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.]

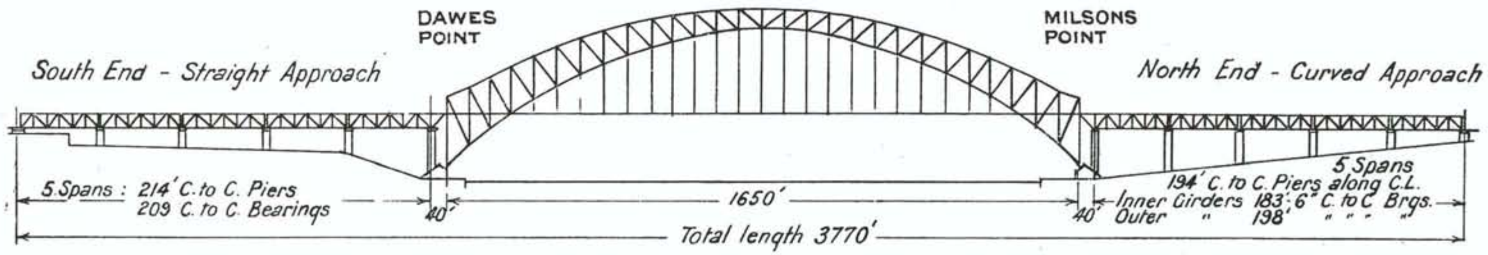
Tender A2.—This tender, Plan No. 10, is also for a two-hinged arch bridge of 1,650 feet span, but with alternative masonry abutment towers faced with pre-cast concrete blocks above plinth level in lieu of granite facing. The length of main bridge and approach spans is 3,770 feet. Owing to the design 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.

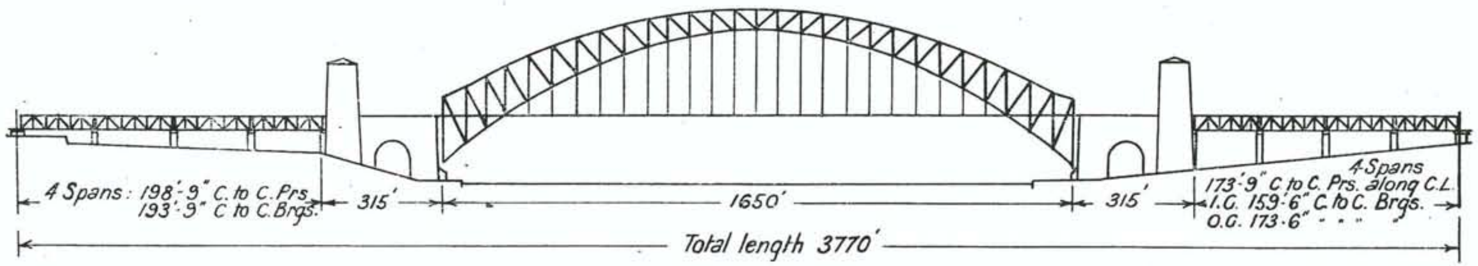
TENDERS FOR AN ARCH BRIDGE

Tender A1



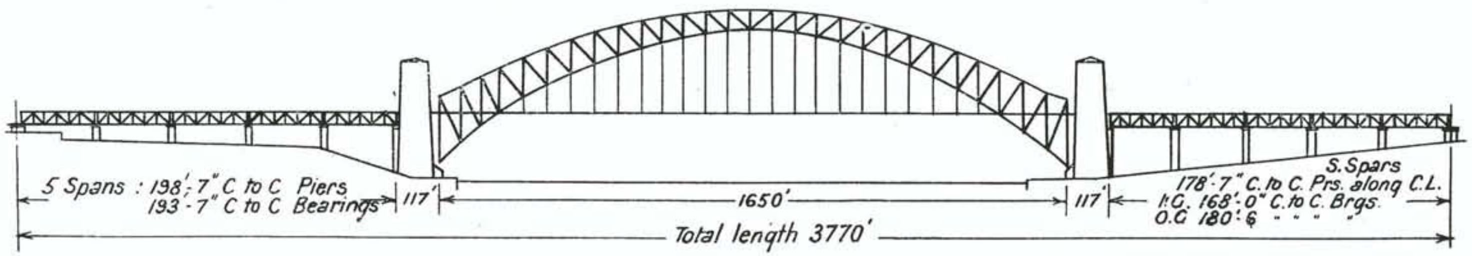
Alternative (A1). Without abutment towers, granite masonry facing ... ... £3,499,815 : 15 : 0

Tender A2



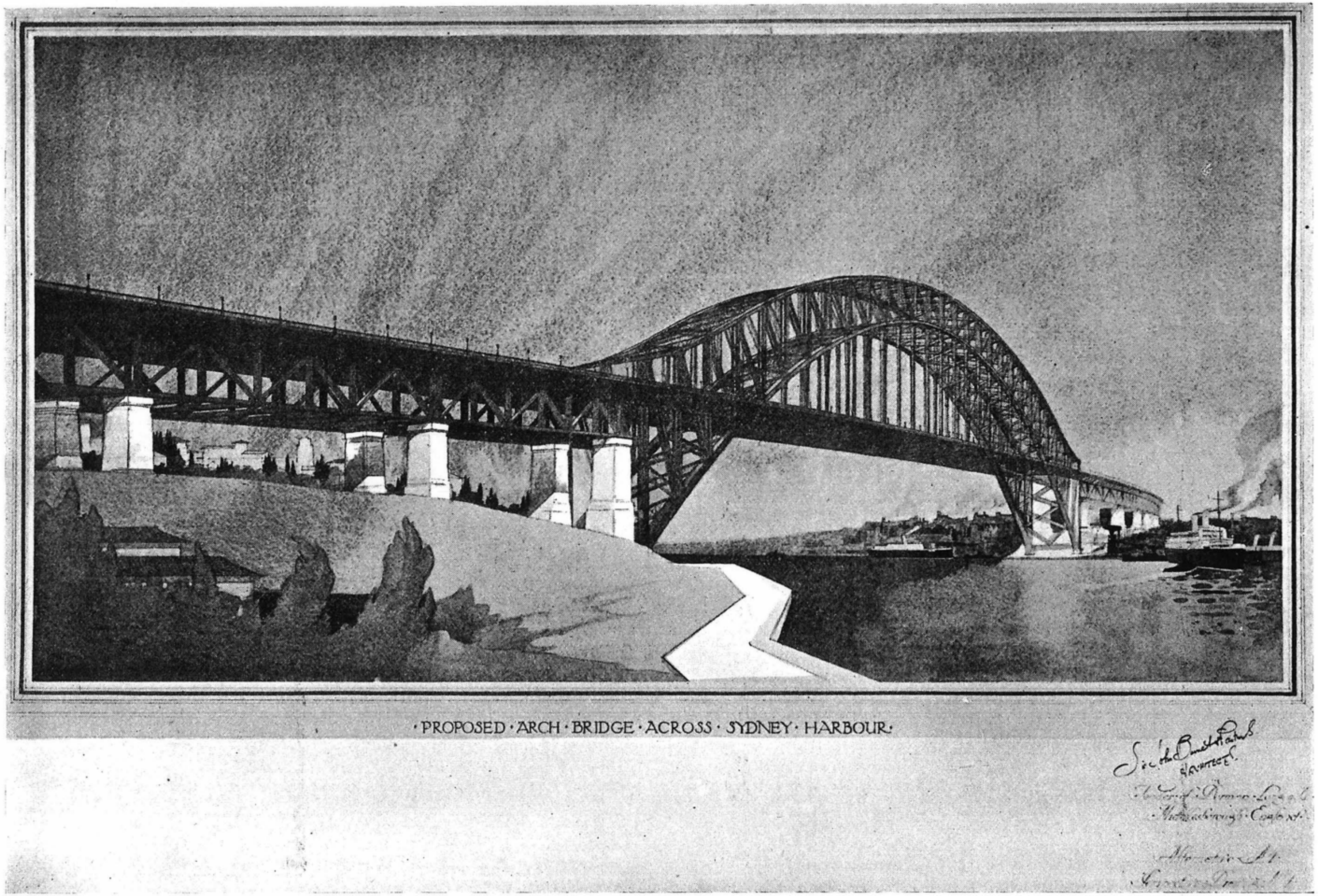
Alternative (A2). Abutment towers, Tenderer's own design, granite facing to plinth level, precast concrete blocks above plinth level ... ... £4,233,105 : 4 : 7

Tender A3

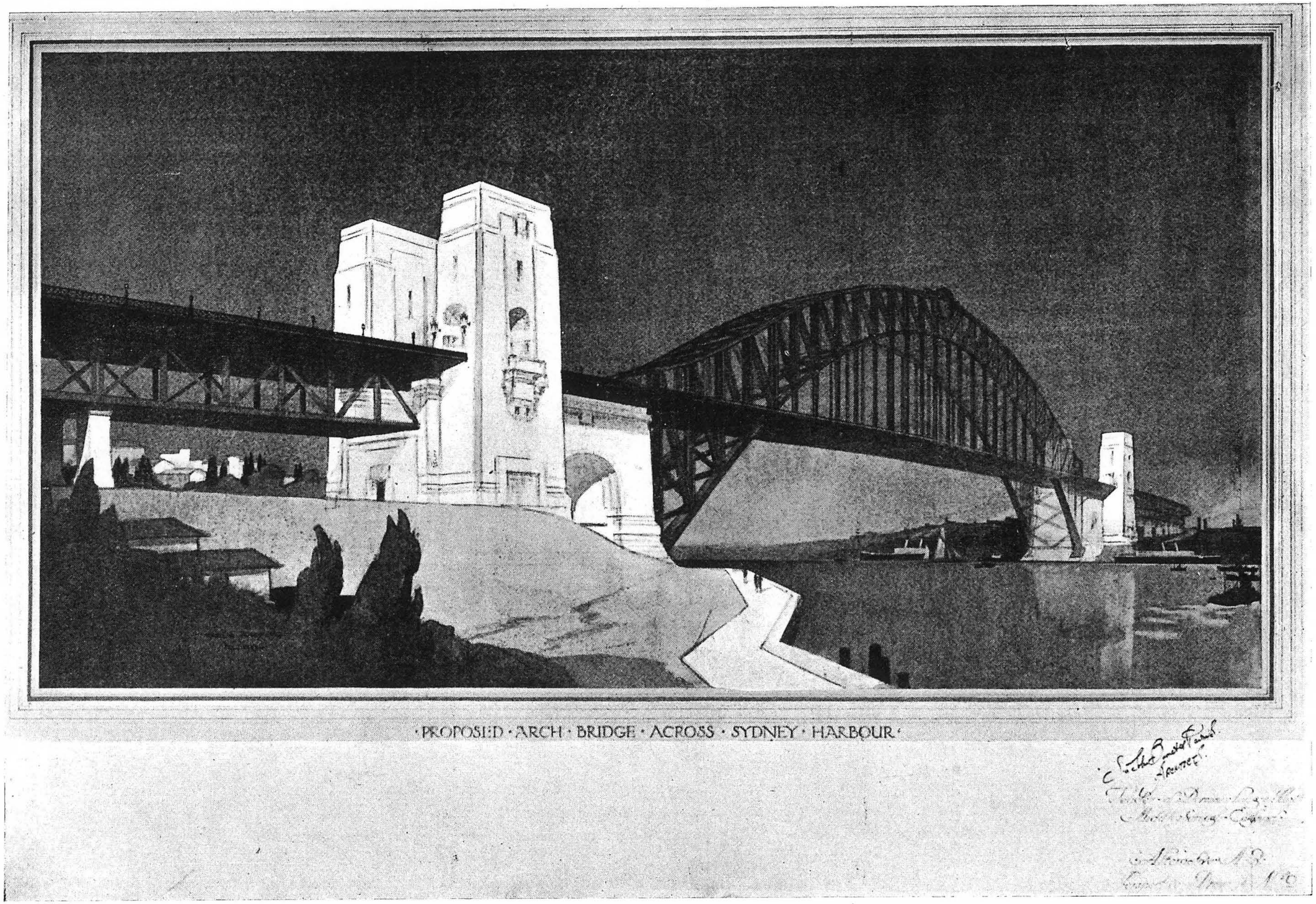


(A3) In accordance with Official Design, granite facing throughout ... ... £4,217,721 : 11 : 10

(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.

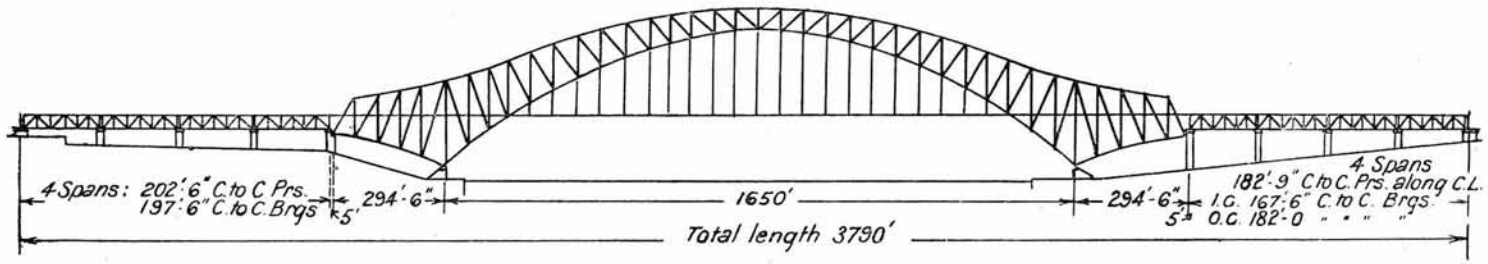
The calculated deflection at the centre of the steel arches included in the foregoing tenders, under full live load and impact, is 3·9 inches, or 3·55 inches for live load, whilst due to a rise or fall in temperature of 60 degrees, the up or down movement would be 7½ inches—a maximum movement under live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

PLAN No. 11.

DORMAN LONG & CO. LTD.

TENDERS FOR A CANTILEVER BRIDGE

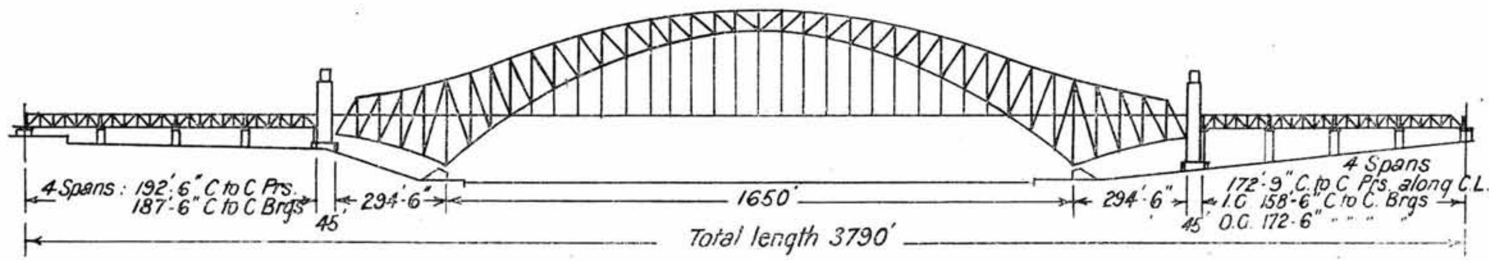
Tender B1



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

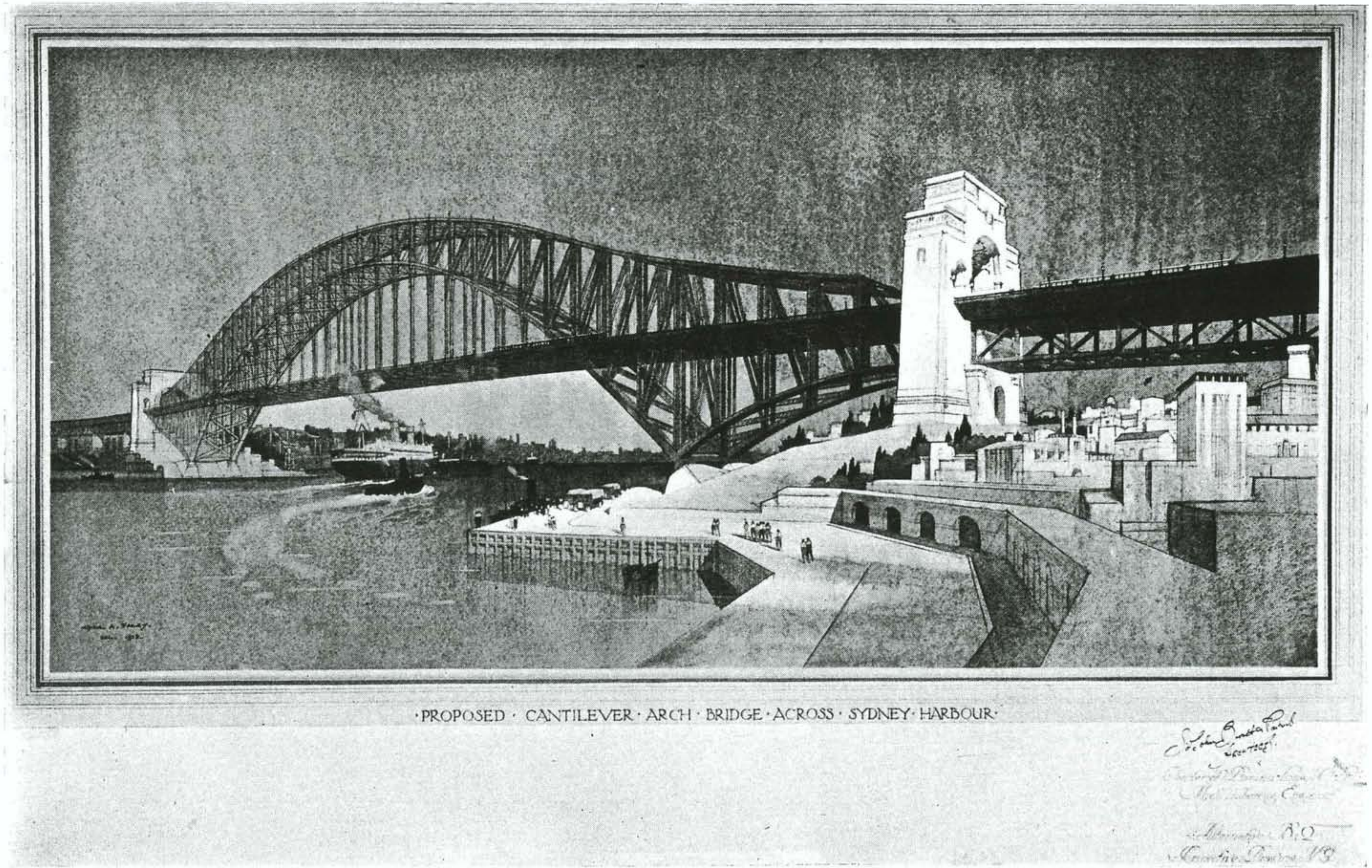
30

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.

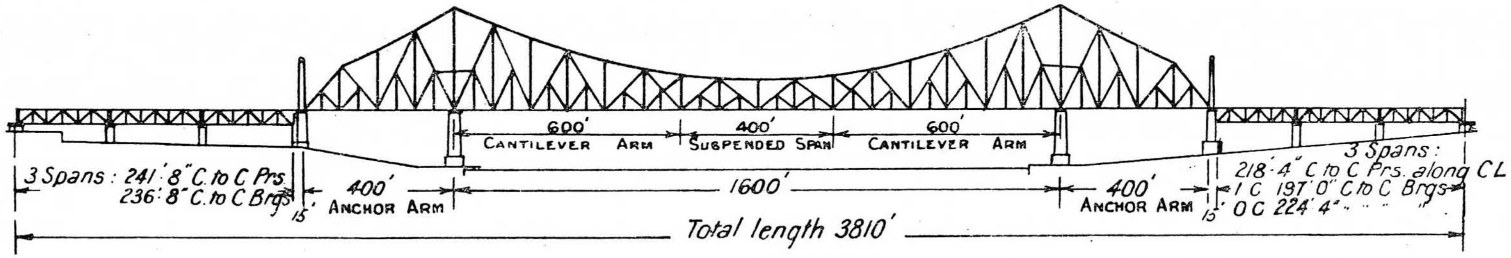
Under live load and impact the calculated deflection at the centre of the cantilever-arch is 4·4 inches, or 4 inches for live load, and due to temperature, 8 inches, or a maximum vertical movement of 12 inches under live load and temperature.

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.

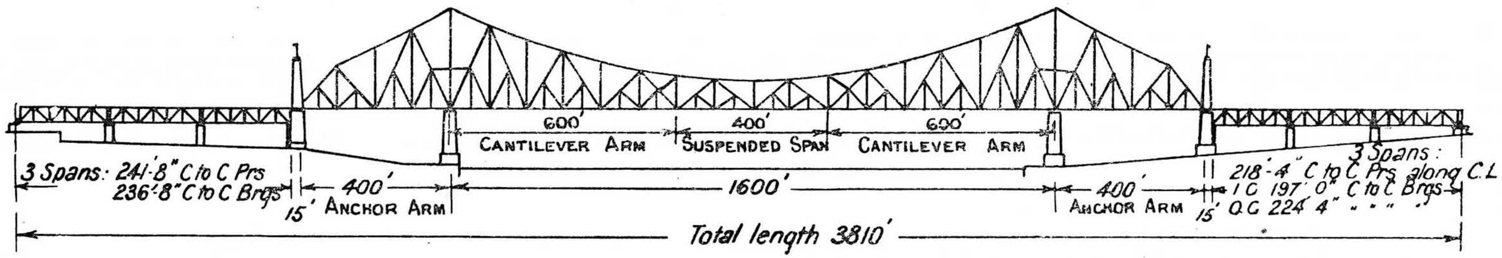
Tenders for a Cantilever Arch Bridge

Tender C1

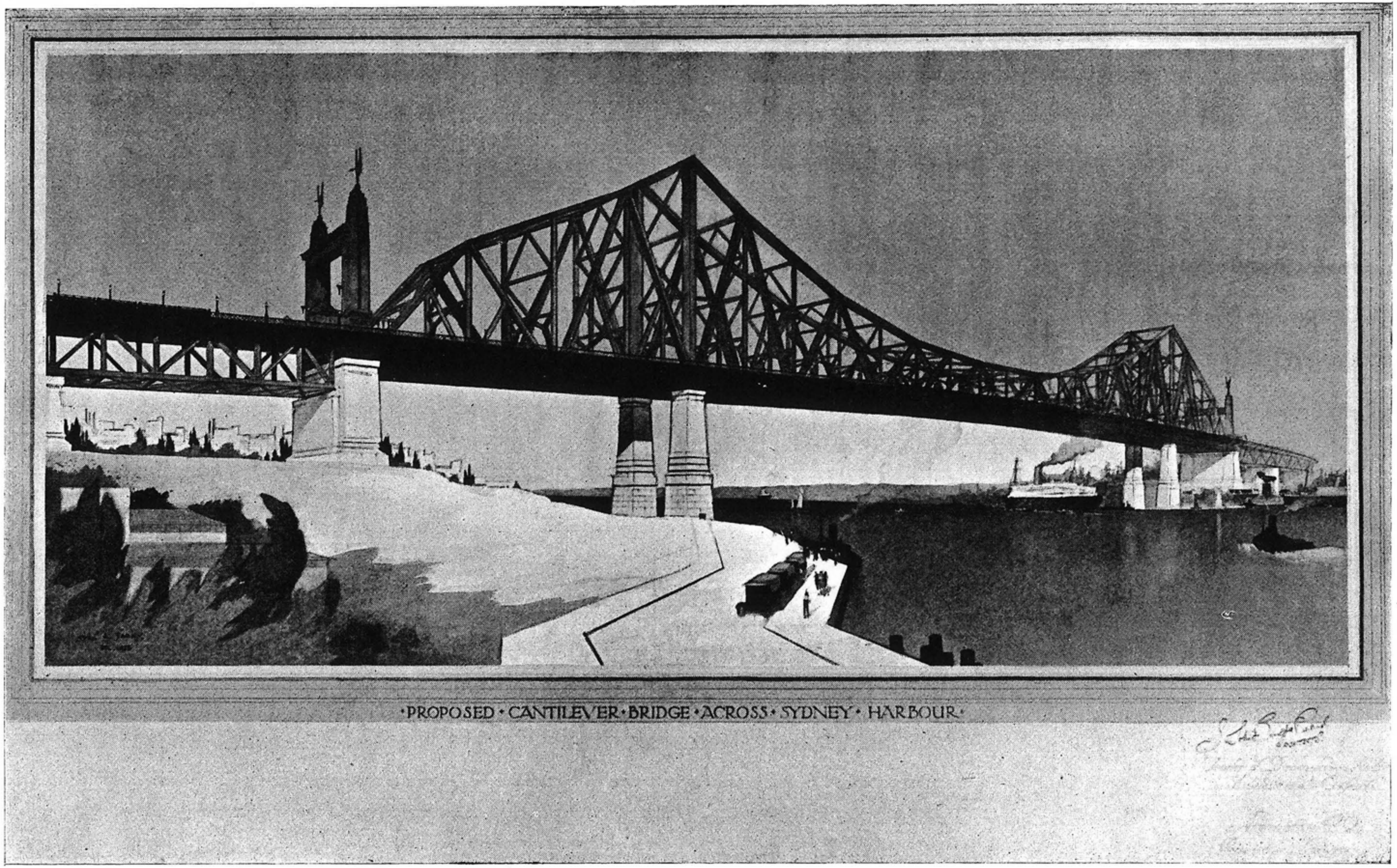


Alternative (C1). Granite facing throughout ... ... £4,551,758 : 13 : 3

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.			Tenderer.
	£	s.	d.	
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 1¼ 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.