The writer has long had the hope of seeing this much-needed connecting link in a general electrification scheme brought into actual existence, and even now is of the opinion that its construction will be forced upon us sooner than many anticipate.

In conclusion, the writer has to thank Mr. Bradfield for kindly permitting the use of some of his plates for illustrating the Metropolitan Railway Electrification Scheme, the extent of which is shown by Plate No. 38.

The writer's thanks are also due to Mr. T. B. Cooper, Under-Secretary for Public Works, for permission to use departmental plans, and for the courtesy extended in authorising the preparation of a considerable number of lantern slides, which were excellently made by Mr. Degotardi, Government Photographer.

Mr. J. G. Lancaster, and others of Mr. Bradfield's staff, kindly assisted in the preparation of the numerous diagrams illustrating the text, also in the compilation of statistical matter, and the computations required in the tables.

Discussion.

Mr. Bradfield: Before discussing Mr. Burrow's excellent paper, I wish to thank you, Mr. President, and your Council, for your courtesy in asking me to be present to-night. The fact that there is a fair sprinkling of visitors to your Society to-night may be taken, I hope, as a happy augury that the labors of the Provisional Council now engaged in putting the finishing touches to a draft constitution for welding the Engineering Societies of Australia into one Institution will bear fruit.

Personally, I hope that this Society, and the Sydney University Engineering Society, will exercise a little judgment, and unite to form a combined civil and mechanical branch of the Institution.

The paper to-night is distinctly a civil engineering paper, and I believe I am right in saying that your papers generally are distinctly civil, with a mechanical flavoring; well, so are the papers of the Sydney University Engineering Society, and the uniting of the two Societies would result in forming "The Branch" of the Institution.

I propose only to refer to the work I have in hand, leaving to Mr. Dare and other gentlemen the more general discussion of the paper.

It has fallen to my lot to have a hand in modelling the land and water gate of this great city, and I propose to show a few slides illustrating the early days of these rail and ferry city entrances.

(1) The slide on the screen is, I believe, the first authentic sketch made of Sydney Cove by Captain Hunter in 1788.

(2) Shows an artistic representation of this sketch.

(3) Shows one of the earliest maps of Sydney, 1802, published by our far-seeing enemies, the Germans. I would draw your attention to Sydney Cove, Woolloomooloo Bay, and Cockle Bay, now Darling Harbour. You will see the creeks flowing into these bays; and it is these old creek beds, since filled up, which are causing the engineering problems of to-day as far as the City Railway foundations are concerned. Across Woolloomooloo and at Circular Quay, in these creek beds the rock is 72 feet below the present surface, the intervening materials being all made ground, carrying a large amount of water.

The same applies in the vicinity of Central Station, Belmore Park, and Hay Street. The old watercourse draining Surry Hills had its location near Hay Street; the stormwater from Surry Hills is at present carried along Hay Street in a sewer 10ft. x 7ft. to Darling Harbour (just below the surface of the street).

(4) Slide No. 4 shows the turning of the sod of the first railway in Australia on July 3rd, 1850. The site depicted is where the old Railway Station stood, near the present Devonshire Street Subway.

(5) Slide No. 5 depicts the same scene; whilst the next slide (6) depicts the interior of the old station.

(7) Slide 7 shows the same in 1870.

(8) Slide 8 the station in 1871; whilst Slide 9 shows how the railway gate of the city is being completed.

The whole of the suburban railway traffic will be dealt with on the eastern side of Central Station. The foundations of the reinforced concrete bridges necessary across Eddy Avenue, Hay and Campbell Streets, are carried down to solid rock.

The Eddy Avenue bridge is designed as reinforced girders, and the piers are formed by means of two shafts sunk to rock, and filled with concrete, and arched over just below surface level.

The retaining wall along Belmore Park is similarly founded. On account of the loose sand overlying the rock, piles could receive no support from the sand, and would carry the load of the wall like the legs of a table.

The depth to rock is 23 feet, 13 feet of sand and 10 feet of a soft sandy clay; the height of the wall above footpath level is 27 feet, with a 4-foot surcharge due to train load. The train load provides for electric locomotives weighing 160 tons, consequently I deemed it inadvisable to found the wall on piles, but decided to carry down shafts 16ft. x 6ft., spaced 22ft. 6in. apart centres, i.e., 16ft. 6in. clear between the shafts, filled afterwards with concrete.

The calculated tension at heel of wall is 89lbs. per square inch, whilst the calculated compression at toe is 20 tons per square foot, or 31lbs. per square inch.

Returning now to the Quay, Slide 10 shows a view from Dawes Point looking east towards Fort Macquarie.

Slide 11 shows a view from Dawes Point looking towards the centre of the Quay; whilst Slide 12 shows a view from Dawes Point looking along the western shore of the Quay. The boat on the slips is one of the first vessels launched in Sydney.

Slide 13 shows a view of Sydney in 1803, from the present Government House Grounds; whilst Slide 14 shows Government House in 1808. It was situated at the corner of Bridge and Phillip Streets.

Slide 15 shows a view of Sydney Cove in 1842, and the then mud flats which the City Railway will pass over.

Slide 16 shows a further view of the Tank Stream, looking along what is now Pitt Street.

Slide 17 shows a view from Lady Macquarie's Chair, looking towards Government House; whilst Slide 18 shows how I hope to leave the water gate of the city: A fine station, containing railway and ferry facilities at the Quay, and the North Sydney Bridge a portal to the shipping and industrial portion of the Harbour.

On the Eastern side of the station the foundations of the arch spans are carried down to solid rock, which is quite near the surface. In passing, I might say that the hardest rock met with in the excavation so far done for the City Railway was just where the portal at Macquarie Street is completed.

On the Western side of the Quay the foundations are in the bed of the old tank stream on rock about 72 feet below surface. The four spans adjacent to the western side of the station are designed as girders, as it would be impossible to economically carry the arch thrusts to rock. Each pier below ground will consist of two cylinders sunk to rock, and arched below ground surface to carry the above-ground portion of the pier.

The foundations for the Quay Station are now receiving consideration, and it may be that cylinders will be adopted, although concrete piles offer advantages. I have not finally decided yet which to adopt.

The foundations of the Sydney Harbour Bridge are on solid rock on either side. Mr. Burrow has traversed the question of the foundations for a central pier, but in recommending a one-span bridge, this question of a central pier did not weigh with me on account of the depth of the foundation, and the impossibility of carrying it out under air pressure.

What I had in view was that a central pier would be a distinct block to the water-borne traffic of this city, which must always be the most important maritime city in Australia.

The average length and beam of the 20 largest steamships afloat in

1851	was	245	feet	length,	37	feet	beam.
1861	,,	310	,,	,,	41	,,	,,
1871	,,	365	,,	,,	44	,,	,,
1881	,,	460	,,	,,	45	,,	,,
1891	,,	507	,,	,,	54	,,	,,
1901	,,	599	,,	,,	65	,,	,,
1911	,,	740	,,	,,	84	,,	,,

I travelled from the United States to England in June, 1914, in the Aquitania, 902ft. by 97ft. beam, gross tonnage, 47,000. The Vaterland, which left New York a few days earlier, was about 910ft. long by 98ft. beam, and gross tonnage 50,000; whilst I saw the Furst Bismarck being fitted up in Hamburg in July, 1914. She was launched about two weeks prior to my visit, and was the largest vessel afloat, about 60,000 tons.

The size of boats trading to Sydney has increased greatly in the past two decades, and it was the increase which must be looked for in the future which decided me in proposing a bridge without a central pier. Undoubtedly a bridge with a central pier would be cheaper than the one-span bridge decided on.

The actual water distance on the site adopted is 1480 feet, but Milson's Point juts out into the Harbour, and reduces this distance, as does also the western point of Dawes Point.

The danger to a central pier founded 160ft. below water, and with a height of 170ft. above water, from a collision with one of the large steamers which must visit this port is large.

The diamond drill bores recently sunk at the side of Dawes and Milson's Points indicate that a satisfactory foundation for the Sydney Harbour Bridge piers can be obtained about 15 feet below mean sea level.

The first bore at Dawes Point passed through hard sandstone, and at a depth of some 50 feet through a thin bed of shale. Subsequent bores at Dawes Point and Milson's Point disclosed a band of shale a few inches thick at about this depth. This band of shale was probably continuous from Dawes Point to Milson's Point, and indicates the existence here in bygone ages of a lake, or lagoon, temporarily cut off from the waters depositing the Hawkesbury sandstones.

Later the lagoon again became part of the sea, and the formation of the sandstone proceeded above the band of carbonaceous shale. Since these remote ages the whole of the Sydney Harbour has been eroded from the solid rock.

In conclusion, I might add that an area of ten acres at the site of each of the main piers has been reserved from mining leases, and again wish to compliment Mr. Burrow on his excellent paper.

Mr Dare said that the interesting paper submitted by Mr. Burrow opens up the question of whether open or pneumatic foundations are to be preferred for the class of structures dealt with. Examples of both methods have been referred to. There are, of course, still other methods which have been adopted in many bridges in this State. In this connection I might refer to the coffer dam system such as was used for the central pier of the Glebe Island Bridge, and at Tabulam, Camden, and many other places; the use of oregon cylinders; and the hydraulic jet method used for sinking the cast-iron piles at Moruya and Carrington bridges. The latter was a particularly interesting and successful operation, and has been described in detail in the Proceedings of the Institution of Civil Engineers.

The design of bridge foundations is one involving a close consderation of the conditions existing at site, and of the materials available. Assuming that it has been decided to adopt the cylinder pier type, the question arises as to whether iron or concrete cylinders, plain or reinforced, shall be used. This is largely determined by the depth of foundation, and whether the sinking is to be done in the open, using grabs or divers, or under air pressure. Monier cylinders have been used in quite a number of bridges, and in some cases have been sunk under moderate air pressure. The chief difficulty in using air pressure has been to prevent leakage at the joints, which cannot be made as tight as in iron cylinders. In the first bridge of this type, that over Wyong Creek, where air was applied, a mixture was used of bitumen and fish oil, with sufficient cork dust added to give the heated mixture the proper consistency. This was smeared hot on the top surface of each cylinder length, and the two lengths drawn tightly together with pilot wedges. In other cases a red-lead joint has been used. As the reinforced concrete cylinders were only 2 inches thick, some doubt was felt as to whether there would be a leakage of air through the shell; but such was not found to be the case. The maximum head of water at Wyong Creek was between 25 and 30 feet, so that the air pressure was low; but there is little doubt that this class of cylinder could be used for moderate air pressures up to, say, 20lb. per square inch.

The same doubt as to air tightness was felt when designing the concrete caissons for Richmond Bridge, and to avoid leakage of air the walls of these were made as thick as possible, viz., 12 inches minimum at the sides, increasing to 3ft. 3in. at the ends, with quite successful results. The air pressure required here also was low, but the results showed that, with compact concrete, no trouble need be anticipated in using concrete cylinders or caissons under moderate heads. When the head becomes greater, however, the thickness of the concrete walls to be used under air pressure requires more careful consideration. In the case of the North Coast railway bridges considerable use has been made of concrete cylinders 8 feet and 9 feet diameter, sunk partly in the open, but mostly under air pressure. I understand that the walls of these cylinders were about 2 feet thick, and that the head varied from about 20 feet to about 70 feet. Further particulars with regard to the sinking of these cylinders would be of interest.

Reference may be made to a work of investigation carried out under air pressure in the sinking of a test cylinder at the site of the northern main pier near McMahon's Point, as originally proposed for the Sydney Harbour Bridge. The depth to rock is here about 170 feet below H.W.M., a depth much in excess of any that has been hitherto obtained in bridge foundations. Overlying the rock there is about 128 feet of clay interspersed with sand, 7 feet of silt, and 37 feet of water. In order to test the sustaining power of the clay, a cast-iron test cylinder, 6 feet in diameter, was sunk under compressed air to 90 feet below high water mark, sealed with concrete, and loaded up to a pressure of 7 tons per square foot, the sinking under load being carefully recorded. The total settlement, after allowing the load on for 8 days, was 4.28 inches. It was estimated from observations made when removing the cylinders that the skin friction on the portion of the column below ground amounted to 0.023 ton per square foot, after the cylinder had been at rest for a fortnight. The removal of the cylinders was effected by disconnecting the bottom length and applying heavy air pressure.

Competitive designs were called for the Harbour Bridge as then proposed (1902), and that finally selected, with which the late Mr. Norman Selfe, M. Inst. C.E., was connected as consulting engineer, provided for dealing with the northern pier foundation in a novel manner. It was proposed to form an island to above high water mark, and to then freeze the material overlying the rock by driving a number of pipes from the surface, through which a cold brine solution would be circulated by powerful machinery. It was estimated that after several months' work a ring of earth from 8 to 12 feet thick would be frozen solid, permitting of the excavation of a shaft to rock, in which the concrete foundations of the pier could be placed in the open. As none of the tenders then received was accepted, the opportunity for trying this somewhat bold scheme was lost.

Generally speaking, I consider that, in view of the much better facilities for inspecting foundations carried out under air pressure, the pneumatic method has decided advantages, in most cases, over the open cylinder method, and I would suggest that pneumatic concrete caissons are worthy of close consideration when dealing with the foundations for structures of any magnitude, the caissons to be either fitted with a false bottom and floated to site, or built up as the work proceeds, where conditions favour the latter method.

Mr. Burrow is to be congratulated upon the preparation of a practical and valuable paper upon a subject with which, from his long experience in foundation work, he is specially qualified to deal.

Mr. Vicars said it was his pleasant duty to propose the vote of thanks to the author. It was a pleasure to listen to the paper presented, coming as it did from such an able exponent of bridge building as Mr. Burrow. He felt much indebted to the author for the information conveyed to them that evening, and also for the manner in which it was conveyed. The references to the different foundations, as illustrated, were indeed excellent. He was fortunate in being able to study the building of the Hawkesbury River Bridge during its construction. He saw the piers sunk, and the difficulties encountered. One of them referred to, viz., the splay length, was, he thought inclined to make sinking easier. In the original design proposed in America it was somewhat different.

S. B. Baker considered that the depth to which the piers had to be sunk was so great that there seemed a possibility that a band may seize on a cylinder, and on this account the plating was thickened, and stiffening increased. Three wells were provided, the outer filled with concrete. Some difficulty was met with in sinking, but the tilting was overcome by dredging on the opposite side, and weighting at the top.

The Pyrmont Bridge caisson was a successful operation, and it reflected great credit upon those who were in charge of the work. The change to incandescent lamps from the smoky candles referred to would be appreciated by anyone who had any experience with air locks. He had the opportunity of inspecting an air lock of the type mentioned by Mr. Burrow, in company with Mr. De Burgh, and would say that he experienced no difficulty whatever due to "decompression," although he was surprised that some better system had not been devised to replace it. He felt indebted to the author for the illustrations of the method of fixing the Hawkesbury River piers, and for the views of the river bed.

He thought the photo. of Aberdeen Bridge (similar to the Ellerslie and Cowra bridges designed by the speaker) did not convey a true indication of the length of the girders, for at the time of their erection it was the largest composite truss bridge in the world.

Mr. Poole, in seconding the vote of thanks to the author, said he would very much like to include in it his appreciation of the data brought forward by Mr. Burrow re the method adopted of grouting the Merrimac piers. He thought it very ingenious, and it gave a good mushroom base to the structure. The wall of towers was formed by a series of square caissons sunk in line and backed one to the other with concrete slabs. The table of skin friction was a good one, and we were indebted to the author for his compilation of the same.

Mr. Bradfield mentioned that 10 acres had been reserved from mining leases in the vicinity of the piers for the proposed North Shore Bridge, and in many mining operations it is usual to resume a shaft block, as the country in settling down has a tendency to throw cracks to the surface. The Sydney coal mine, at a depth of 3000ft., would not, of course, affect the surface at all. He had much pleasure in seconding the vote of thanks to the author.

The President said he noticed Mr. Goldsmith (one of the original members of the Association) among the visitors, and would be pleased to hear him discuss the paper.

Mr. Goldsmith said it gave him great pleasure to be able to express his approval of the data brought forward that evening. One point which interested him was the method employed of obtaining greater bearing area by forcing concrete out under the footings. The speaker referred to the many difficulties met with in determining the foundation of a new bridge, particularly with regard to obtaining a true record of the subsoil upon which the footings rest.

A peculiar incident, he thought worth bringing before the members, was the failure of one of the piers of the Rockhampton Bridge, built in 1878, and damaged in the 1893 flood. One of the piers founded upon rock was washed away, and when examined it was discovered that the rock was merely a ledge, and had broken off owing to the stresses set up by the flood waters on the face of the pier. A new bore was put down, and the true rock surface encountered at no great depth below the old facing. The pier has withstood the onset of several floods since its re-erection, and does not evidence any sign of failure to date.

During the last ten years he had sunk about 62 cylinders, 22 under the air pressure system, the balance open dredging. He thanked them for the opportunity of being with the members of his old Association that evening, and congratulated Mr. Burrow on the successful rendering of an important paper.

The President said that very little ground was left for him to cover after the very interesting and able discussion that they had heard that evening. He congratulated the author upon the paper presented, and felt sure that the members present would agree with him that the data available was of considerable value to them as engineers. He had pleasure in conveying the vote of thanks to Mr. Burrow.

Mr. Burrow, in reply, said he was pleased that his paper had met with the appreciation of the members. He thanked the speakers for their kind remarks re his effort, and thought that when the Metropolitan Railway had been constructed that some very valuable and interesting data would be available for the members.