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A PROPOSED

SUB-AQUEOUS VIADUCT

ACROSS SYDNEY HARBOUR, FROM DAWES BATTERY TO MILSON'S POINT.

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The subject of this paper is one which will remind every member of this Association that a large number and variety of schemes have been published for the purpose of making a direct railway and tramway connection between the city of Sydney and its picturesquely situated northern suburbs. In submitting this paper, the author would like it to be known that it is not his desire or intention to criticise any of the work done by his predecessors, and that he has strictly endeavoured to confine his remarks to those matters which appear to be inseparably linked to the schemes offered for your notice this evening. In a primal contemplation of the essentialities of a direct connection system, we cannot ignore the positive requirements of rapid transit, and are therefore compelled to reject the time-honoured and slow-moving harbour ferry. Though it is possible that the present excellent service of ferry boats can be improved beyond recognition, a constantly increasing harbour traffic, and consequently additional navigation precautions, together with some certain loss of time spent in transhipment of rolling stock at each end of a short distance trip, would seriously handicap the best class of ferry boat engaged in competition with a scheme that combined maximum rapidity of safe transit, continuity of transport, punctuality in windy weather or dense fog, and an entire absence of those collision dangers, which are of such frequent and increasing occurrence in our harbour.

Though it may not require much imagination to suggest a bridge or a tunnel in lieu of a ferry boat, the difficulty of definite selection was fully recognised by the Royal Commission on City and Suburban Railways 1890-91, which exhaustively inquired into the relative merits of various methods of crossing the harbour by bridge or tunnel. The Committee decided that whenever it may be desirable to build a bridge it would be advisable to give it a clear headway of 160 feet, and one span of 1,500 feet, or two spans of 700 or 800 feet, with a central pier not obstructing navigation. (*Vide* report page 68.) Several suggestions for proposed tunnels to be carried under the harbour at depths varying from 130 to 150 feet below water level were separately discussed, and it is probable that the generally brief description of designs and their modes of execution, the conflict of expert evidence, and the admitted uncertainty of cost were the governing factors in causing the final rejection of every tunnel proposition.

Before dealing with any of the tunnel schemes, the author proposes to examine into the characteristics and final cost of a bridge built to comply with the Committee's suggestion. The rail and road level of this bridge would be 165 feet above water level, and, though electric traction were used on the railway or tramway, it would not be advisable to use steeper gradients than 1 in 30 from a point near the centre of bridge down to each respective abutment. These gradients have enabled him to select a south abutment site at the north end of Prince's-street, Sydney, and a north abutment on the grounds of Dind's Hotel, North Shore. The rail level at Prince's Street abutment would be 105½ feet above water level, and at North Shore abutment 107ft. above water level. In accordance with the experience supported teachings of Sir Benjamin Baker, Claxton Fidler, and other bridge building experts, that a pair of balanced cantilever beams carrying a central independent girder would be the best type of bridge to fulfil the Committee's conditions, the author has pleasure in submitting to your notice a skeleton sketch (Plate XXXI.) of what he considers to be the shortest bridge that can be erected across Sydney Harbour. The total length and approaches would be 1,645 yards. The roadway would carry a double tram line or railway; double carriage ways 15ft. wide; and double footpaths 10ft. wide. Careful observation of recent colonial bridge building experiences, together with data derived from the cost of constructing a similar type of bridge across the Firth of Forth, seem to positively indicate that they could not, at present market prices, build a bridge as shown upon the author's sketch for a less sum than £745,000, exclusive of land and property resumptions.

He will now attempt to briefly describe the main features of a few of the tunnel schemes. The first example (Plate XXXII.) is a double tunnel completely piercing the bedrock of harbour, 560 yards long, and connected to ground surfaces by vertical shafts and direct elevating machinery at each terminal. The rail level at the half distance of tunnel would not be less than 120ft. below water level, and with working gradients of 1 in 20, we should require vertical lifts of 90ft. to enable us to connect with shore rail level, 10ft. above water level. The cost of this tunnel, with complete working equipments, would be about £190,000.

The second example (Plate XXXIII.) is a double tunnel exactly similar to the first mentioned, excepting that it would be approached by spiral or circular tunnels, instead of vertical shafts. The curved portions are graded 1 in 25, and the total length of tunnel and approaches is 2,016 yards. By forming 128 yards of each approach in open cuttings we could reduce the length of the tunnel to one mile between its portals and where the rails would be 5ft. below water level. This tunnel could be built and equipped for about £210,000.

The third example (Plate XXXIV.) is a double tube projected through the silt and other deposits forming the bed of the harbour. Assuming that numerous complete borings justified the conclusion that these tubes could be driven by the travelling shield and compressed air system, as originated by Brunel for the Thames Tunnel, and since elaborated by Greathead and others, it seems apparent, by preliminary examination of exhibited cross sections of harbour, that the central rail level would not be less than 85ft. below water level. Two tubes, each 560 yards long, with gradients of 1 in 30, would require vertical terminal lifts of 6ft., and if curved tunnels were used in lieu of lifts and graded 1 in 25, the total length of the system would be 1,676 yards. By cutting off 265 yards for open cuttings, we should then have a through tunnel 1420 yards long and 300 yards shorter than the second example. There is at present no available information referring to the natural consistency, water infiltration, or load bearing capacities of the silt and other deposits to be tunnelled, therefore it is practically impossible to estimate the cost of either propositions of the third example. The best feature of the last proposal is that the length of the subway passage would be 20 per cent. shorter than the all rock tunnel of the second example. As this saving is entirely due to the raising of the rail level at the centre of harbour, it is reasonable to believe, that if we were to lift the tubes so that their upper surfaces offered no obstruction to navigation, and thereby placed the rail level at a minimum depth below water we should obtain the ideal short passage subway, and be more certain of that popular patronage which is essential to commercial success.

As a result of personal inquiries at the Marine Board offices, the author is assured that a clear depth of 36ft. from high water spring tide mark to the tops of the tubes would be amply sufficient for all requirements of navigation. The rail level would then be $50\frac{1}{2}$ft. below water level, and by grading as shown on the exhibited drawings, the subway would be 1,166 yards long. The bottoms of tubes would be 53ft. below water level, and, as nearly half of their length would be above and clear of the soft surfaces of the mud and silt, it is obvious that their stability and alignment would have to be preserved by rigid connections with the bed rock of the harbour. The vertical transposition of the tubes and the employment of pier supports transforms the original mud and silt surrounded subway tubes, into a perfectly sub-aqueous bridge or viaduct. Sub-aqueous bridges have been proposed frequently, and by various engineers, for the crossing of navigable streams, and especially where tunnelling would be too costly or impossible. The proposals have been marked by a general similarity of design. Each engineer has chosen a tubular beam for his superstructure, and provided for the depositing of the same upon solidly bedded supports. Some have proposed plain cast iron tubes from 2in. to 3in. thick and ballasted sufficiently to prevent flotation, others have suggested thinner tubes lined with 1 to 3ft. of brickwork, another has proposed to place one thin tube within a larger one, and fill the concentric space of 30in. with concrete. The first mentioned suggestions would require the tubes to be built with very much larger factors of safety than would be needed for the concentric tube method, because of the constant corrosion of the metallic surfaces exposed to the action of the sea water. *The Circular Tube when treated as a Beam does not show the economy of Material possessed by the Conventional Type of flanged Girder, and, in recognition of this fact the author proposes a form of Cross Section for this bridge that will enable us to calculate all working stresses as would be done for an Ordinary Flanged Girder with a rigid web.* Assuming that the bridge is intended to carry two lines of way, the cross section would be as shown thus :— The  middle partition is the web of a girder whose flanges are embedded in the protective and cement filled chamber between inner lining and outer casing of bridge. The roadway passages are formed by attachment of semi-circle wings to the top and bottom flanges of central girder. These wings are designed to transmit all working loads to the central girder. The outer casing or envelope is 2ft. away from the wings all round, and would be retained in position by light bracing until the concrete filling was completed and perfectly set. It will be seen, therefore, that the inner wing plates could be replaced when required, and though the outer shell would, at some indefinite time, corrode and fall away from the bridge, the presence of the age-hardened concrete wall 2ft. thick would preserve the wings and girders from damage by salt water. The length of each span—(Plate XXXV.)—is about 210ft. The length conforms to good practice in economic continuous girder building, and would be convenient to handle when being placed in position. Each tubular span would be completely finished on shore, with the ends securely closed by temporary bulk-heads, and then be floated and towed out to the position indicated for sinking. The piers are of the ordinary central well type, and, judging by cross section of harbour, plotted from actual borings, it is reasonable to believe that not more than 314 lineal feet of sunk cylinder would be requisite for the founding of the whole of the five piers. Assuming for argument's sake that 400ft. of cylinder be required, and the finished price was £25 a foot, the author thinks it will be generally admitted that £20,000 is not an extravagant price to pay for five rock born supports for the bridge. The ends of each span are splayed out on wings and bottom, and are provided with jointing flanges on the lining and casing. The flanges would be drilled to standard templates for the reception of joint bolts. The temporary bulk-heads in tubes, would be fitted with air-lock door, and be set back three feet from end, so that when two spans were brought together, a convenient working chamber would be provided for the divers when bolting the flanges for a water-tight joint. The gross buoyancy of bridge per lineal foot is 12 tons, the actual weight is 11·1 tons per foot. This means that when this bridge was empty, there would be an upward bending moment equivalent to 18 cwt. per lineal foot, and if we impose a total rolling load of 30 cwt. per foot for the double line, we should change the upward load of 18 cwt. per foot, into a downward load of 12 cwt. per lineal foot, and by so doing produce a bridge which would be safest when crowded with traffic from end to end. It is evident that such extremely favourable working conditions permit us to secure a very large factor of safety with a minimum expenditure of material. This factor is sufficient to provide for the remote contingency of accidental flooding of tubes prior to the final completion of the bridge. The influx of water could not possibly occur, except by injury to bulk-heads, or negligent use of water-tight doors when the various tubes were being joined. The flooded bridge would receive an extra load of 710 tons per span, or 3·38 per lineal foot. As no other loading would be possible with water in the tubes, we need only provide for this additional load at each pair of pier cylinders. Each pier has a bearing area of 102 square feet, with an ordinary working load of five tons per foot. The additional load of seven tons due to flooded tubes, plus five tons for working load, equal 12 tons, and would be perfectly safe. The author now proposes to demonstrate the practical impossibility of capsizing or displacing the bridge by side pressure. As the silts and other deposits might be softened and scoured by tidal currents or by future dredging operations, no allowance will be made for their side support to piers. In plan, this bridge presents itself as a horizontal, continuous six span tubular girder, fixed upon five intermediate piers and two rigid abutments. The cylinders are securely fixed to superstructure, and being only three to five diameters long, they can be treated as vertical cantilevers, and relied upon to transmit to the bed rock, all horizontal forces of the continuous girder at each pier. In discussion, the girders and tubes are supposed to be weightless and valueless, excepting as vehicles for transmitting simultaneous strain to all the piers and abutments. The aggregate positive weight at all the piers is 1,750 tons. The centre of applied pressure would not average more than 45 feet above bed rock. The effective straddle of pier legs is 30 feet, and by solution of equation

$$\frac{1750 \times 30}{45 \times 2}$$

the overturning pressure required in 583 tons. In addition to this result we must now ascertain the value of attachment of the girder to rock abutments. The length of the bridge is 1,275 feet, and the moment of inertia for the steel wings is 4,300,000 inch units, and taking the elastic limit of steel at 17 tons per square inch, the moment of safe resistance of the horizontal beam at the centre of span would be 271 tons. The moment of inertia of concrete casing is 5,862 foot units, and by reinforcing the cement by wire ligaments so as to bring the safe tensile strength up to 100 lbs. per square inch, or 6.5 tons per foot, the moment of resistance of concrete jacket is 21 tons. The sum of the moments is 875 tons, and that represents the united breaking strengths of 12 steel wire hawsers, each 6 in. circumference. The author thinks it is quite safe to say that, unless purposely done, it would be impossible that such a load could ever exist. The approach tunnels and cuttings are of the ordinary character, and present no great difficulties in their construction. The greatest engineering problem is how to make the connection between approaches and bridges. The junction with bridge at the Sydney end is proposed to be made by a tunnel 200ft. long, and driven through rock and silt to the first pier of steel viaduct. The approach tunnel under the battery hill having been driven to a vertical shaft near the sea wall at Dawes' Point, and a temporary shaft having also been sunk at the Sydney end of bridge tubes, a temporary embankment of clay in bags would then be formed between the two shafts. The clay bank would range from 5 to 7 feet deep by an average width of 36 feet. Ordinary iron tubes, about $2\frac{1}{2}$ inches diameter, with solid pointed ends, would then be driven at 3 to 4 feet intervals, and in such numbers as to fill a portion of the area covering the position of proposed tunnel. The points of tubes would be driven within a few inches of the contour line of arch and flanks of proposed tunnels, and then be provided with inside circulating pipes, for the purpose of freezing the soft mud and water-bearing deposits into solid matter. The soft core could then be excavated without trouble. Access to the drive for miners and bricklayers would be made by doors provided in the temporary bulkheads of vertical shafts. On completion of the tunnel a sealing arch of concrete and steel would then be built between tunnel and bridge, and there being no further use for clay banks, freezing pipes, and temporary shaft, the whole of these materials could be cleared away. At Milson's Point a caisson shaft, with temporary bulkheads on its north and south faces, would be sunk to the required depth, and connection made to tunnel and bridge by jointing up as described for separate spans of viaduct. The majority of those people who have ridden upon the underground railways in London, are not unnaturally opposed to the very name of underground or tunnel railways. It must be remembered that the great objections to the London system would not exist in the project. Stifling vapours due to the fuel-burning locomotives and the consequent evil smelling, dismal and dirty surroundings, would not be found in this bridge or its approaches. Electricity would be used for traction and lighting purposes. The whole of the approaches and viaduct linings would be of white enamelled encaustic brick and tiles. Two ventilating shafts each 200 square feet area, and eight others each not less than 50 square feet, would be distributed at convenient distances along the crown of tunnels. The provision of a mid-feather in bridge section, permits of a completed division of up and down traffic, and any vitiated air left by a passing train of passengers would be propelled from the tunnel by the following train. The curves and grades are easier than those to be found in the streets of Sydney. The estimated complete construction and equipment, exclusive of cars and electric power plant, would be £185,000. The whole of the quantities are based upon colonial labour and materials, and the estimated time required for construction is two years. Any of the past or present suggestions for electric tramways or railways for the city of Sydney, can be readily connected with the proposed subway. A terminal dock or return loop may be constructed between the cable tram, and Milson's Point railway platform; or a direct connection can be made with the main line and continuous rapid transit obtained from Redfern to Hornsby via the city; the junction with the George-street and Pitt-street lines would be at a point opposite the Mariners' Church, and 26 feet above water level. The line then proceeds on road surface, and past the Public Wharves Office, to a point situated in Metcalfe's Bond; from thence in an open cutting with retaining walls to the southern portal of tunnel at the Government Boat Sheds; from this point the line passes through a tunnel approach under Dawes Point Reserve, to its junction with the bridge in the harbour. The North Shore end of bridge joins its approach tunnel at a point near the ferry wharf, and now occupied as a cab stand. The north tunnel is helical, and is graded to bring its portal within the railway goods yard, and by running the line from thence on a parallel to the railway platform, we are enabled to finish in a terminal dock at the same level, and not more than 20 feet from existing cable cars and railway carriages. The author has minutely calculated the quantities of every portion of the work, and as *there are no Land or Property resumptions on any part of his project*, he has great confidence in quoting the final cost. The direct and easy methods of communication, combined with low cost of accomplishment, and absolute certainty of rapid transit, inspired him with every belief that his project would be a great commercial success, and an incalculably beneficial factor in the future development of North Sydney and its suburbs. In concluding this paper he begs to offer his sincere thanks to those engineers whose labors, in attempting to show the necessity of a direct connection, had enabled him to gather sufficient information for the projection of his own schemes.