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

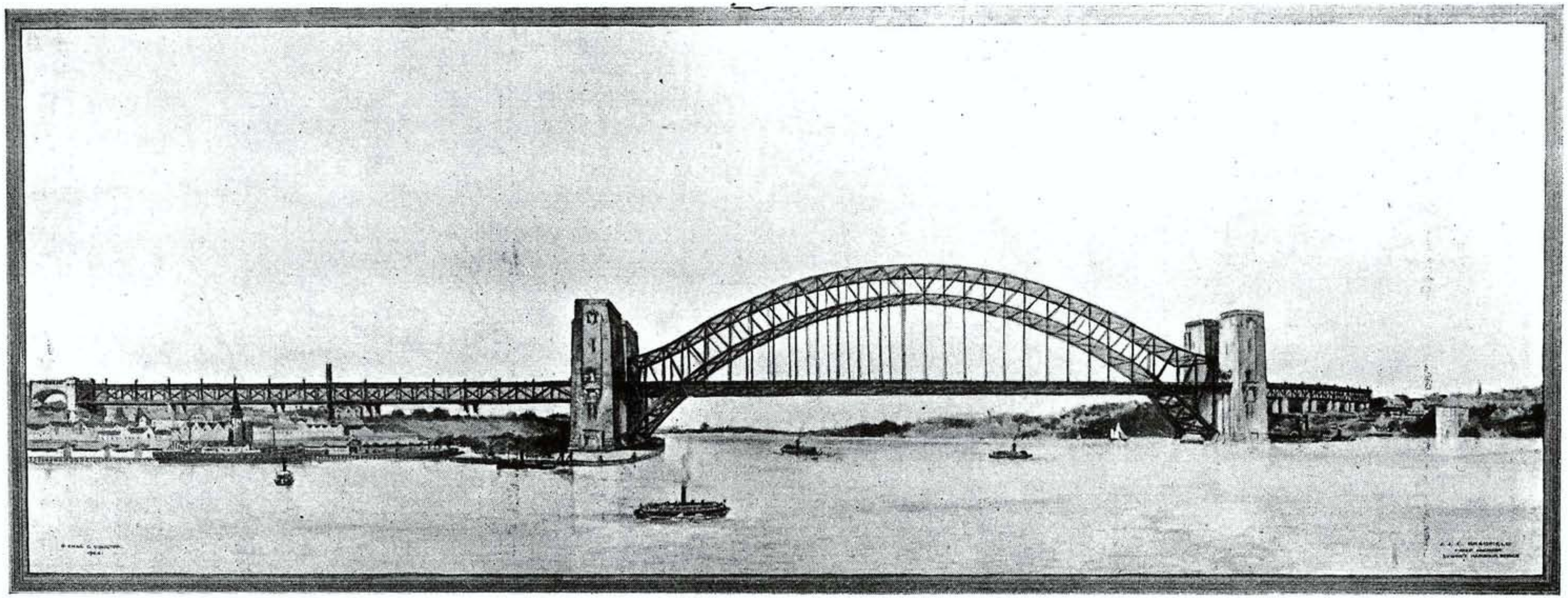
52 inches in diameter, enclosing a solid key pin 14 inches in diameter, divided into four lengths, one for each web of the lower chord. The whole is covered by a thin steel sheet casing and is kept in position during erection by six holding-down bolts each 4 inches in diameter. The weight of each complete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

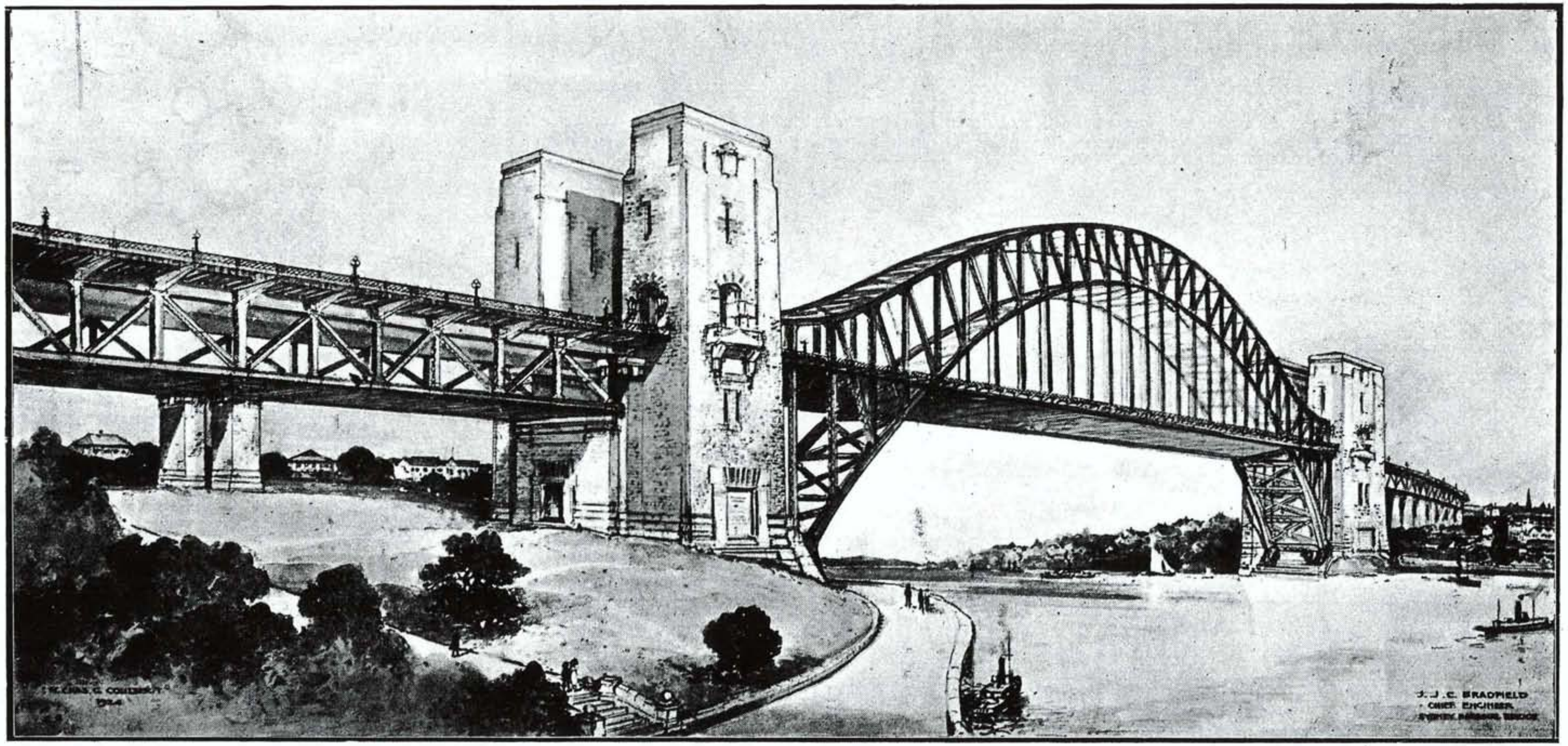
Every main chord member of the trusses consists of a built-up section composed of four web plates and sixteen flange angles 10 inches by 10 inches, together with flange plates forming a rectangular box section. Vertical and diagonal main truss members are composed of four web plates with eight flange 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 $3\frac{1}{2}$, 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.

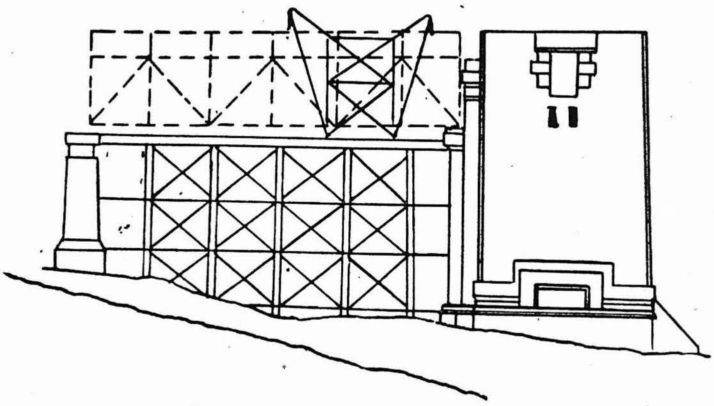
Stage 4.—As soon as sufficient cable is provided to sustain the reaction, the cables secured to the end post will be slacked, and these cables will then be available for augmenting the cables attached to the fifth panel as the reaction increases due to the moving forward of the crane. The crane will 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.

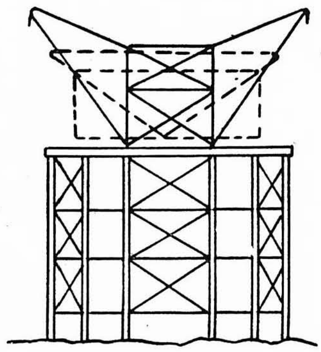
Stage 6.—(*Plan No.* 21, *Photograph No.* 20).—Hydraulic rams will then be inserted in the top chord members and an initial stress will be put into the members to correspond with the stress which would arise in these members if the arch were built as a complete elastic two-hinged structure of the correct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

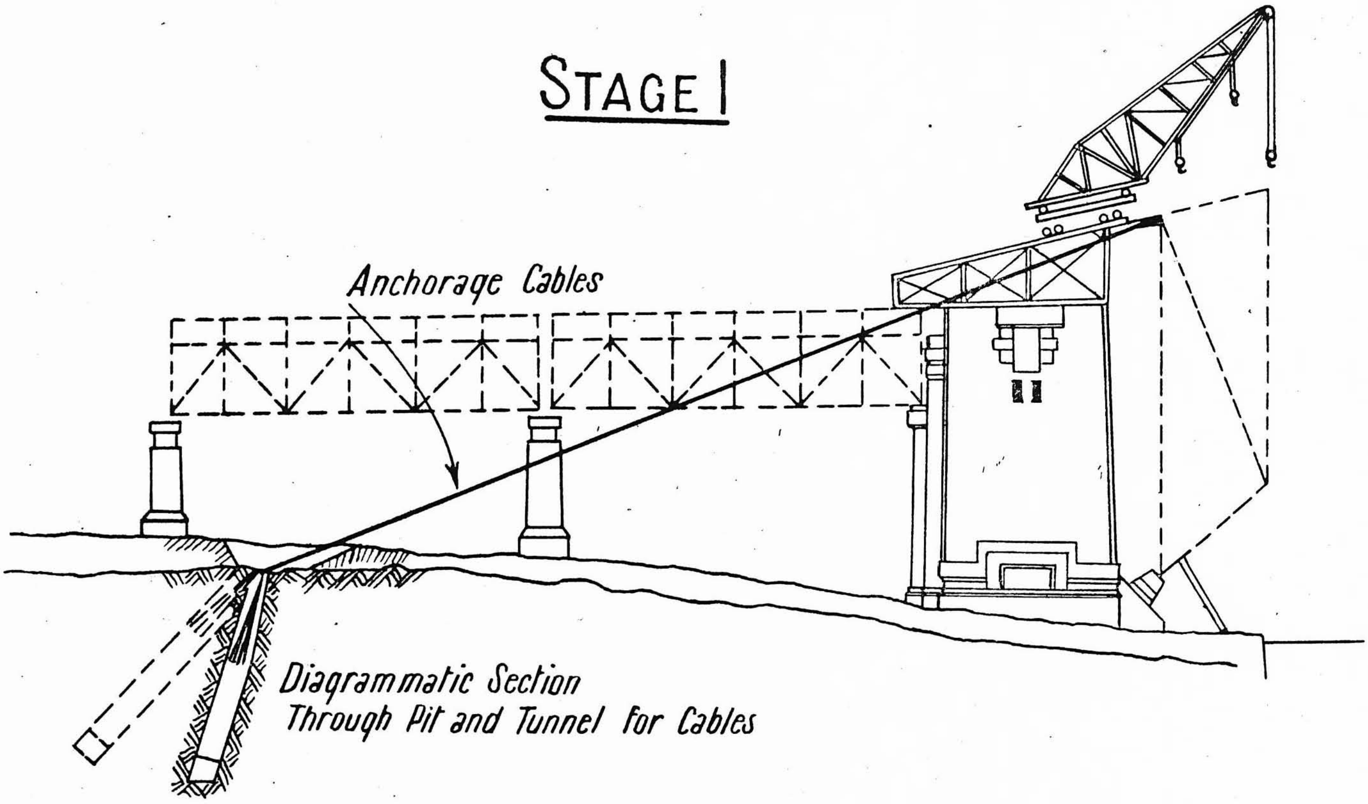


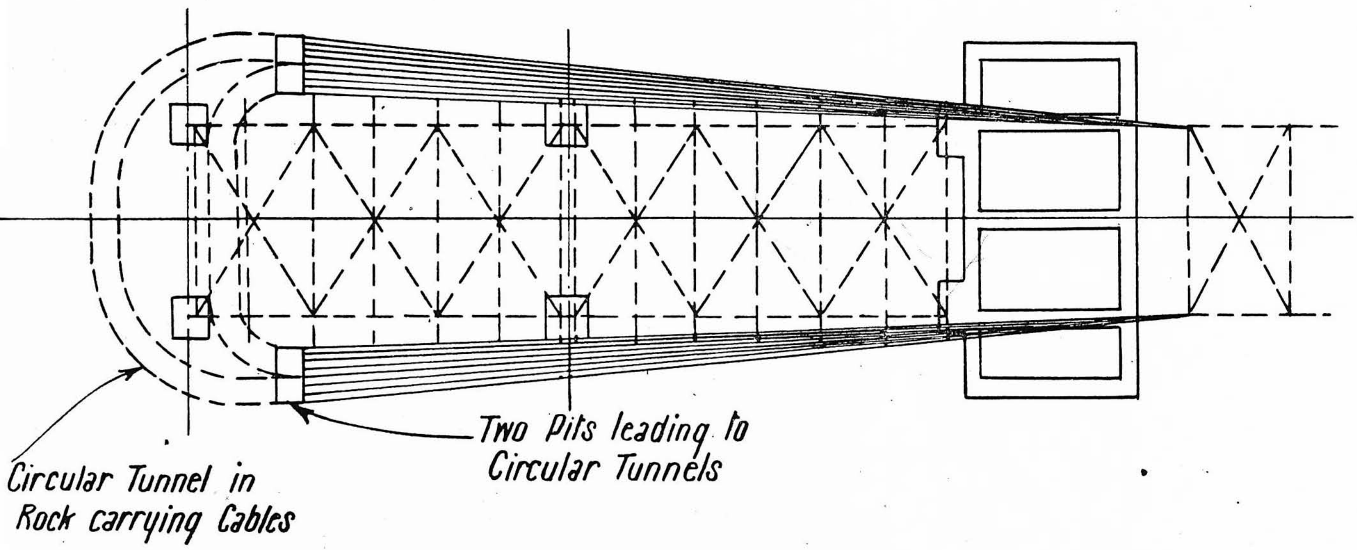
SIDE ELEVATION



END ELEVATION

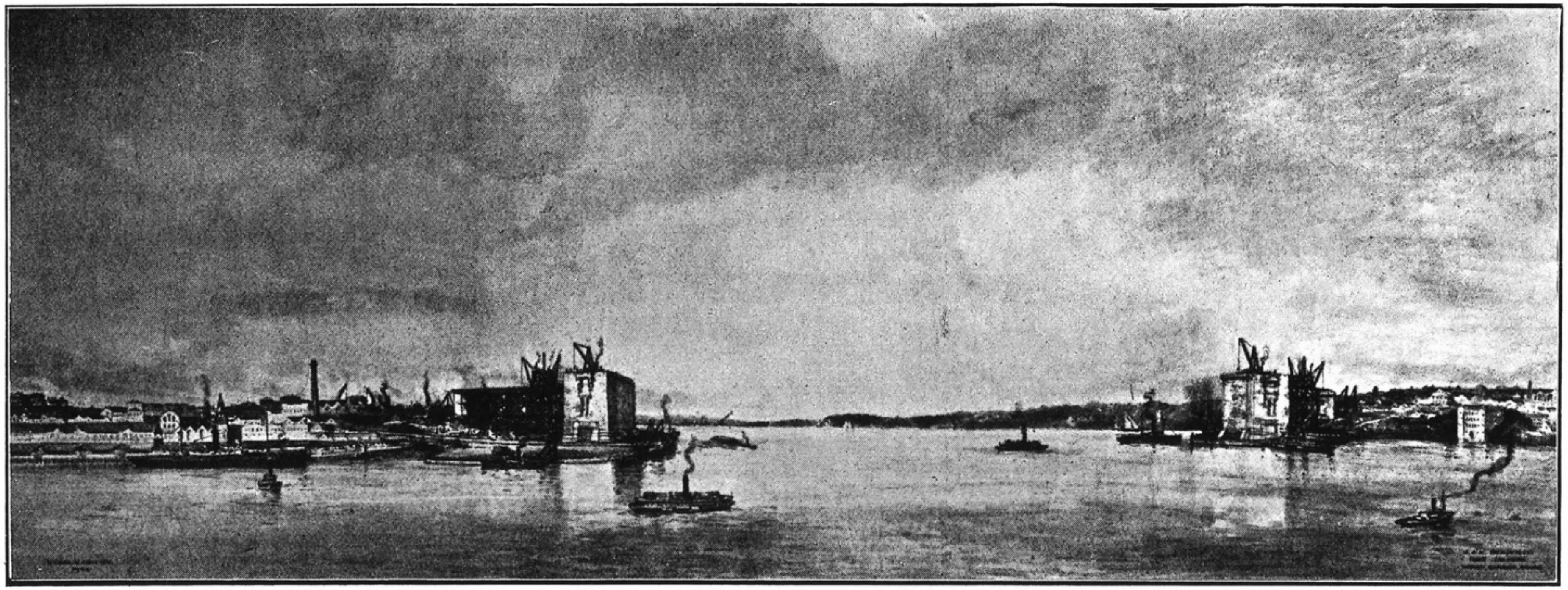
STAGE 1





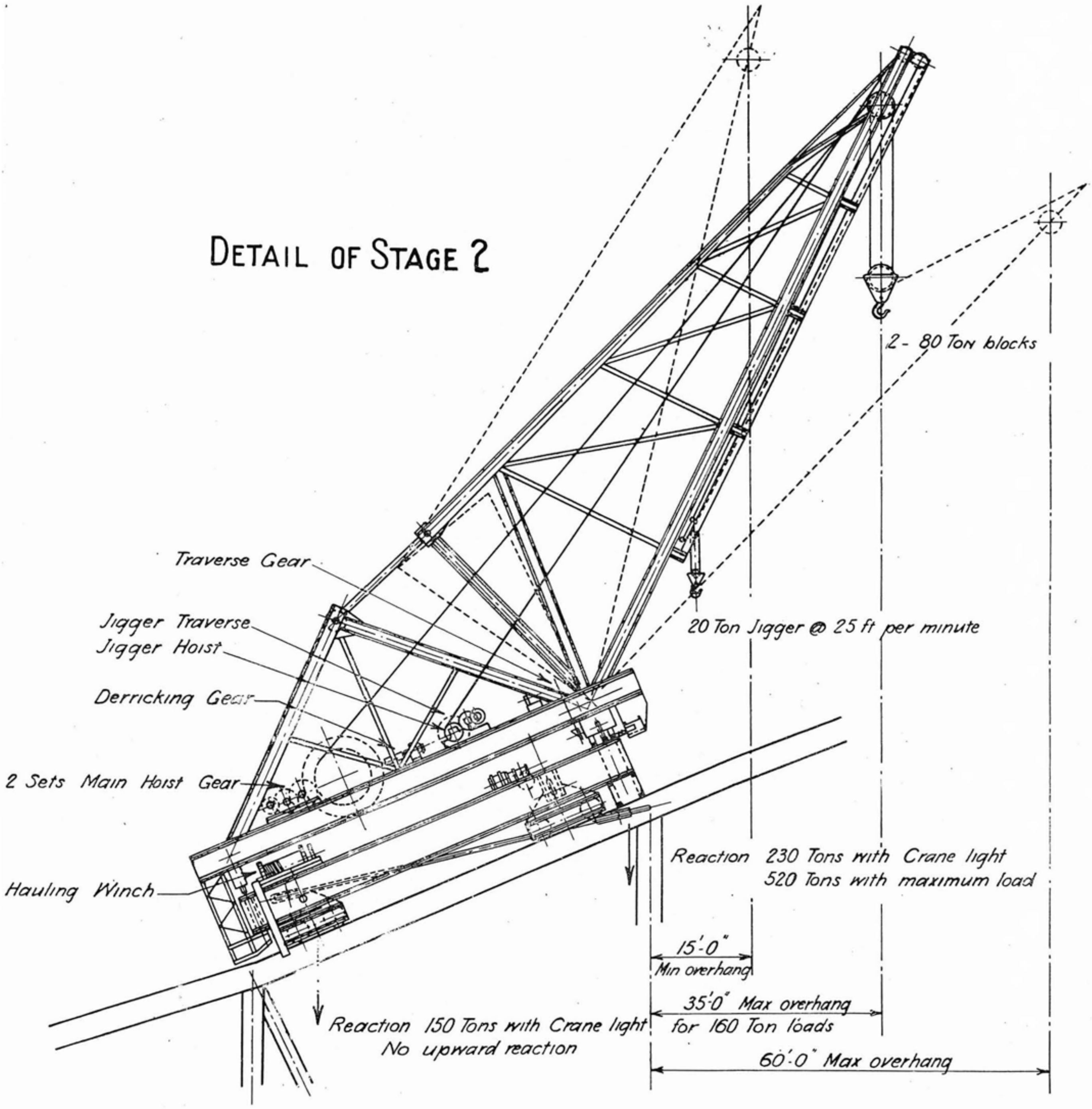
PLAN

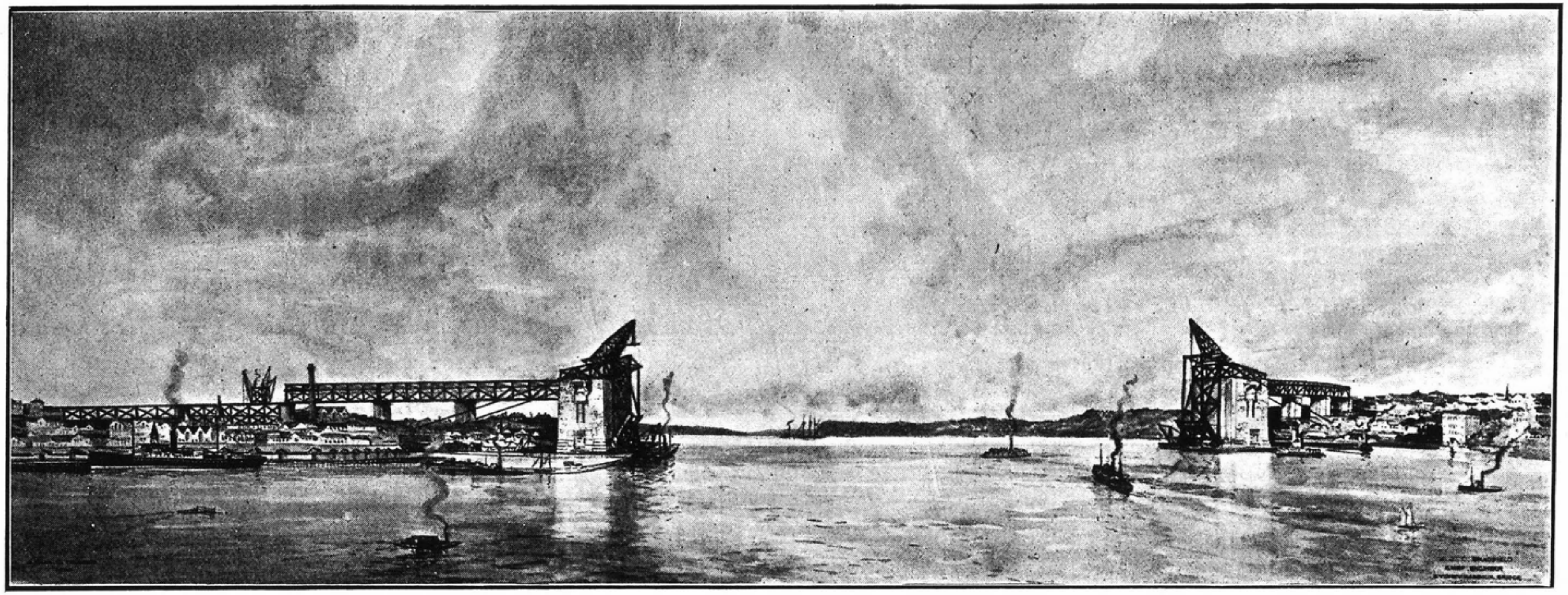
STAGE 2



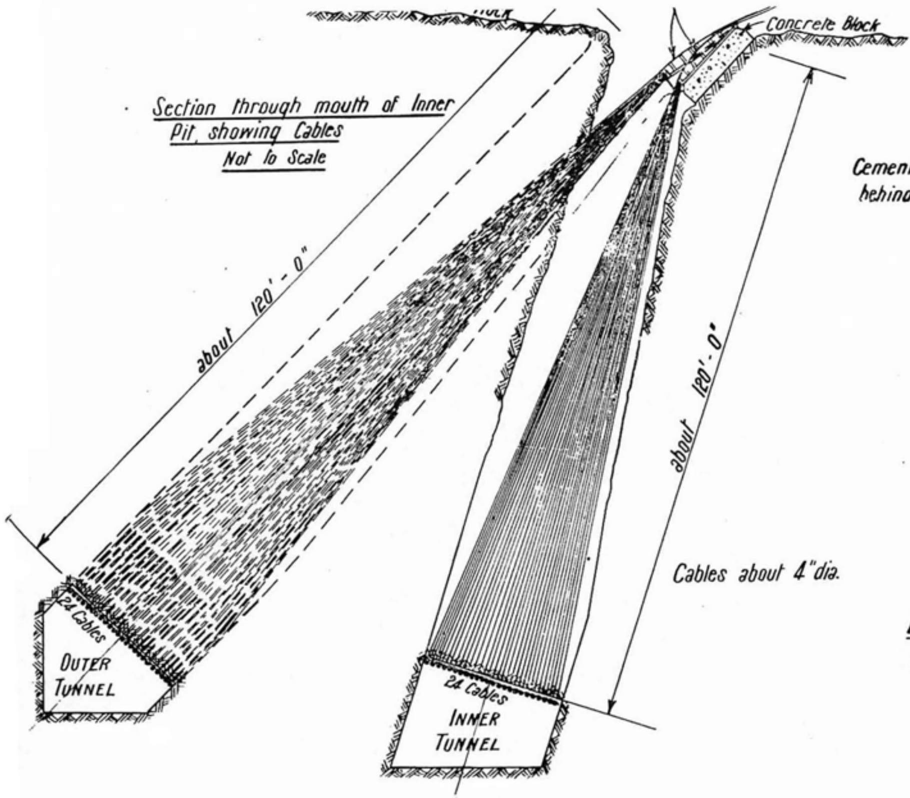
Photograph No. 15.—Stage 1.

DETAIL OF STAGE 2

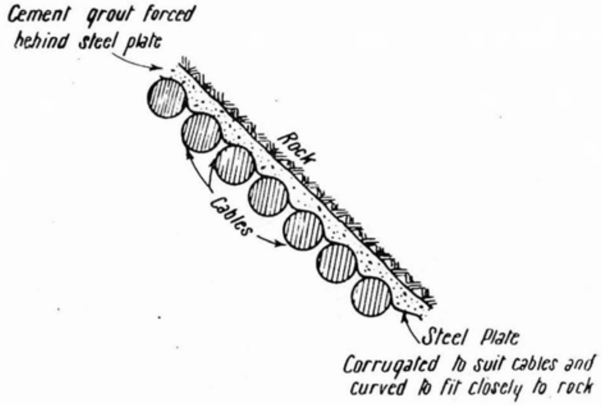




Photograph No. 16.—Stage 2.

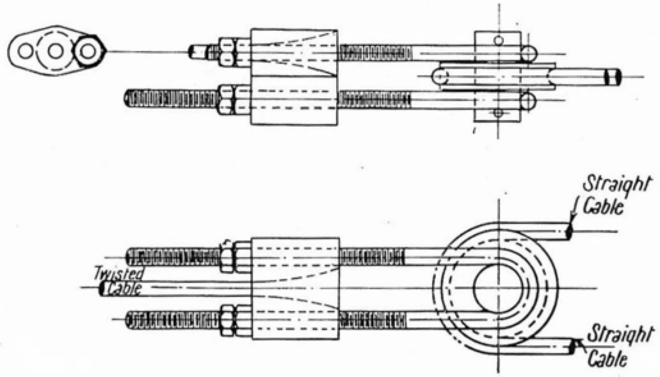


Section through mouth of Inner Pit, showing Cables
Not to Scale

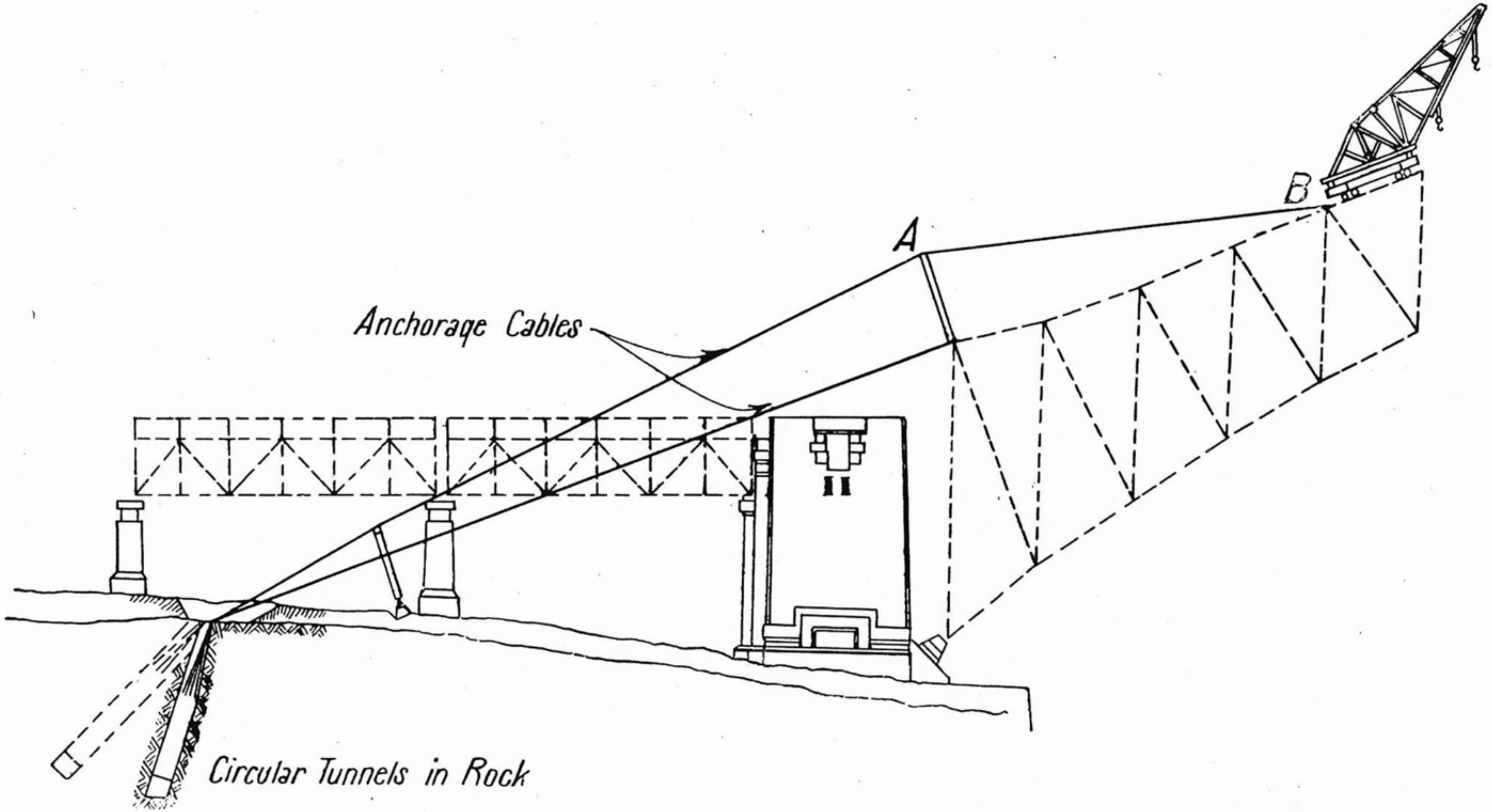


Detail showing Method of Bedding Cables against Rock in Tunnels
Scale 1 Inch = 1 Foot

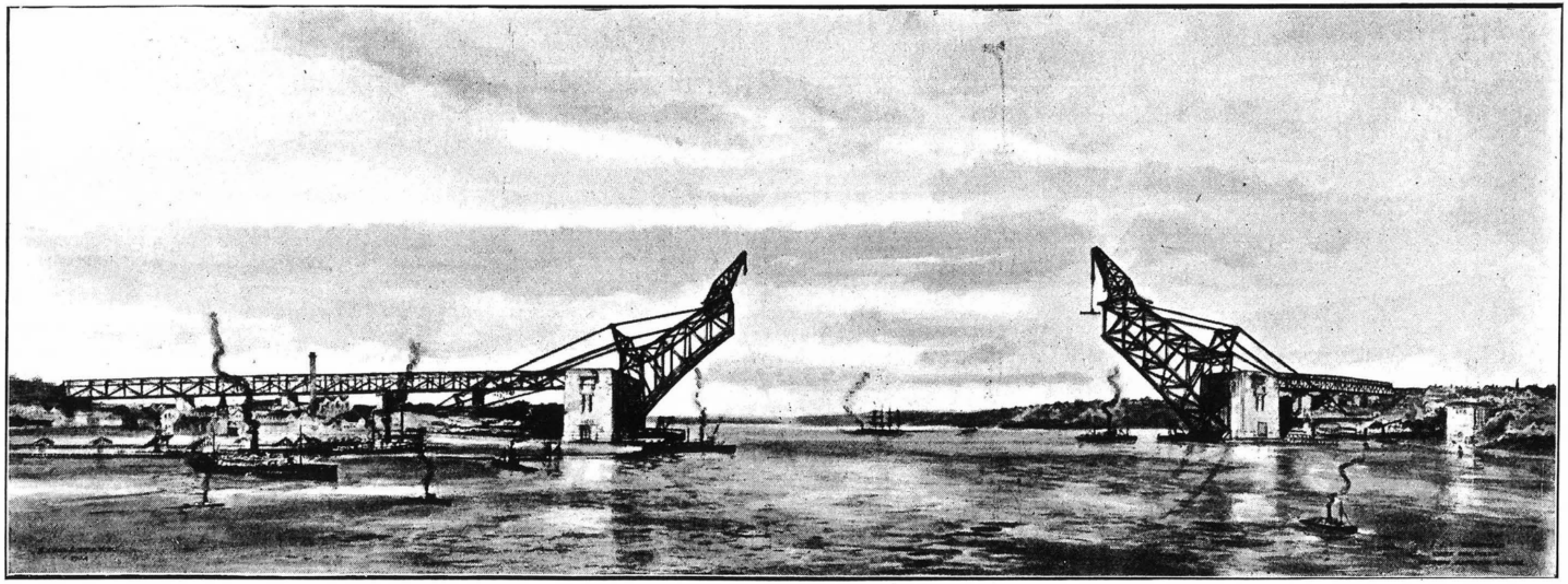
DETAIL OF STAGE 2



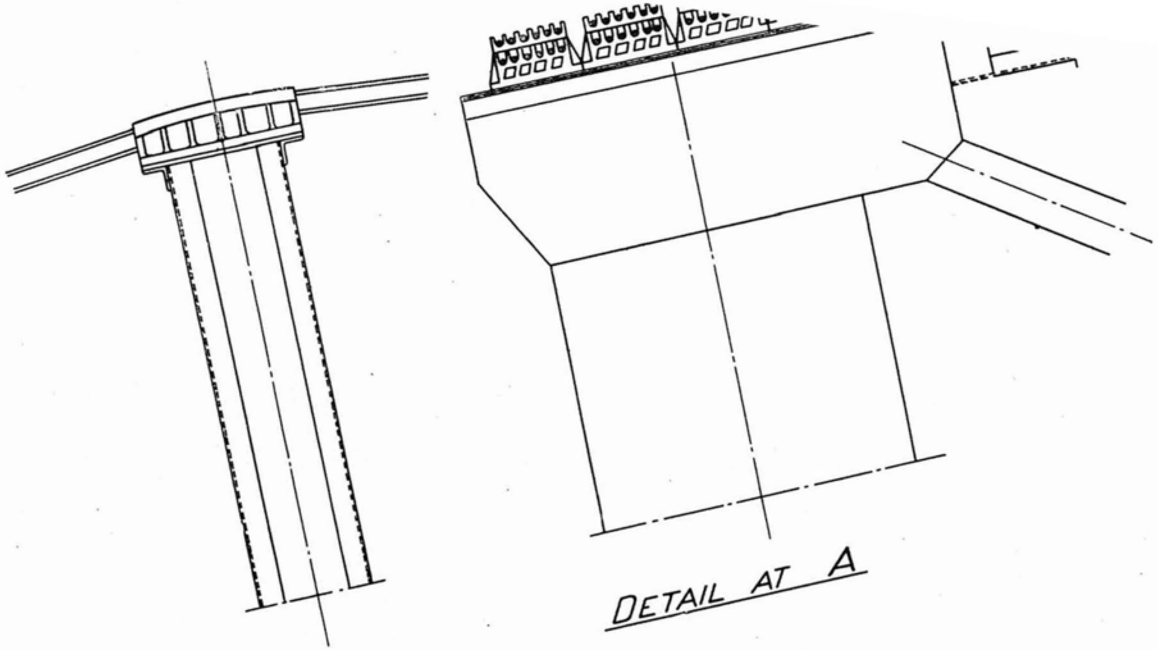
DETAIL OF SHACKLES
Scale : ½ Inch = 1 Foot



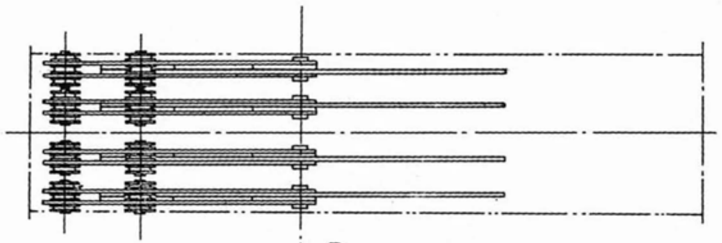
STAGE 3



Photograph No. 17.—Stage 3.

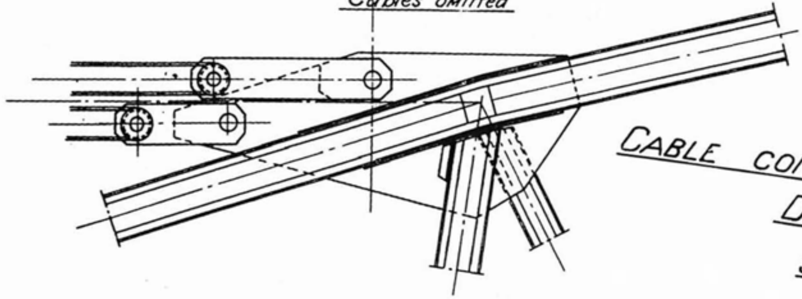


DETAIL AT A



PLAN

Cables omitted



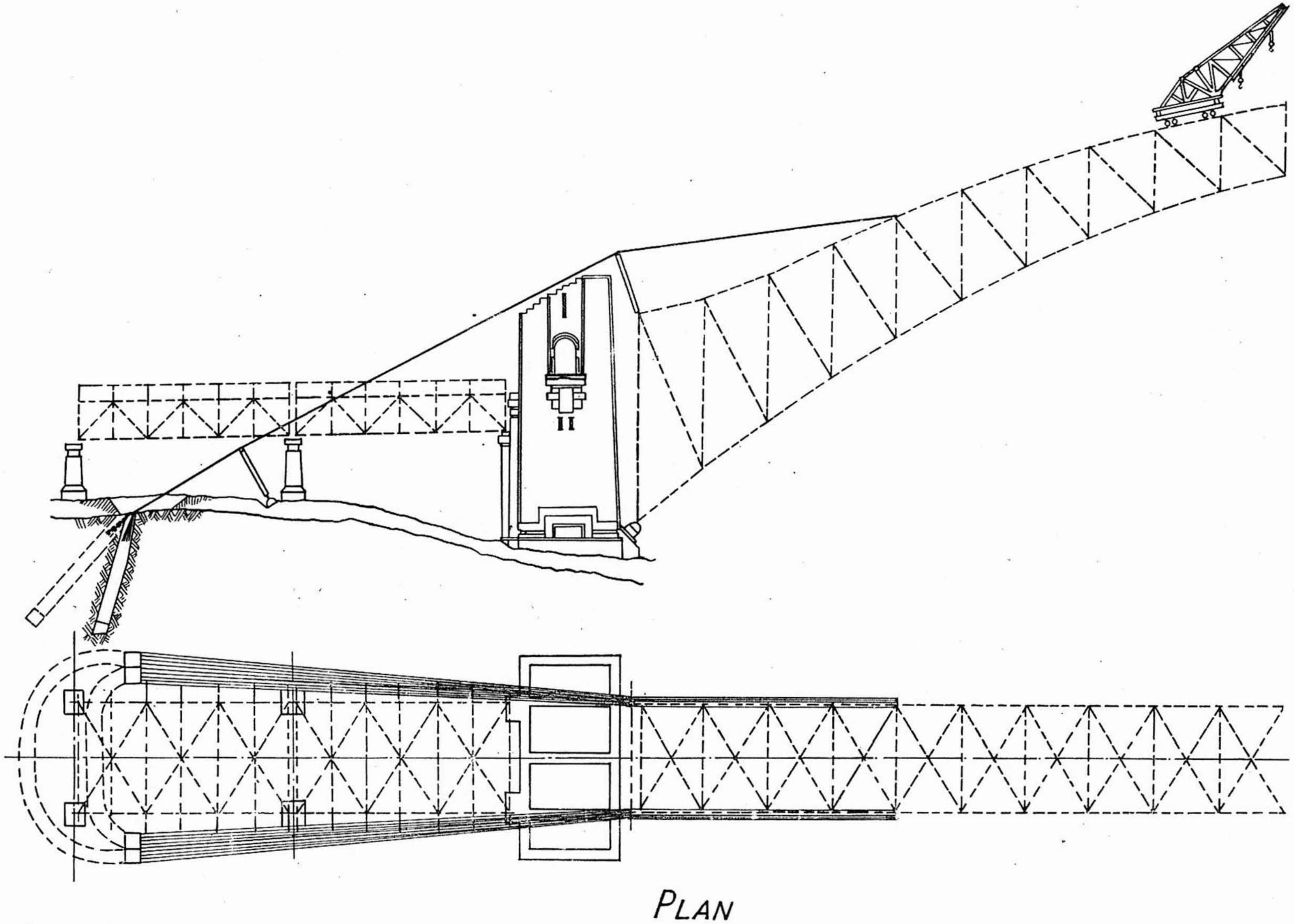
CABLE CONNECTION ON TOP CHORD

DETAIL AT B

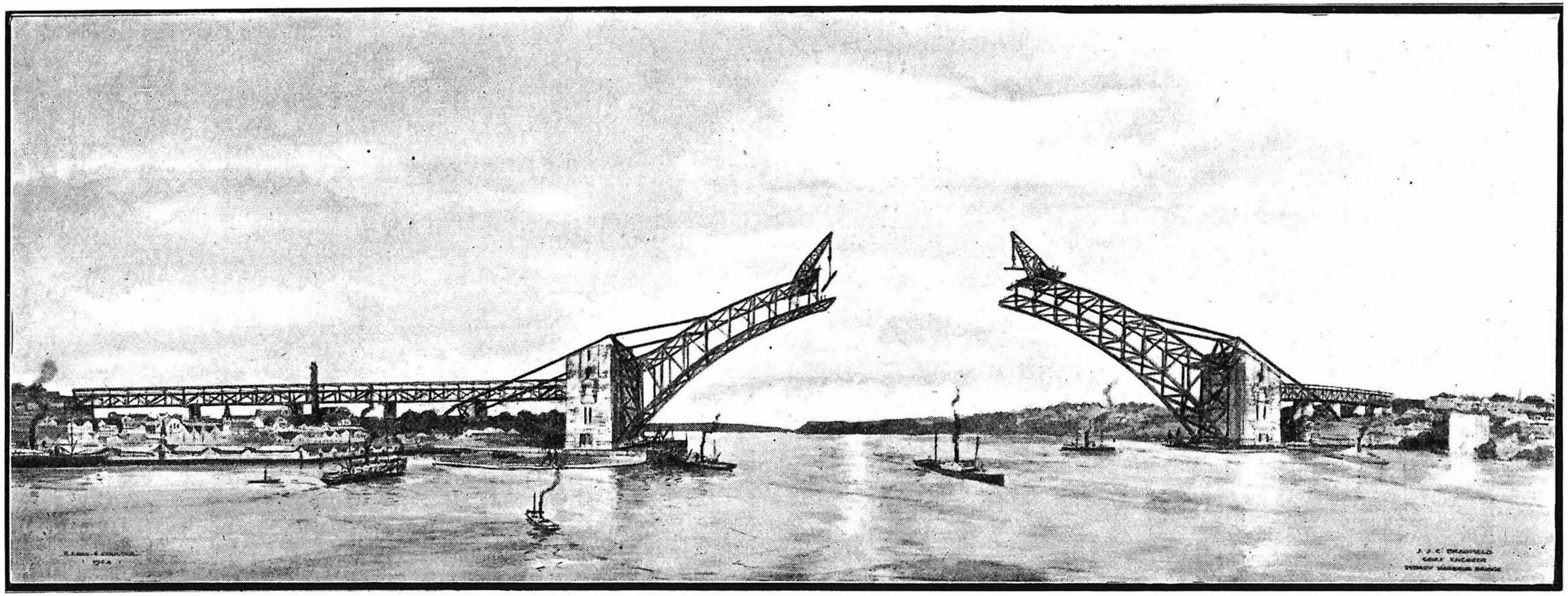
Scale $\frac{1}{8}" = 1'0"$

22406–K

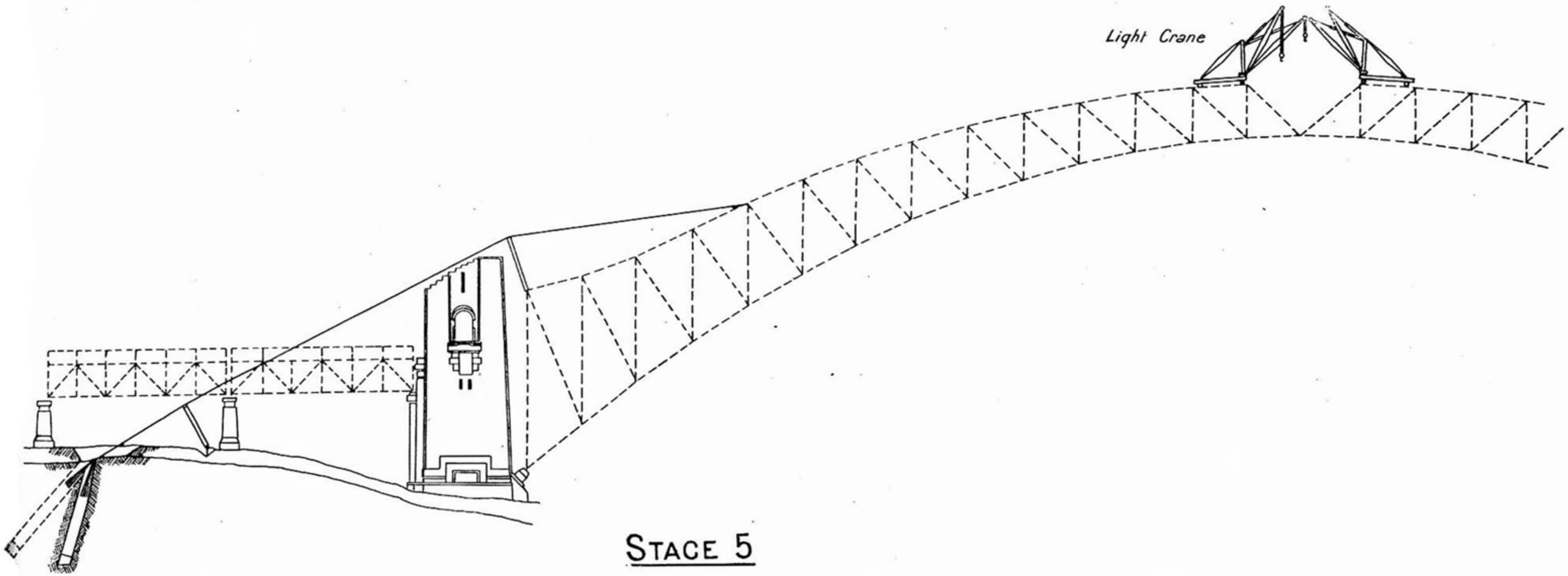
DETAIL OF STAGE 3



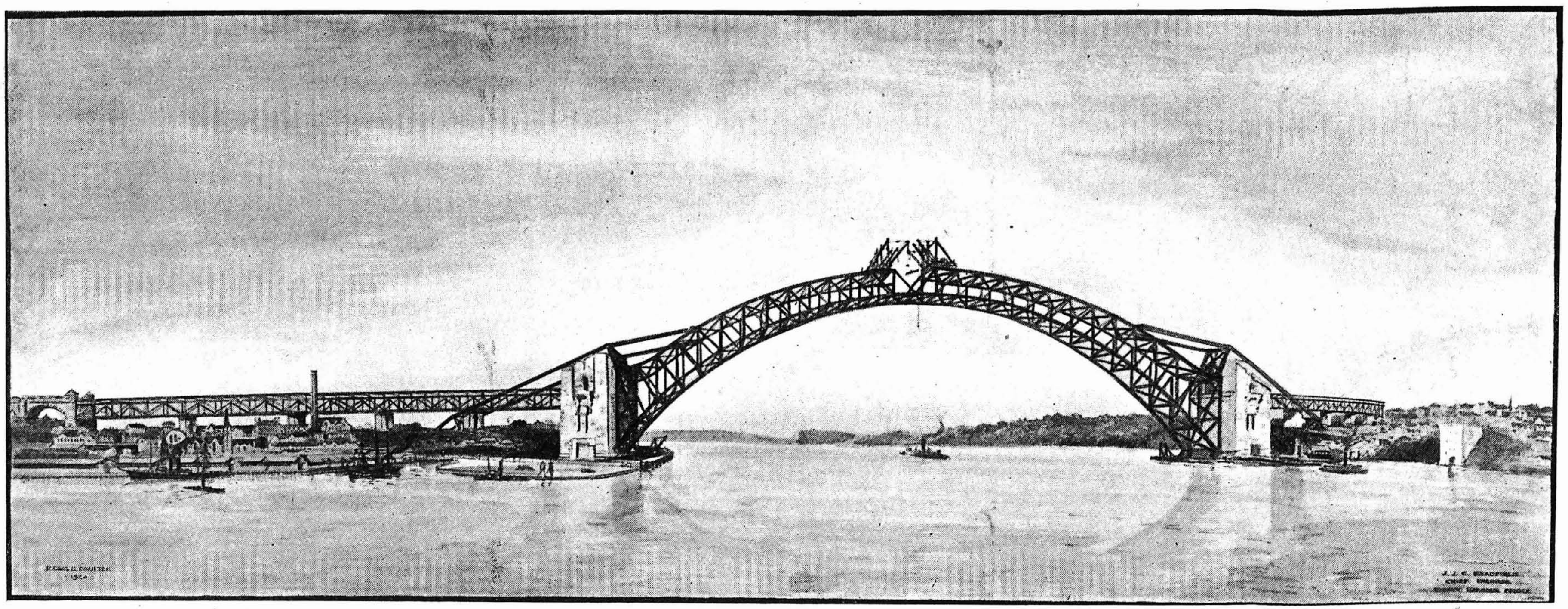
STAGE 4



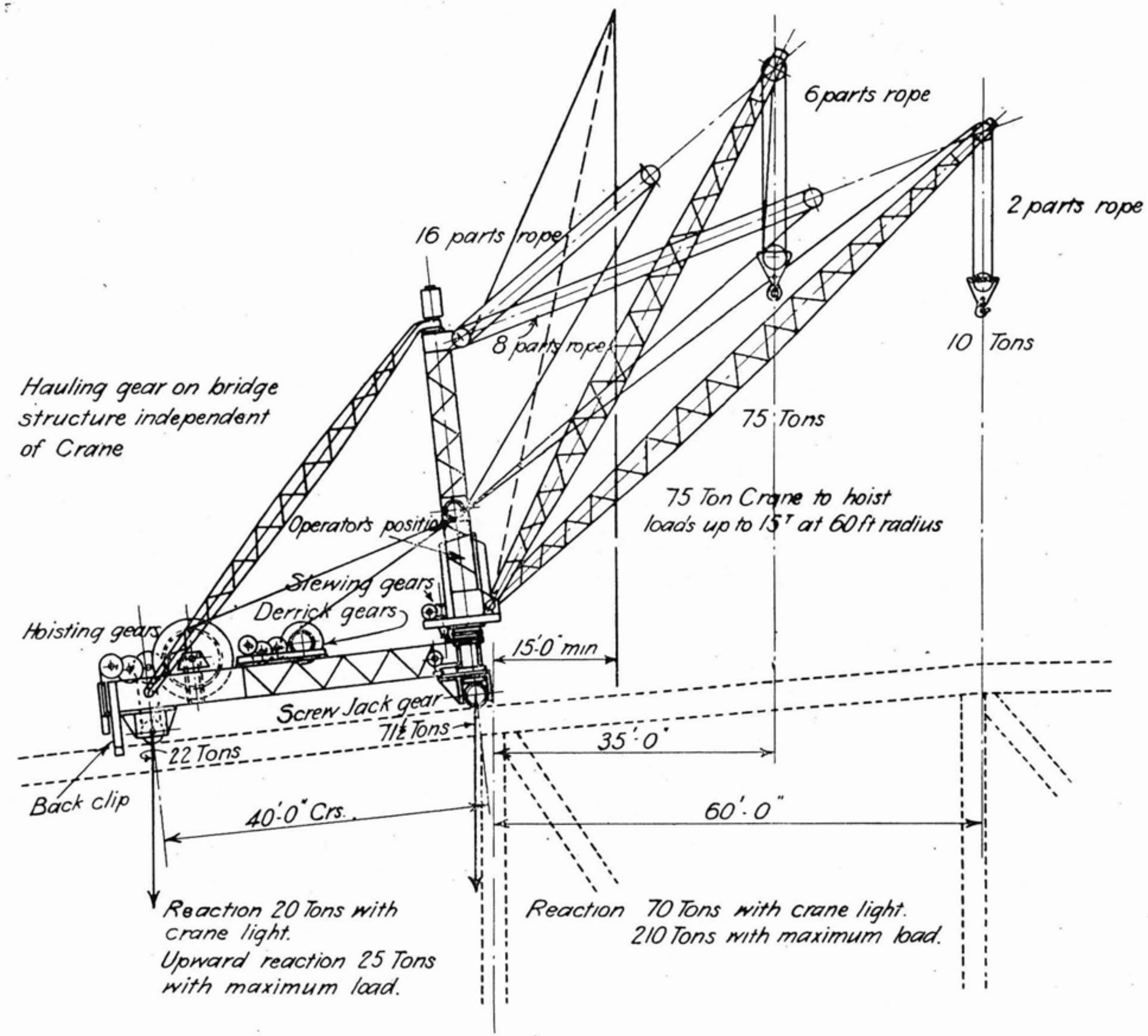
Photograph No. 18.—Stage 4.



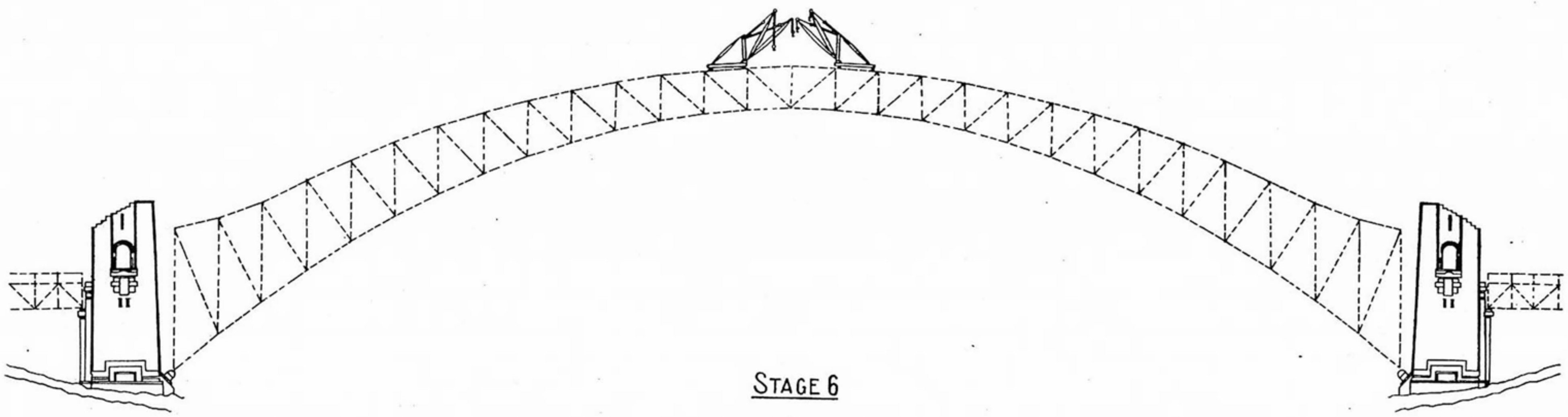
STAGE 5



Photograph No. 19.—Stage 5.

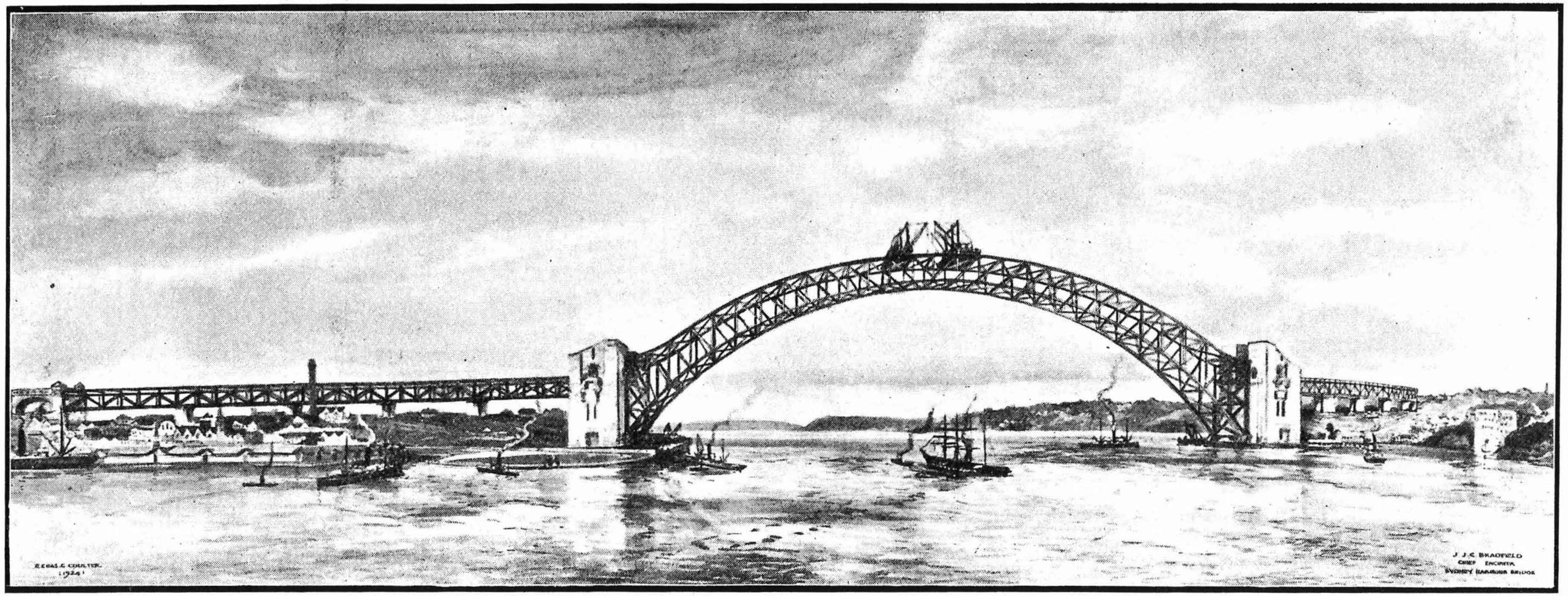


DETAIL OF STAGE 5

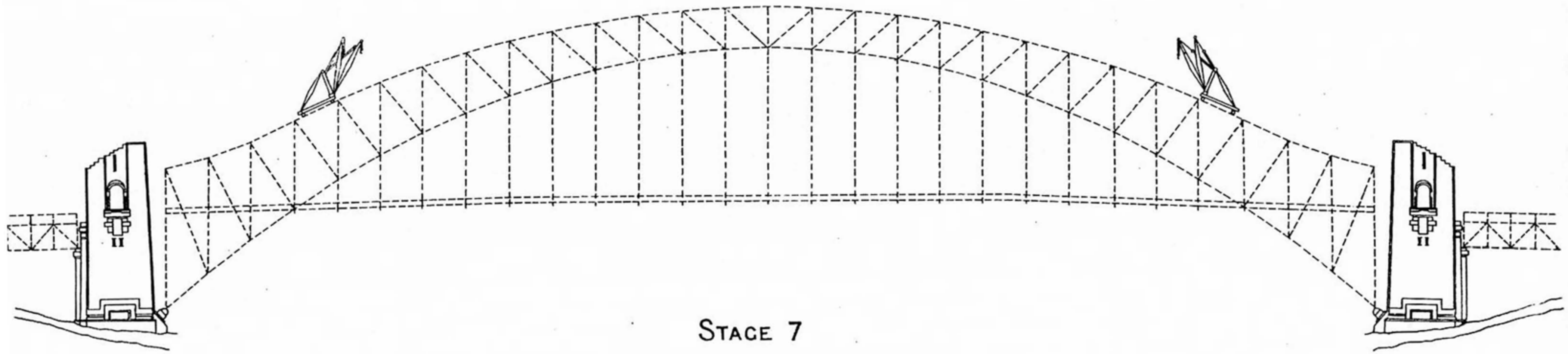


STAGE 6

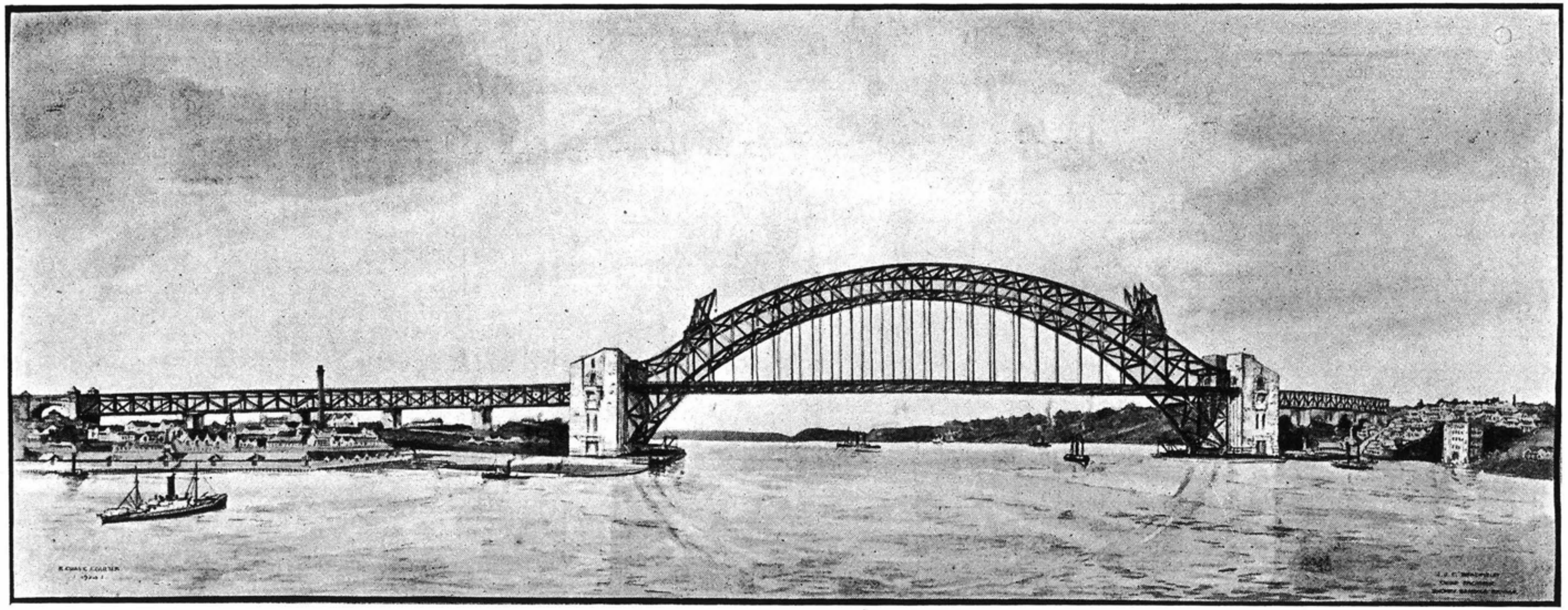
22406—O



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.

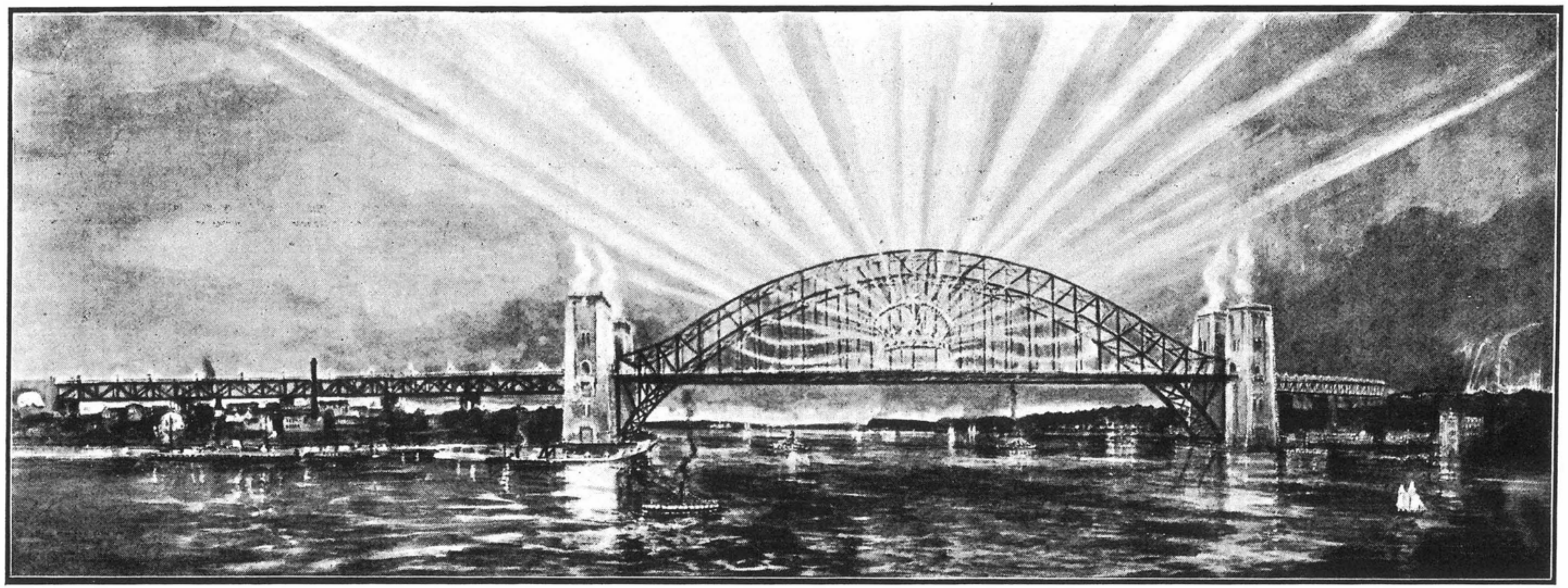
In making my recommendation I have kept in view the past and future as well as the present. One characteristic of modern thought is the increasing tendency to study the past, and in looking backward we find a nation's manner of life and civilisation written in those works of its rulers which have survived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