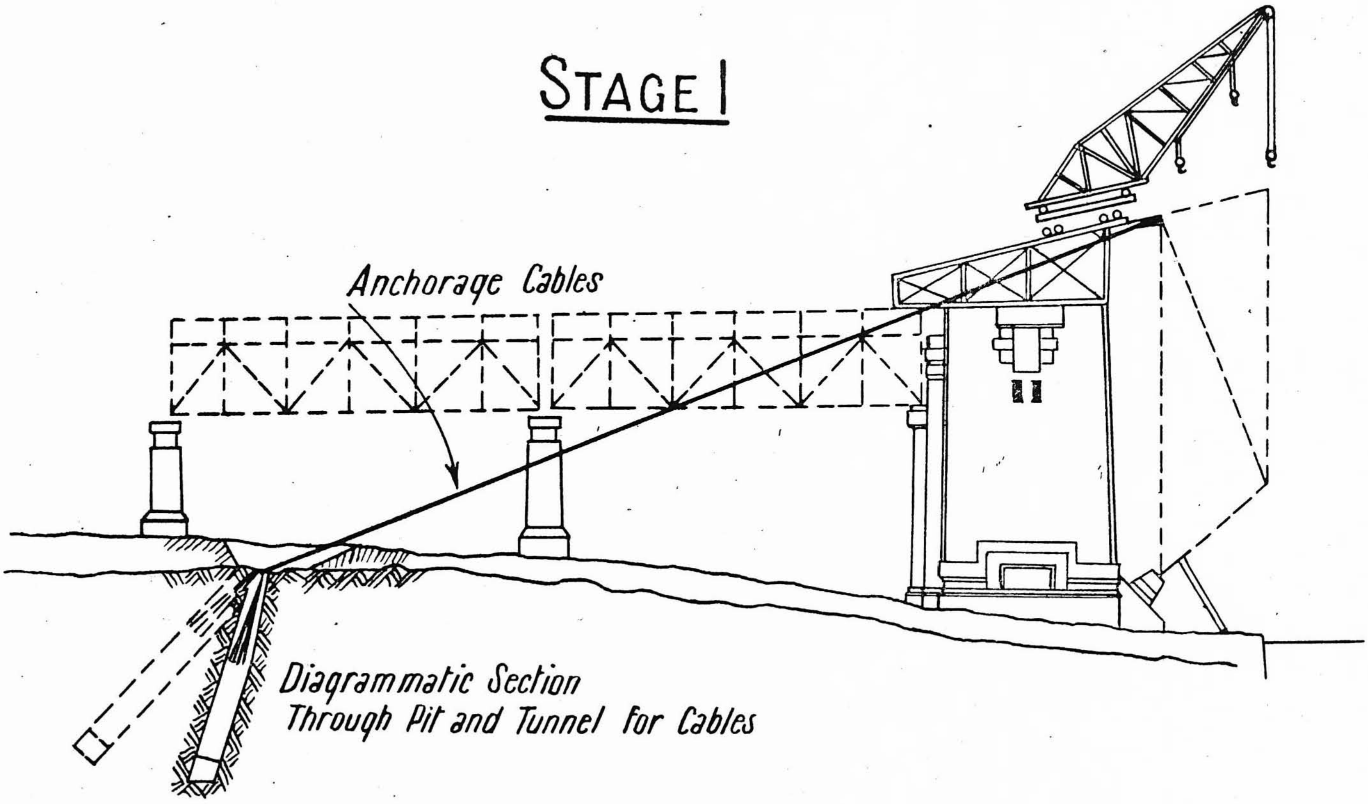
Stage 7.—(*Plan No.* 22, *Photograph No.* 21).—After the main trusses have been completely erected, the erection of the floor will proceed simultaneously and symmetrically at both ends by fixing in position the hangers, main cross-girders, stringers, and the necessary finish to the floor. Abutment pylons will then be completed.

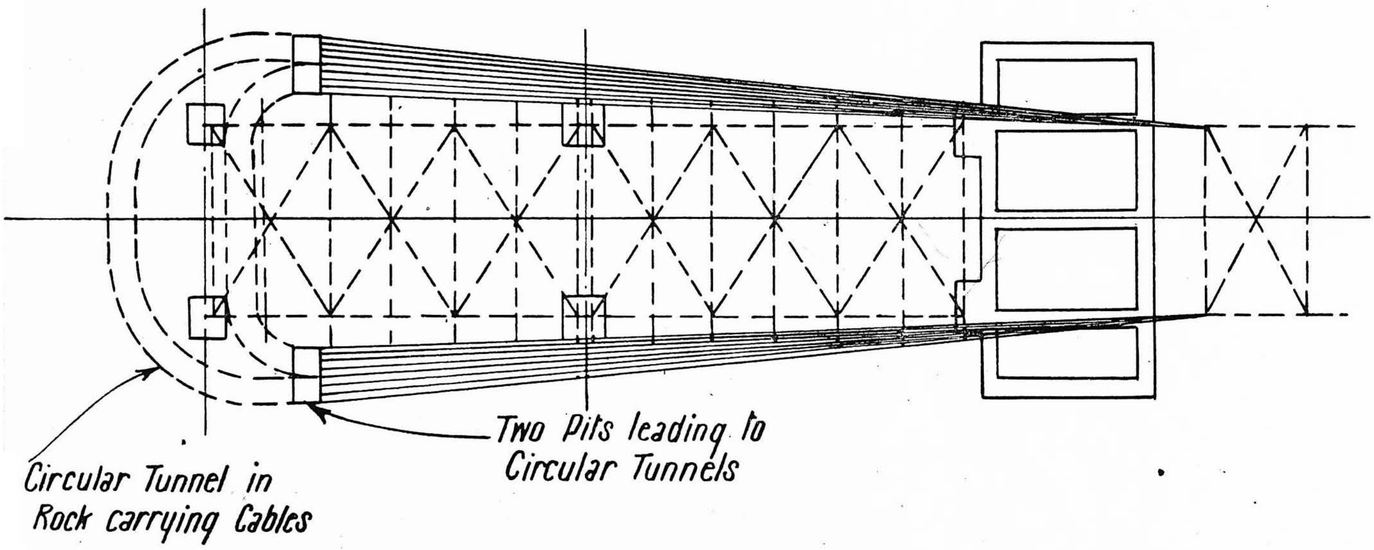
Erection riveting will proceed on the lower chord members of the main arch where the condition of the structure is practically identical as a cantilever with its condition as an arch. The erection rivets of the remaining steel members will be deferred until the arch structure is complete. Each portion of the lower chord will be planed at the ends to bear on the middle third only so that bearing on the edges is precluded, and when erection is complete the joints will have taken up the gap remaining in the outer thirds, and riveting may proceed under dead load conditions.



SIDE ELEVATION END ELEVATION

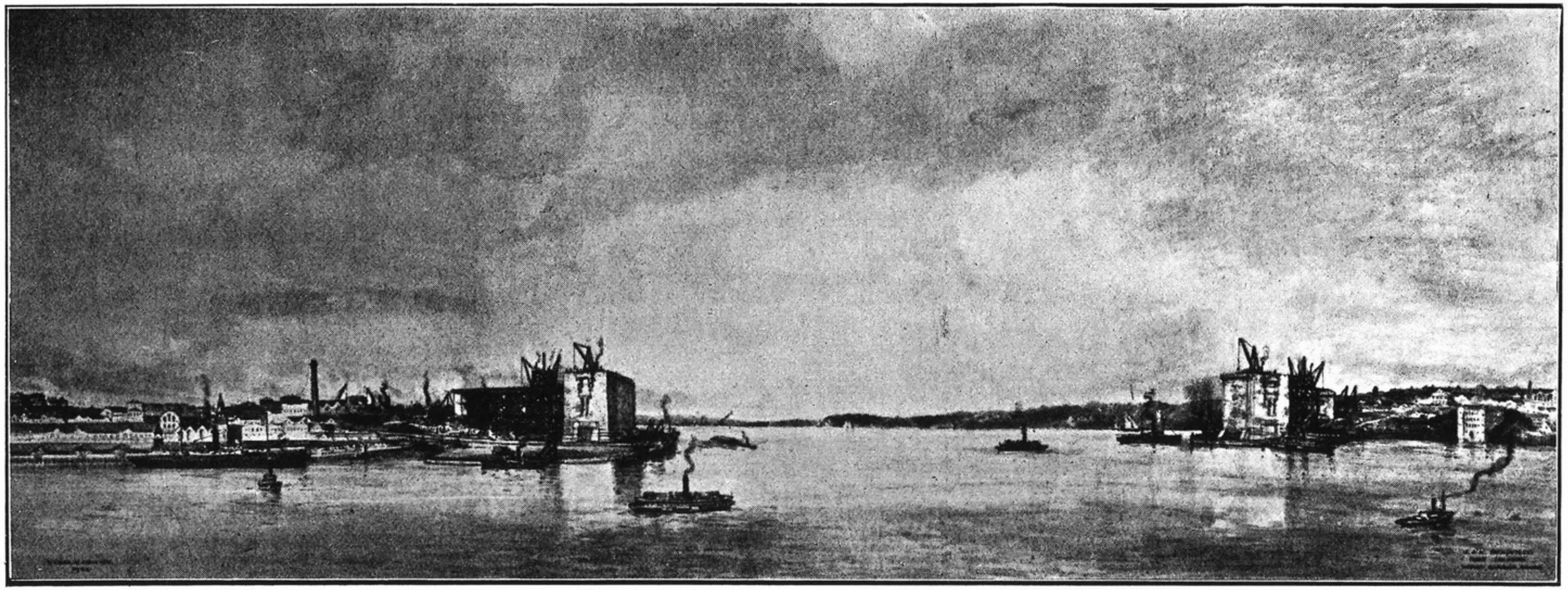
STAGE 1





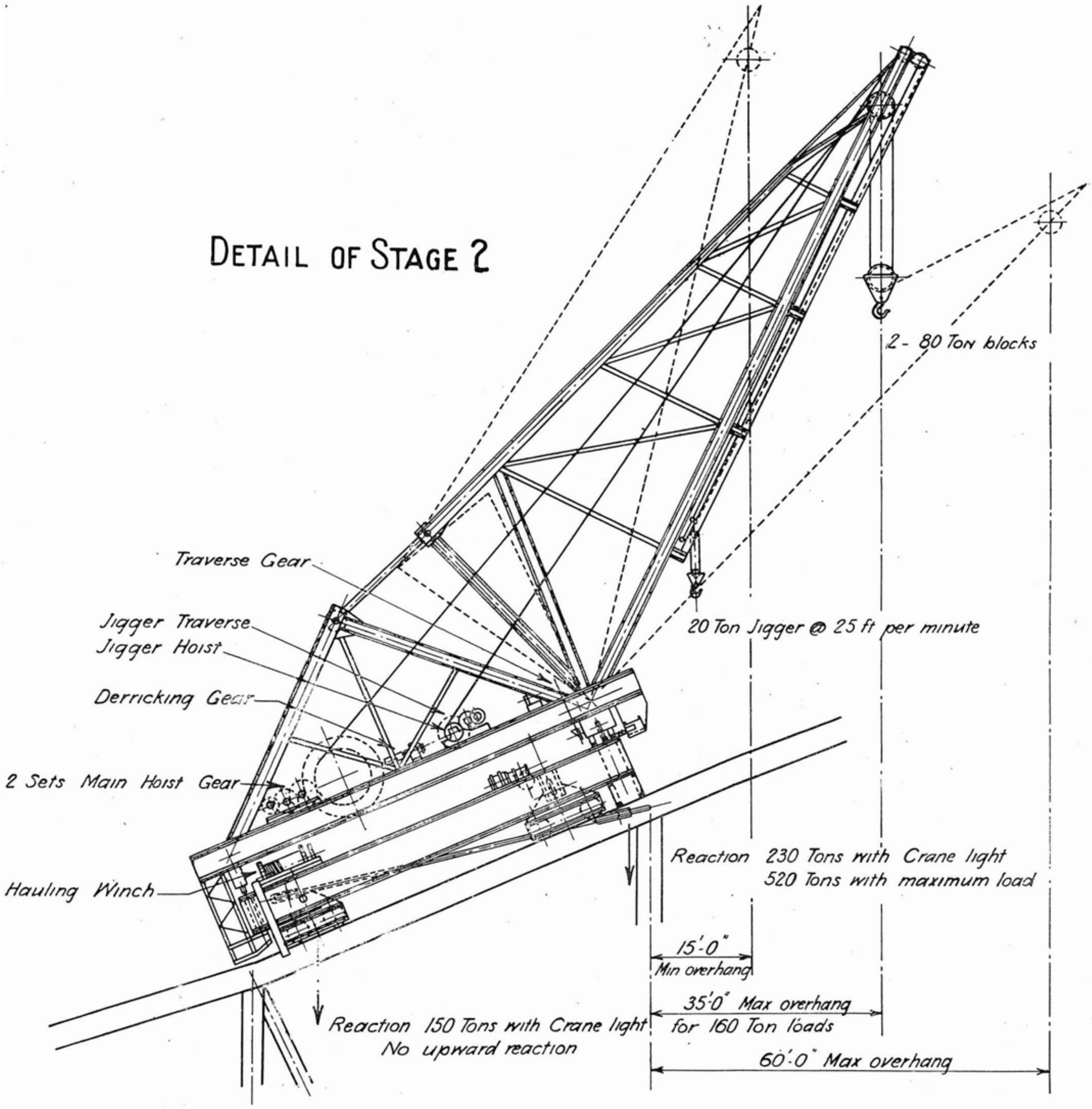
PLAN

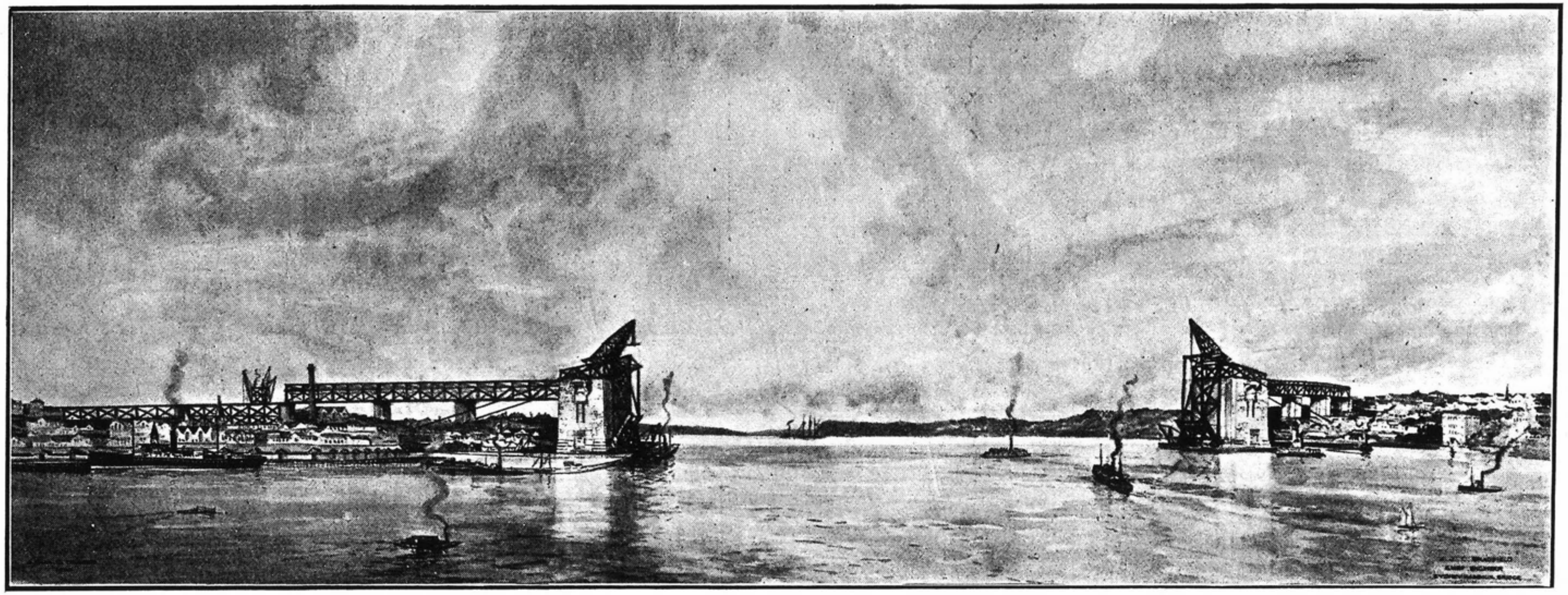
STAGE 2



Photograph No. 15.—Stage 1.

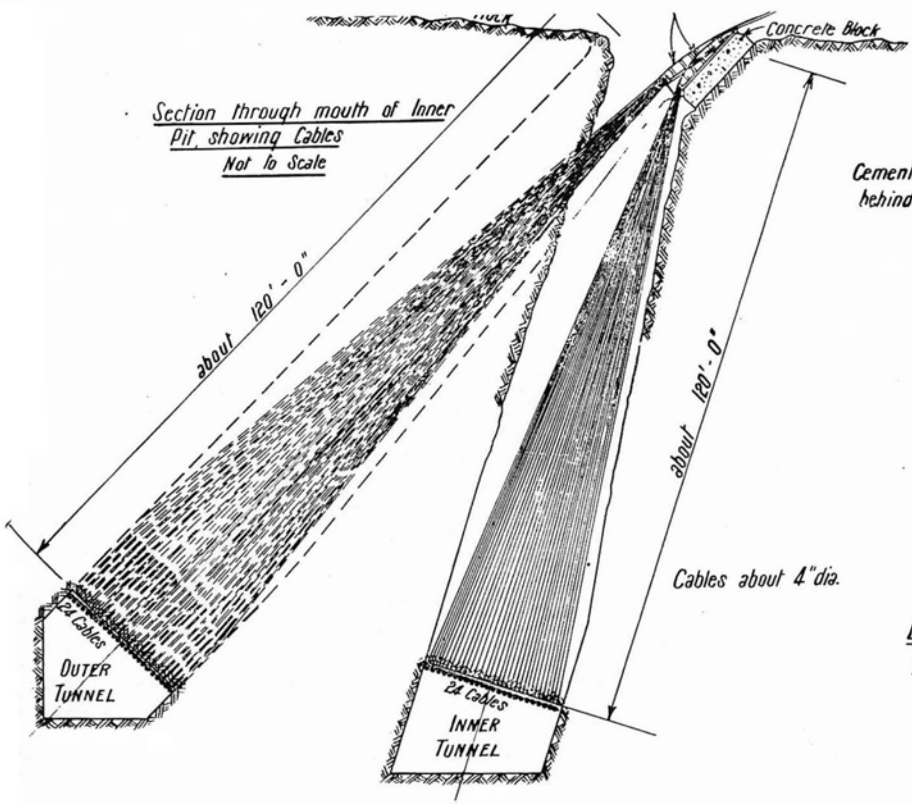
DETAIL OF STAGE 2



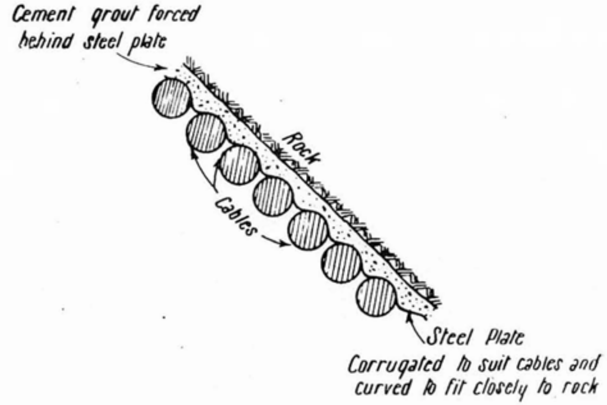


Photograph No. 16.—Stage 2.

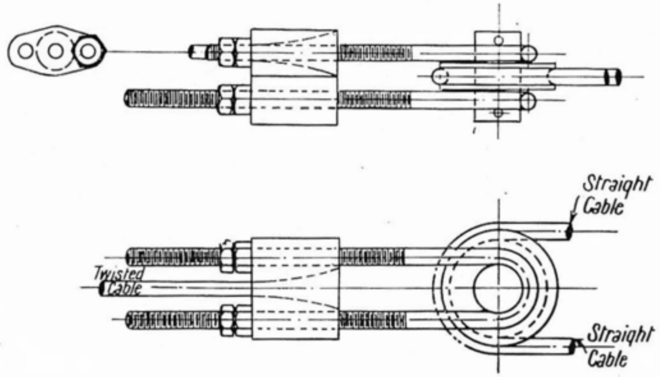
DETAIL OF STAGE 2



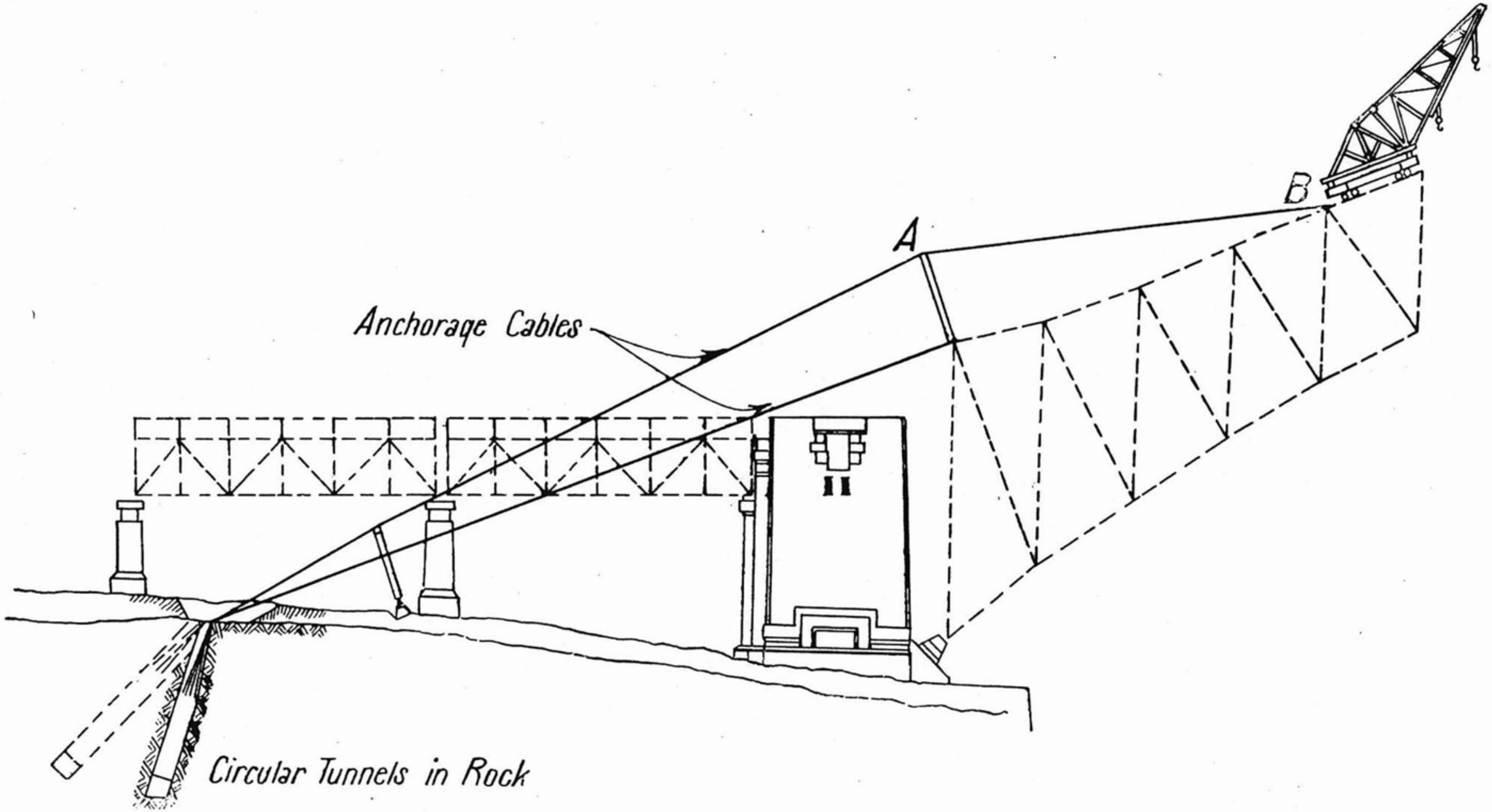
Section through mouth of Inner Pit, showing Cables
Not to Scale



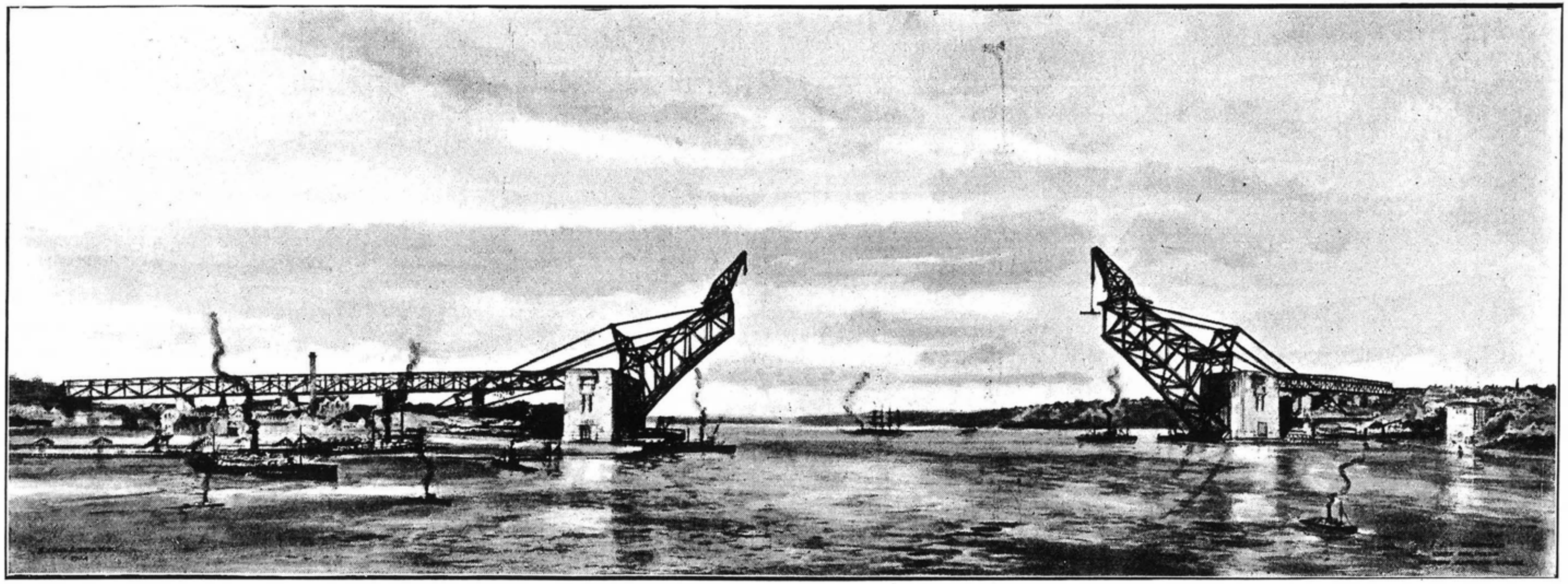
Detail showing Method of Bedding Cables against Rock in Tunnels
Scale 1 Inch = 1 Foot



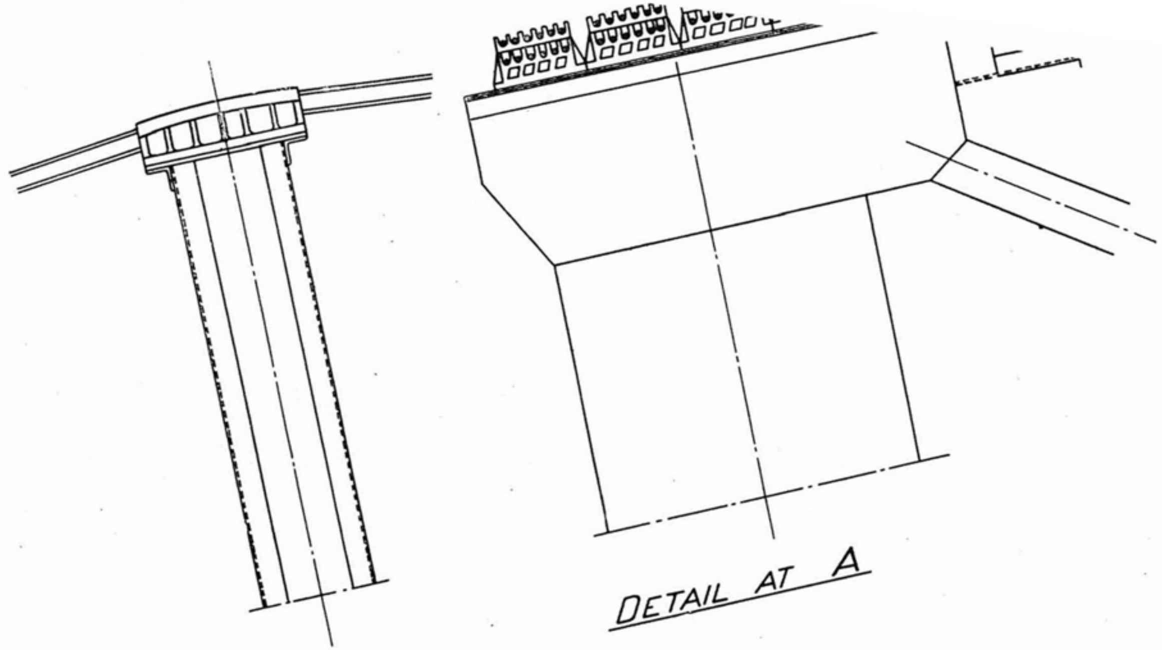
DETAIL OF SHACKLES
Scale : ½ Inch = 1 Foot



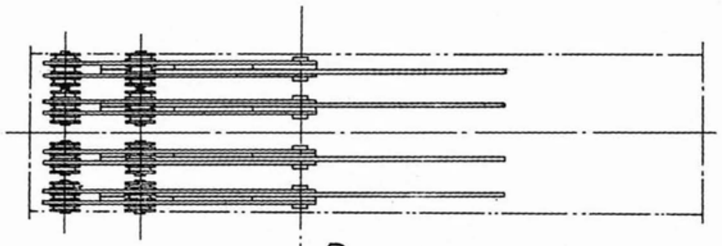
STAGE 3



Photograph No. 17.—Stage 3.

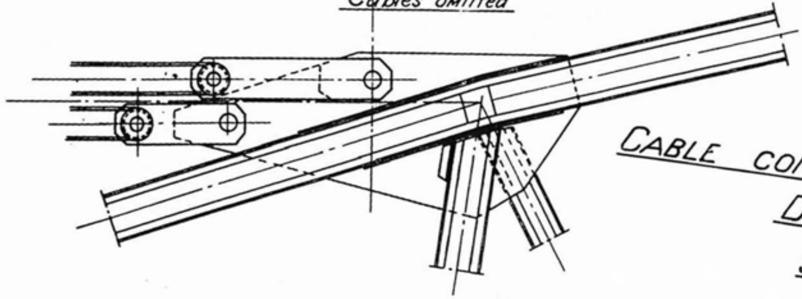


DETAIL AT A



PLAN

Cables omitted



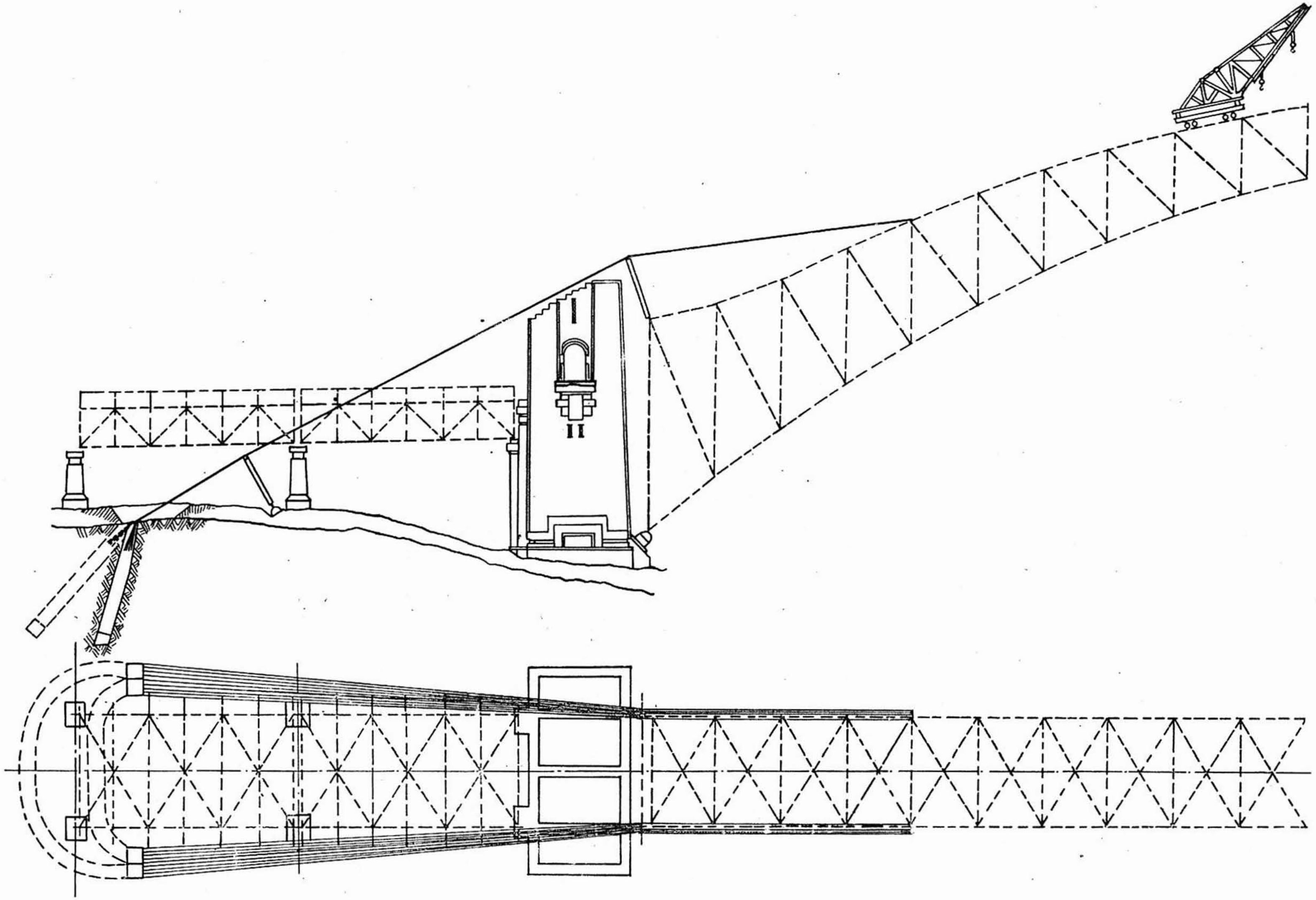
CABLE CONNECTION ON TOP CHORD

DETAIL AT B

Scale $\frac{1}{8}" = 1'0"$

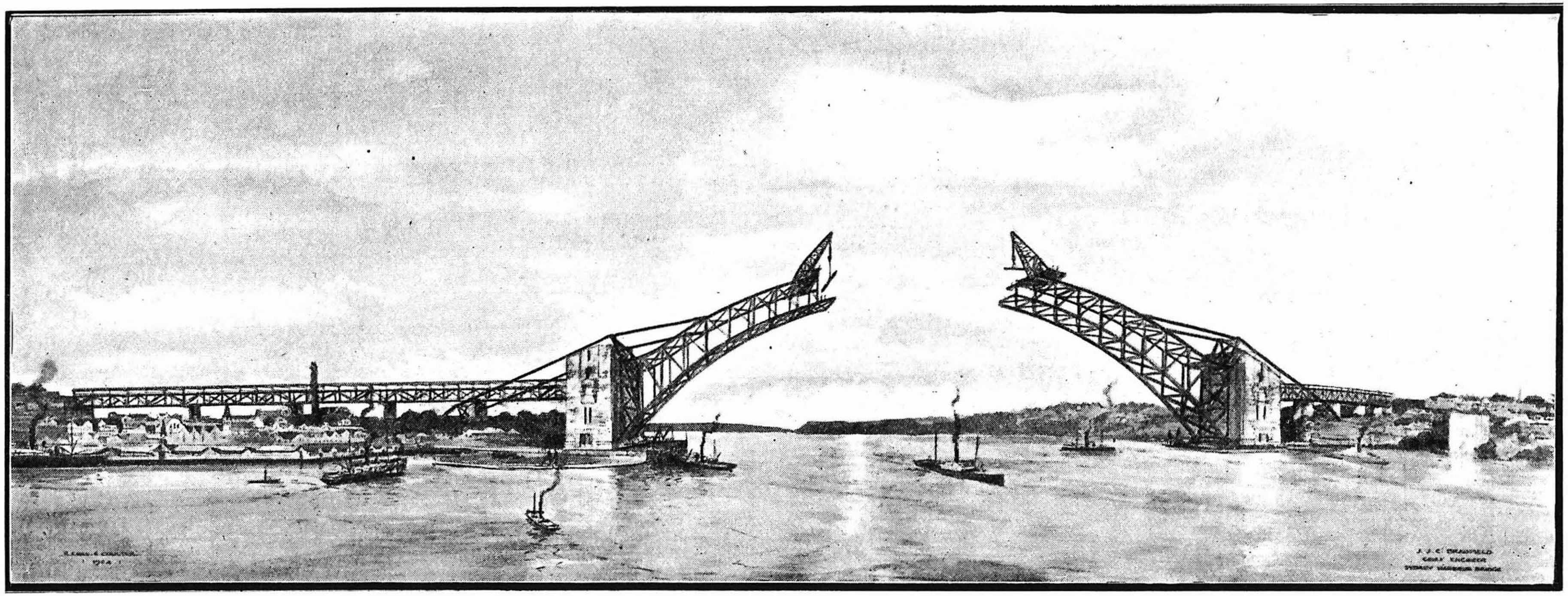
22406—K

DETAIL OF STAGE 3

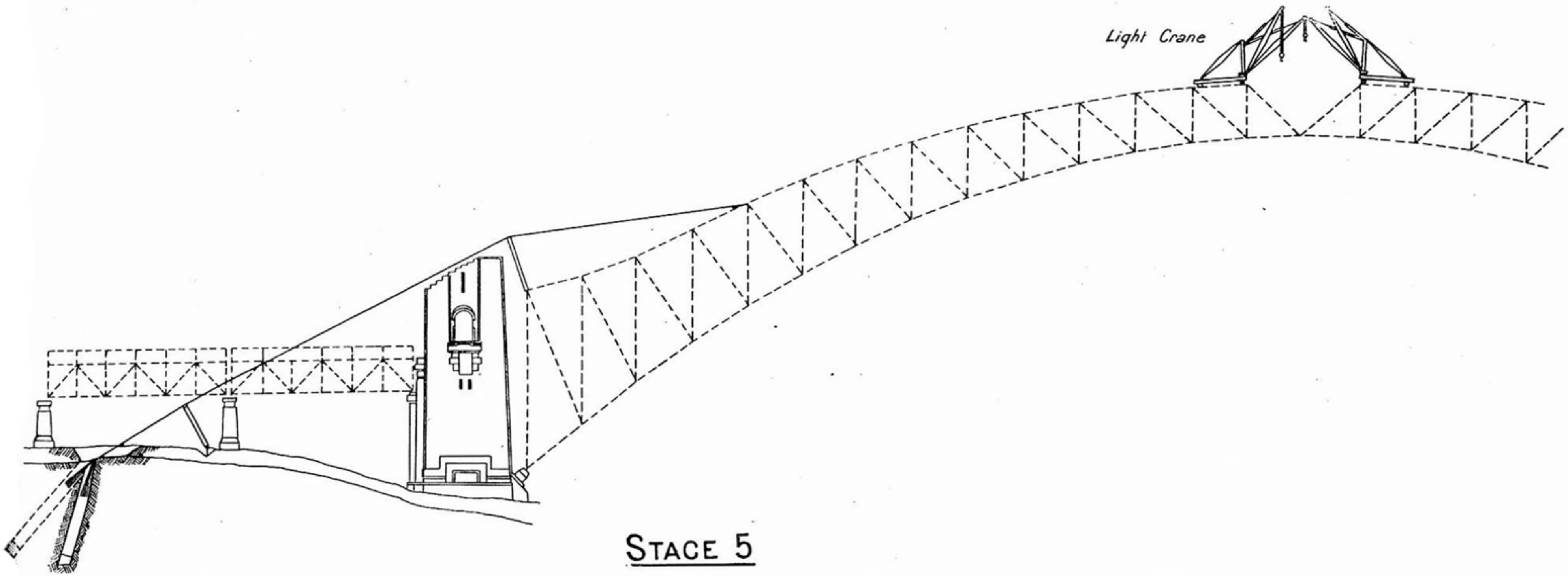


PLAN

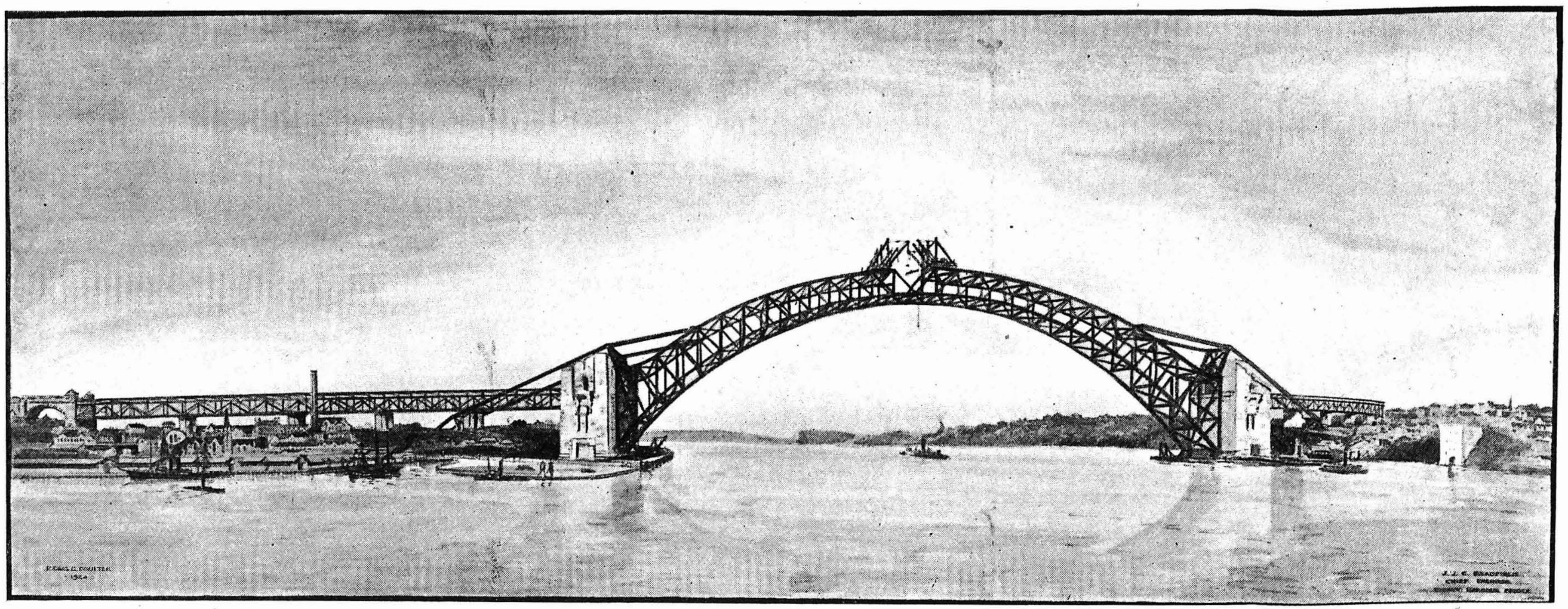
STAGE 4



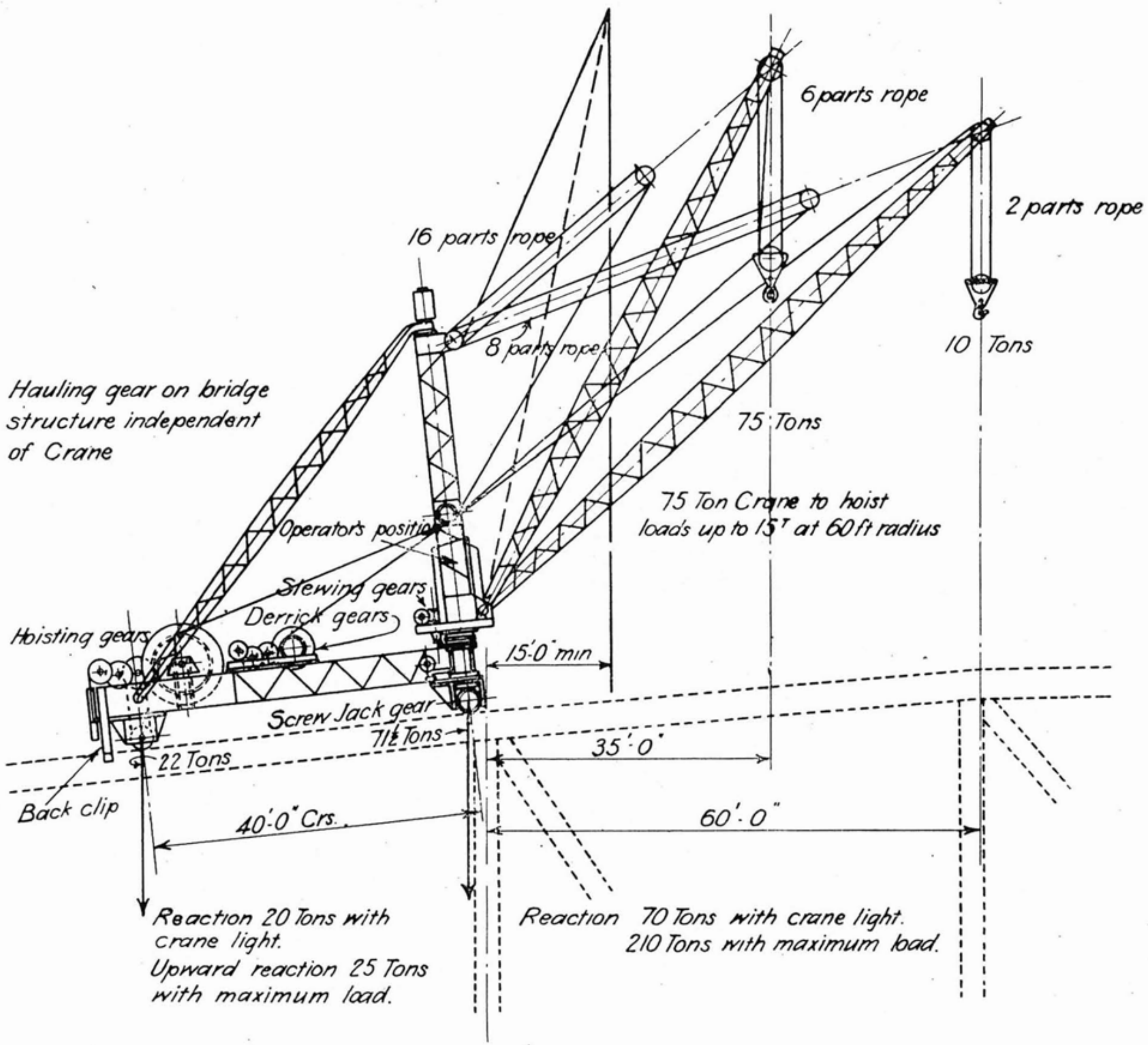
Photograph No. 18.—Stage 4.



STAGE 5

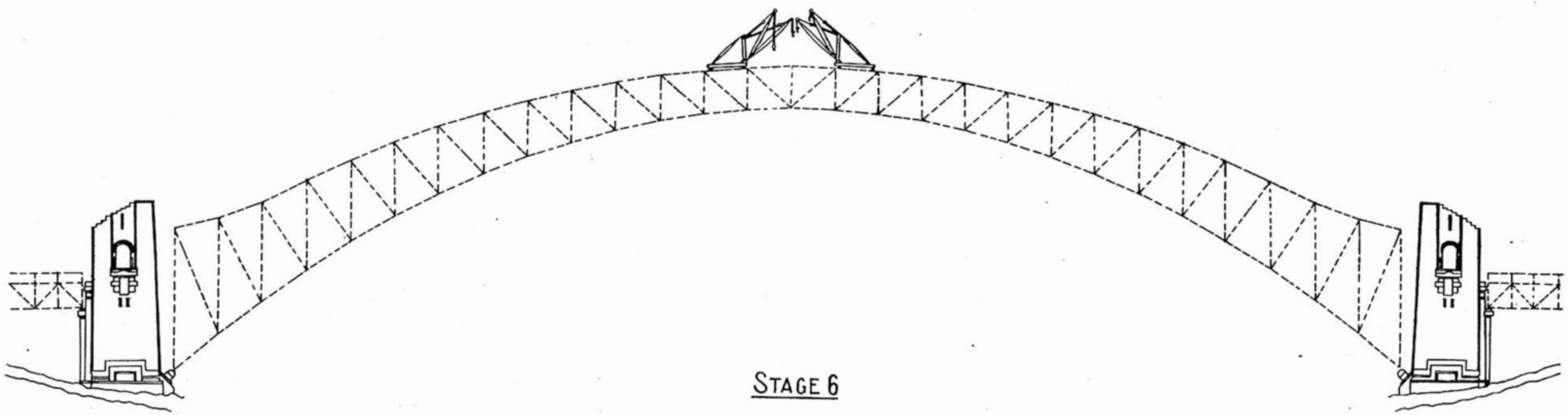


Photograph No. 19.—Stage 5.

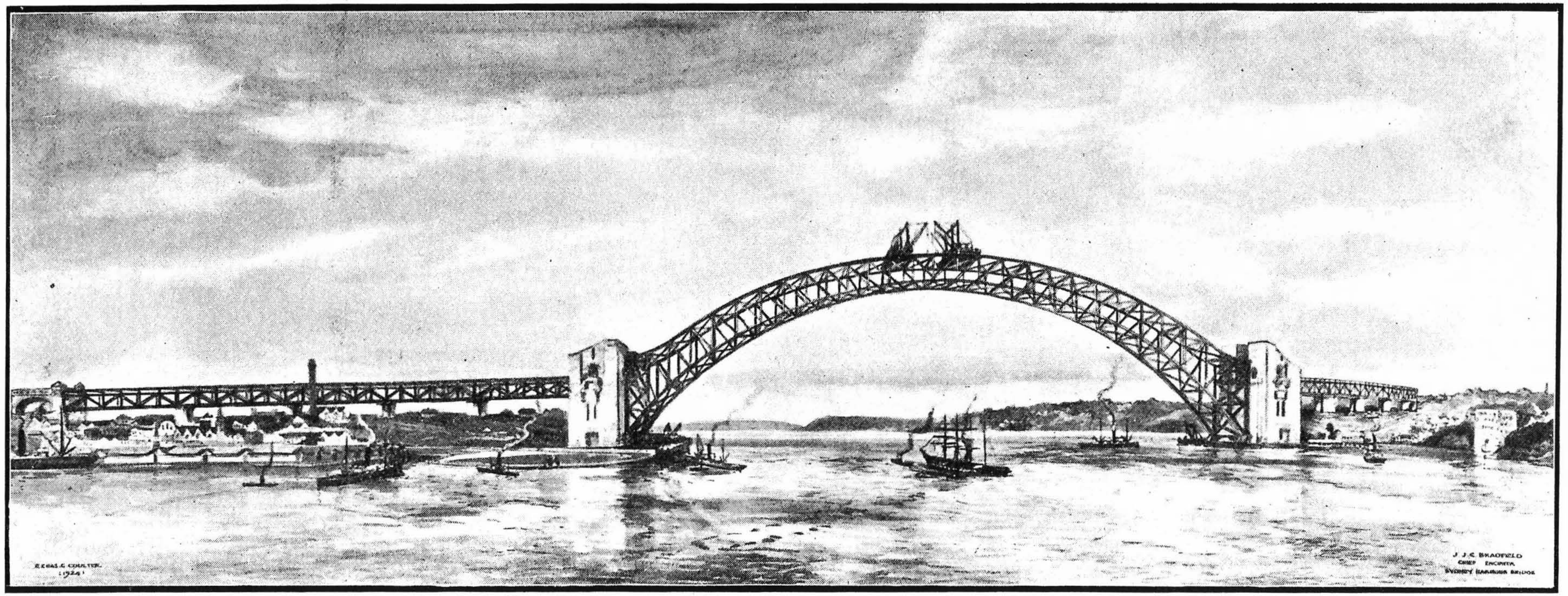


DETAIL OF STAGE 5

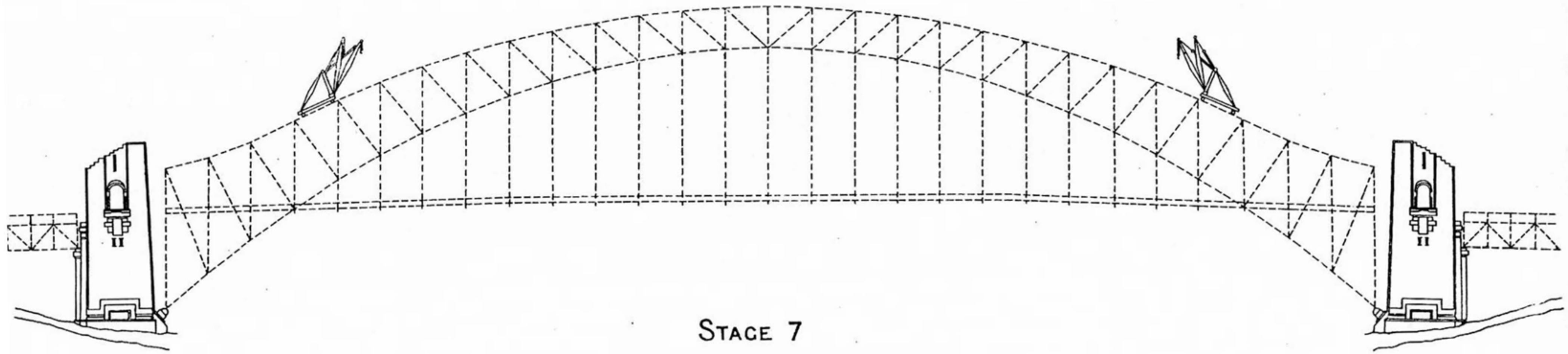
22406—N



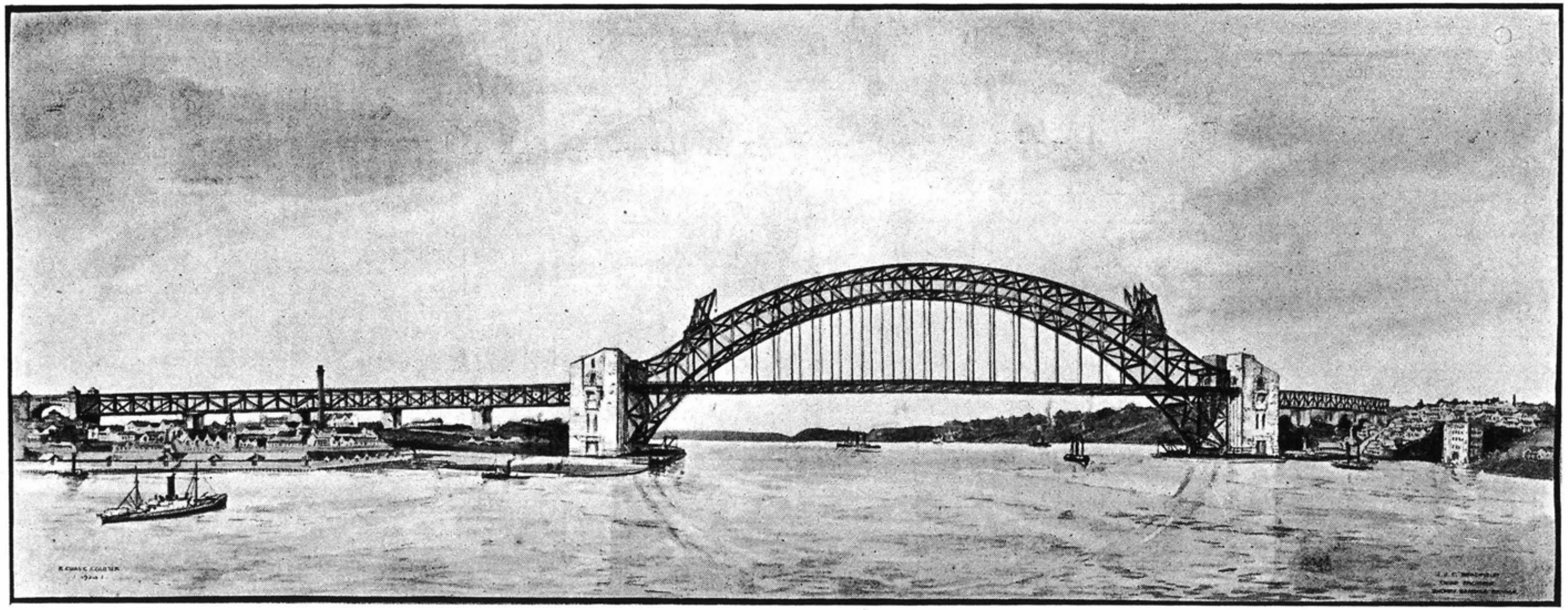
STAGE 6



Photograph No. 20.—Stage 6.



Stage 7



Photograph No. 21.—Stage 7.

10.—Conditions Attaching to Messrs. Dorman Long & Co.'s Tender.

Fabrication of Bridge.

The tender is based on the understanding that the fabricating shops together with the necessary offices are erected at Milson's Point on the site extended in accordance with the Chief Engineer's letter of 14th December, 1923, and the plan accompanying same. To accommodate shops of the dimensions necessary, an additional area of land will be required. In the event of the contract being placed with them, Messrs. Dorman Long & Co. ask that this land be resumed and placed at their disposal free of cost, Messrs. Dorman Long & Co. to excavate the site to suit their requirements.

The plan accompanying my letter of 14th December indicated the area of land available at Milson's Point for constructional purposes and was sent to all firms who had tendered.

The Valuer-General estimates the value of the additional area of land mentioned above at £12,000, and if Messrs. Dorman Long & Co.'s tender is accepted, I recommend that the land be acquired.

In the case of strikes or labour disputes in Australia interfering with the satisfactory progress of manufacture, the right is reserved to undertake fabrication in England of materials essential to maintain erection programme. This provision is reasonable, as once the erection of the bridge commences, it is essential that it be completed without delay; the risk and difficulty of erection would be greatly increased if the work could be so held up. Ministerial approval must first be obtained.

Granite.

The firm intends to make use of the Moruya quarry and ask if, after reasonable efforts, it is impossible to obtain the granite in the large blocks required, they have the right to appeal to the Chief Engineer for a modification of the sizes.

Referring to quantity, should the present area of quarry offered be insufficient, it is understood that a further resumption of granite area would be granted to the firm, free of cost.

These requests are reasonable. The blocks specified are in accord with the best practice, but if it is found necessary on account of the stone not being quarryable in the sizes specified, to reduce the size of the blocks there will be a saving on the cost of the work in that less high-priced granite but more concrete will be used. As this firm tenders to use granite aggregate for the concrete, the strength of the substructure will not be affected thereby.

I told all firms before they tendered that if the stone was not procurable in the sizes specified, a reduction in size would be favourably considered.

The request for an additional area of land adjacent to the existing quarry, if it should be found to contain an insufficient quantity of granite for the bridge, is also reasonable, but it is hardly likely there will be an insufficiency of granite for the bridge. The land surrounding the quarry for miles is all a granite formation.

Whether or not an additional area of land is wanted from which to obtain the granite for the bridge, it would be a good investment to acquire a further area of land. The quarry will be developed and the latest modern machinery will have to be installed to obtain the stone necessary for the bridge. The granite quarry at Moruya is most accessible for water carriage. Granite is superior to any of the other metals for road-making either as concrete roads, macadam roads, or asphalt concrete roads, and Sydney badly lacks good roads. The opportunity is now offering to obtain a granite quarry for road-making purposes, which, in the first instance, will be developed at the cost of the Sydney Harbour Bridge.

If the contract is let to Messrs. Dorman Long & Co., and additional land is found necessary, I recommend it be acquired, and would further recommend that, in any case, if the contract is so placed, additional land be acquired.

On completion of the bridge the quarry equipment could be bought and the quarry taken over, if thought desirable, by the State, or Messrs. Dorman Long & Co. might have the option of purchasing the quarry at a price to be agreed upon, which their General Manager informs me is in line with the policy of development of Messrs. Dorman Long & Co. in New South Wales.

Rolled Steel.

The tender provides to use all sections rolled in New South Wales up to 16th January last, the date of closing of tenders.

The prices quoted to the tenderer by the Broken Hill Proprietary Company are not firm prices covering the whole period of contract, but are subject to market fluctuations, and necessarily the tender is so made. The rates on which the tender has been based are given by tenderer ; if there is a decrease in the price of the sections the Government will benefit, but if the Broken Hill Proprietary Company ask for an increase there are two courses open :—

(*a*) Either the Government allow the increase per ton asked for and so increase the price of the bridge; or

(*b*) The Government allow the tenderer to supply the material from the firm's own mills at Middlesbrough, England, when the price as tendered will be adhered to, and there will be no increase.

This stipulation is perfectly fair. Should the situation arise the Minister can then decide which course he will pursue, but the tender should be accepted with its above proviso.

The tenderer has also reserved the right to manufacture the material in England if it cannot be obtained in Australia in conformity with the specification without serious delay, or if for other reasons, to the satisfaction of the Chief Engineer, it is desirable to supply material from England to avoid serious delay and ensure reliability of material.

These stipulations are fair; it may not suit the rolling-mills to roll the material at a reasonable notice, and thus delay may be caused in the fabrication of the bridge, and its cost on that account increased.

Erection Material Payment.

In the arch bridge some members have to be of greater section to provide for erection stresses than they will need to be after the bridge is erected and carrying the live load. The tenderer asks that the additional material required for erection and which cannot be removed, be paid for.

This is the intention of the specification. All material which is required for erection purposes and cannot be removed, and which will form part of the finished structure must be paid for. All temporary struts, more particularly in the cantilever bridge, which could be removed on completion of the bridge would not be paid for.

Masonry Quantities.

In the arch bridge the price per square foot for four-cut work covers the entire surface of all sides of all stones used in the following positions :—

(*a*) Top capping course of approach spans;

(*b*) Three top courses of skewbacks.

In addition, the schedule rate for special finish, Item 10, will be paid on the surface area of the skewbacks under the main bearings of the arch.

The surface area on all rusticated or moulded surface will be measured over the entire area of the finished external faces of the stones.

This is the intention of the specification.

Arbitration on Technical Matters.

The tenderer asks that, in the event of difficulties arising as to the correct method of calculations or details of design to be adopted between the Department and the tenderer, the points in dispute should be referred to an independent engineer appointed by the Minister who has had personal responsibility for the design and erection of a bridge of first-class magnitude.

The decision of the Chief Engineer should be final.

Approval of Drawings and Calculations.

The tender states that the calculations and working drawings will be made in Great Britain, probably London, and states it is assumed that arrangements will be made for examination and approval of these drawings in London by the Chief Engineer.

This will expedite the work and was specified in the event of the bridge being fabricated abroad, Clause 61, and might be agreed to as the contractor's engineers are domiciled in England.

Force Majeure.

It is suggested that in the general conditions of contract to provide for circumstances arising from interference with the due execution of the work as a result of force majeure, including outbreak of hostilities, riot, epidemic, famine, loss at sea, seismic disturbances, strikes or combination of workmen.

This may be considered under two headings :—

Damage to the bridge owing to the outbreak of hostilities, riot, or seismic disturbances during construction.

These risks are beyond the control of the contractor and should be taken by the Government.

Extension of time due to outbreak of hostilities, riot, severe epidemic, loss at sea, famine, seismic disturbances and strikes or combination of workmen.

If these were due to no fault of the contractor, the Minister would, in the ordinary course, grant an extension of time.

If Messrs. Dorman Long & Co.'s tender is accepted, clauses embodying the above provisions should be embodied in the contract.

11.—Conclusion.

Before concluding this report, might I say that since my appointment on 1st July, 1912, by the Hon. Arthur Griffith, then Minister for Public Works, as Chief Engineer of these two great projects, the electric railways of Sydney and the Sydney Harbour Bridge, I have received the utmost consideration from the Hon. Arthur Griffith, the Hon. J. H. Cann, the Hon. J. Estell, and the Hon. R. T. Ball, Ministers for Public Works, from the Director General of Public Works, Mr. J. Davis, and the Under Secretary for Public Works, Mr. T. B. Cooper. The trust reposed in me has enabled me to lead public opinion straight and to bring tenders to a successful conclusion with the least possible cost to the State, and with the confidence of the firms tendering.

The tender recommended, for the two-hinged arch bridge with granite masonry facing, is my design as sanctioned by Parliament and as submitted for tenders. The bridge, with piers and abutments faced with pre-cast concrete blocks instead of granite, would be equally efficient as far as the traffic is concerned, and would cost £240,000 less.

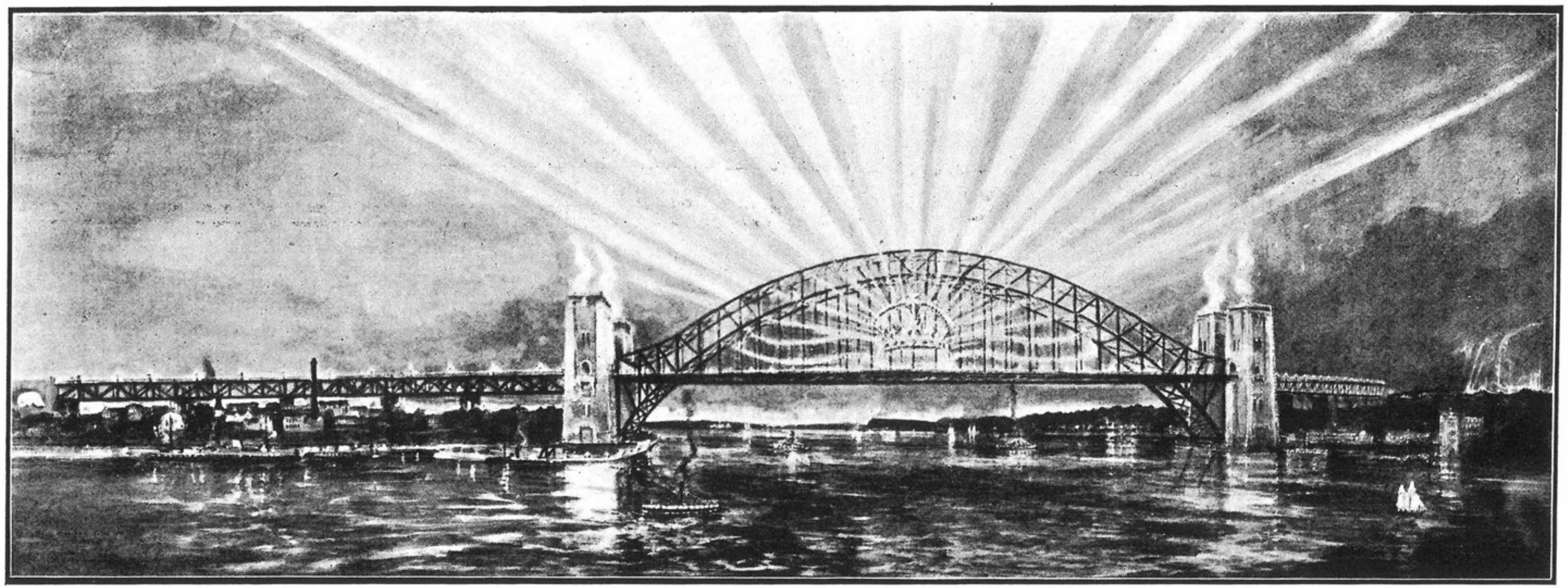
In making my recommendation I have kept in view the past and future as well as the present. One characteristic of modern thought is the increasing tendency to study the past, and in looking backward we find a nation's manner of life and civilisation written in those works of its rulers which have survived the ravages of time.

Due to our gallant soldiers, Australia has recently been acclaimed a nation. In the upbuilding of any nation the land slowly moulds the people, the people with patient toil alter the face of the landscape; clearing forests, draining swamps, tilling fields, constructing roads and railways, building factories and rearing cities, they humanise the landscape after their own image. Thus in the years to come will result the perfected product, land and people, body and soul, bound together by innumerable and subtle ties.

Future generations will judge our generation by our works. For that reason and from considerations of the past, I have recommended granite, strong, imperishable, a natural product, rather than a cheaper artificial material, for the facing of the piers, although the cost is £240,000 greater; humanising our landscape in simplicity, strength, and sincerity.

Of no moment whatever in considering the acceptance of a tender, but which still is, perhaps, worth recording, at times of national rejoicing when the city is illuminated, the arch bridge would be unique in that it could be illuminated to represent the badge of the Australian Commonwealth Military Forces, the sun and crown, a fitting tribute to our soldiers, unparallelled in the annals of any nation. (*Photograph No. 22*).

Much has appeared in the press since tenders closed about preference to Australian tenders, but quite apart from the unfairness to tenderers from abroad if this aspect received undue consideration, it has almost invariably been forgotten that not the people of Australia nor of New South Wales are paying for the bridge, but the 91,361 taxpayers in the city of Sydney and the Northern Suburbs, who paid the tax last year and will shortly again receive their assessment notices from the shires and municipalities defraying the municipal portion of the cost. When the bridge is completed the residents of the Northern Suburbs will pay in railway fares



Photograph No. 22.

for the railway portion of the bridge. The tender recommended is for all-Australian manufacture and is lower than any of the tenders received, so the bridge taxpayers will have the satisfaction of knowing that they are paying for an all-Australian bridge without any additional cost to themselves.

In conclusion, I wish to record my appreciation of the work undertaken by Miss K. M. Butler in the preparation of this report, who has dealt with all confidential matters in connection with the tenders; of Mr. G. A. Stuckey, B.Sc., B.E., who has assisted me in checking any calculations and technical matter in connection with the tenders. Since 16th January, these two officers have cheerfully worked incessantly, Saturdays and Sundays, assisting me to present my report to the Minister at the earliest possible moment.

I also wish to thank Mr. R. C. Coulter, of the Government Architect's Branch, who had made the perspective drawings submitted with this report, other than those supplied by tenderers, and Mr. R. A. Bowden, Government Photographer, who has supplied the photographs.

J. J. C. Bradfield. M.E. M. Inst. C. E

Chief Engineer,
Sydney Harbour Bridge,

16th February, 1924.

Report checked with tenders.

Kathleen. M. Butler.

Secretary.

Sydney: Alfred James Kent, Government Printer—1924.

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