Discussion.

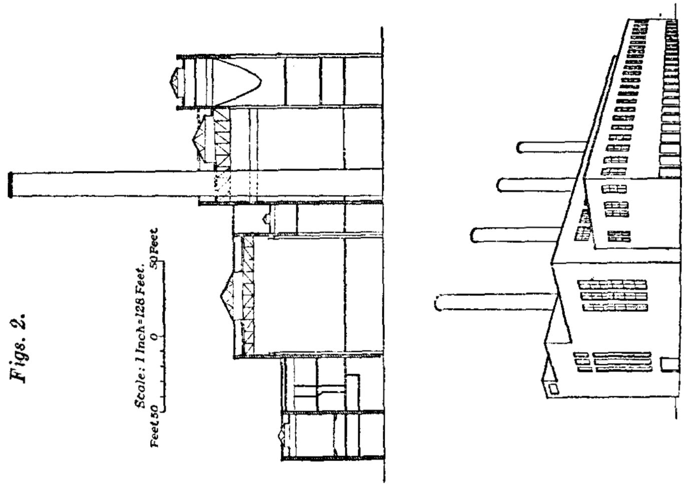
The Authors. The AUTHORS exhibited a number of lantern-slides illustrating their Papers.

Mr. Dean. Mr. DEAN wished to illustrate certain phases of the architectural work and to show the progress of the design from its inception to its final stage. *Figs. 1* showed the arrangement of the station as it was proposed when sanction for its construction was received. At a later date it was suggested that the station should be re-designed with four chimneys carried at ground level, as shown in *Figs. 2*. The design shown in *Figs. 3* (p. 98) was next developed, certain modifications having also been made in the cross-section of the building as the schemes for the actual plant to be installed became defined.

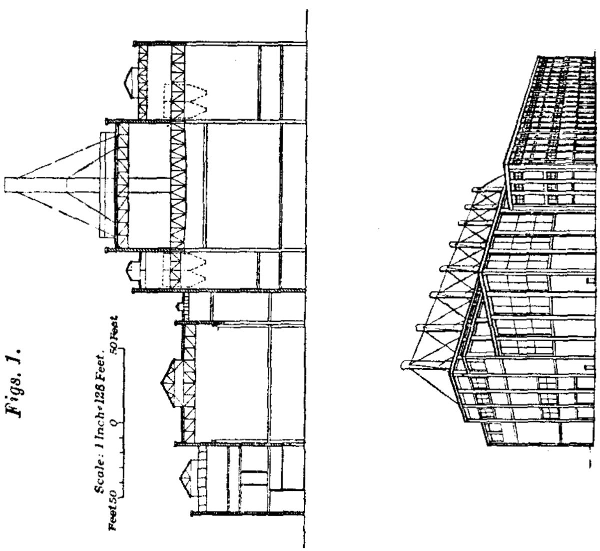
The next scheme, shown in *Figs. 4*, p. 98, was never developed beyond the stage shown, except in so far as the cross-section was concerned. The question of gas-washing was becoming important, and it was proposed to conduct the gases by an overhead flue to washer-towers. That design was developed, with certain modifications in the cross-section and floor-levels, as shown in *Figs. 5*, p. 99, and the tower at each end, instead of having simply a downtake followed by an uptake, had double downtakes and a single uptake. The foundation work for the towers was put in hand at about that time. Sir Giles Gilbert Scott was then consulted, his original sketch for the elevation of the station being shown in *Fig. 6*, p. 99. Owing to the progress which had already been made in the foundation work, and the heavier weight which would have been imposed by square chimneys, that design could not be carried out in its entirety, but it led to some modification of the preceding design. *Figs. 7* (p. 100) showed the building as actually constructed.

The President. The PRESIDENT, in proposing the vote of thanks, observed that the Papers were very timely because they dealt with the latest practice in the erection of the great power-stations which were now becoming general. There were two related questions which he hoped would be discussed. It seemed to him that there would be centred at one point an enormous consumption of fuel, enormous quantities of sulphuric acid gas and other deleterious substances being poured into the atmosphere. If they were not eliminated, their effects not only on the buildings but on all the art treasures of London would be very considerable. If the consumption of fuel were scattered over a wide area the effect would be much less deleterious. In most countries he believed there was an increasing

Mr. Dean

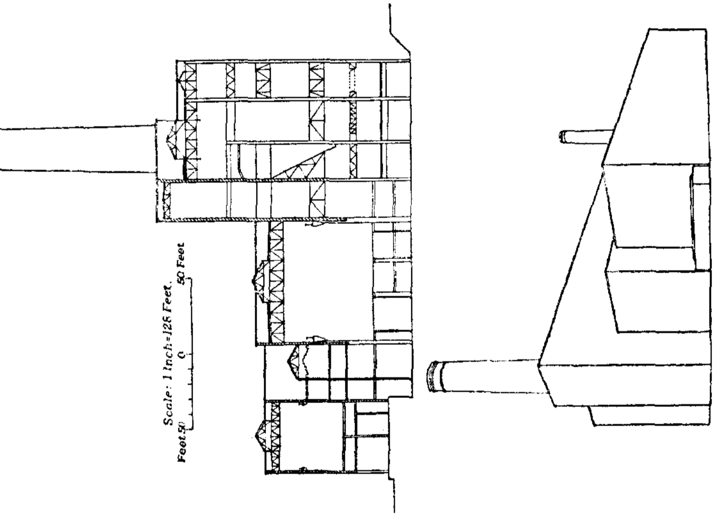


Figs. 2.

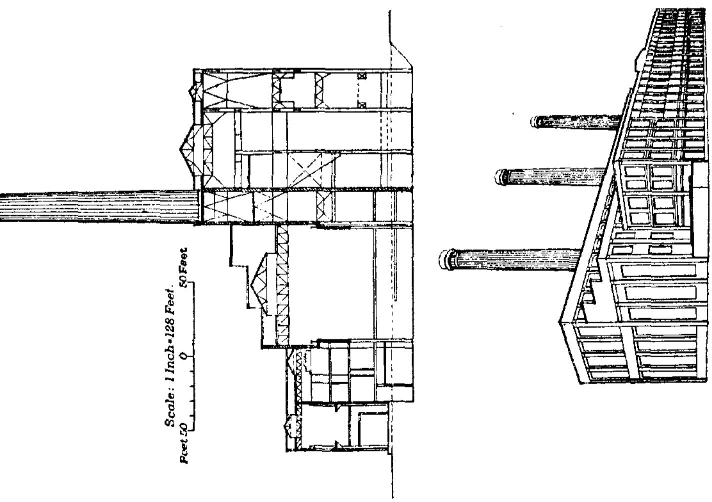


Figs. 1.

Mr. Dean.



Figs. 4.



Figs. 3

Mr. Dean.

Figs. 5.

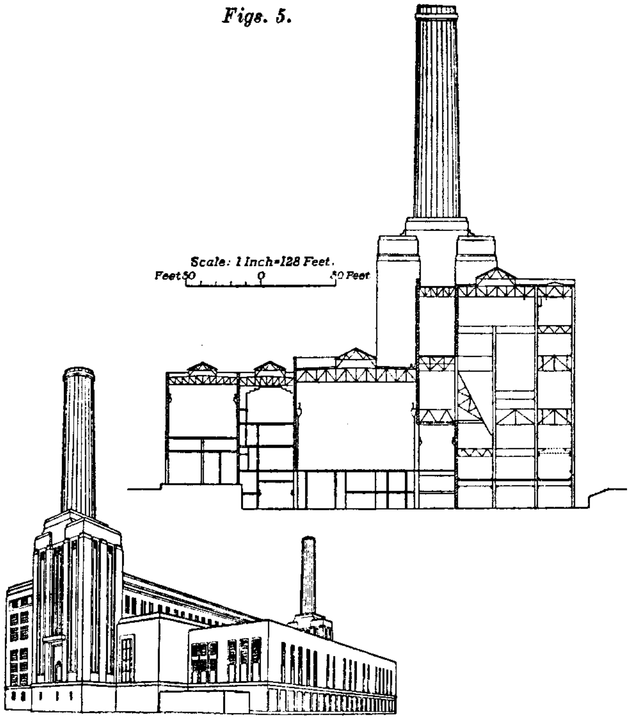
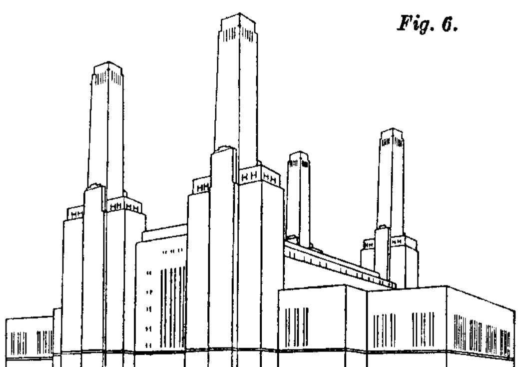
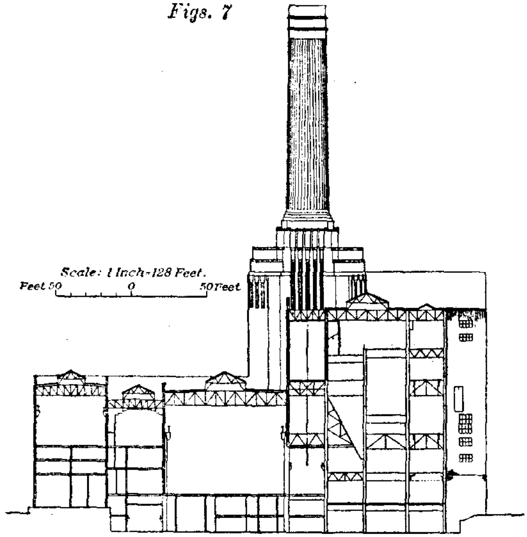


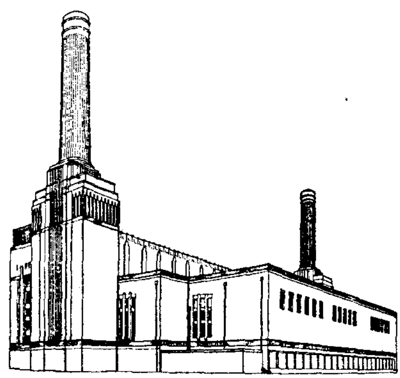
Fig. 6.



Mr. Dean.

Figs. 7





The President. tendency to place great power-stations far from the towns, but in England they seemed to be put near the centres of great population. He would have thought that, with the possibilities of modern power-transmission, the former policy would be better from every point of view.

Sir Henry Japp. Sir HENRY JAPP remarked that the architectural treatment of the power-house at Battersea was most striking. The engineers responsible were to be congratulated on their thorough exploration of the ground by a complete set of borings, by means of which they had found the potholes to which reference had been made, and had been able to arrange the work, and especially the tunnels, so as to miss them. He was particularly interested in the work done by

Sir Henry Japp.

Messrs. John Mowlem & Company, and especially the excavation for the screening-chamber. That was a pit 81 feet long by 51 feet wide and 51 feet deep, taken out within Universal steel piling. The remarkable point was that only two sets of walings and struts were employed in the 51 feet of depth, which was made possible by driving heavy rolled joists as soldiers. The first frame was 17 feet and the next 37 feet from the top of the piles, leaving a non-supported distance of 14 feet. The object of that special treatment was to allow for the cutwater shuttering and also to enable the reinforcing bars to be put in without bending or cutting them. He agreed with Mr. Bartlett that it might have been better if the dredging had not been taken down to —17·50 O.D. before the cofferdams were built and the work within them completed. It exposed a very much greater length of steel pile to the head of water. The Larssen No. 5 section which was available when cofferdams Nos. 2 and 3 were built was of great help in allowing more open spacing of the walings, thus facilitating the reinforcing work. Mr. Bartlett spoke in his Paper of one Universal pile wandering out horizontally. Those piles were generally made of soft mild steel, but the Ougree piles which were also used were of high-tensile steel. It might be useful to remember that a soft steel pile was apt to turn off horizontally or in any other direction if it struck a boulder. He remembered that at Workington dock, when extracting the cofferdam made of Lackawanna steel piles, a piece of pile was noticed sticking up about 4 feet out of the foreshore and was thought to be a burned-off piece thrown up by the sea and partly buried in the sand. His surprise might be imagined when he found, in extracting one of the piles, that that projecting piece 20 feet away started to go down, and it turned out to be the toe of the pile. That reminded him of the remarkable occasion when a soft steel pile being driven from a barge in the Great Lakes struck a boulder, turned up, pierced the bottom of the barge and sank it. Cofferdams Nos. 2 and 3 at Battersea were of the same design, but whilst No. 2 stood up to the work even with the high tide, part of No. 3 collapsed. On investigation he found that if a tangent at 60 degrees to the horizontal were drawn to the side of the tunnel, which had been driven ahead of the building of the dam, it passed through the point where the dam gave way. The first part of the tunnel had been driven in free air, but, just when the face had reached the front of the dam, the engineers had ordered compressed air to be employed. The face had therefore to be left standing on timber during the 2 weeks required for building the bulkhead and air-locks, so that the settlement of the wedge of clay above the tunnel at the stationary face took place right beneath the steel piling. He remembered that when

Sir Henry Japp.

the Great Northern and City Railway had been under construction he visited his brother's warehouse in the City Road after the tunnels were completed, and his brother pointed out two vertical cracks in the party wall and asked what they were due to. He took measurements and plotted the position of the City and South London Railway and of the Great Northern and City Railway above it, and found that tangential lines from those cracks at 60 degrees to the horizontal struck the sides of the two tubes, so that there was a wedge between those two lines on each side of the street which settled, and in settling the buildings came closer together; thus Moorgate Street was made narrower than it had been. The buildings pushed the paving against the tops of the curbs, while the concrete of the road surface held the bottoms of the curbs, and therefore they tilted inwards. Some time later, he was glad to see the City authorities repairing the curbing without asking any questions! The break in the cofferdam at Battersea was about 56 feet long and was repaired by putting in an offset 14 feet out from the face of the piles and about 100 feet long, the work being completed without further difficulty.

Although the scope of the discussion hardly included the machinery, he would remark that he had been most interested when Mr. Bartlett took him through the completed power-house and informed him that on account of the superheating of the steam to 900° F. the high-pressure turbine and the steam-pipe would be seen to be at a dull red heat if the asbestos lagging were removed. Mr. Bartlett also showed him the oiling system for that turbine, and asked him what size of supply-pipe he imagined would be required. He hazarded a 4-inch pipe, and Mr. Bartlett then showed him the actual pipe 14 inches in diameter for lubricating only one of the turbines.

Dr. Lowe-Brown.

Dr. W. L. Lowe-Brown observed that the gas-washing plant was the outstanding feature of the Battersea station, but the brevity of its description in the Paper might give a wrong impression as to the amount of time and attention that it had required. It was true that a number of different materials used for the purpose of protecting the structure against attack by the moist gases were mentioned, but nothing was said about their relative resistances or about the other materials which had been tried and found unsatisfactory. It would be of the greatest possible value to engineers if the Authors could give further particulars with regard to that matter, or, better still, present a special Paper describing that part of the work.

There was one striking feature of both stations which appealed to him. He had always thought that a chimney was a hot place, but in the case of the Battersea station pitch-pine scrubbers were installed, and in the Dunston station lead flashing was used inside the flue. Those details drew attention to the efficiency of modern power-stations and to the low temperatures at which the gases were discharged into the air. Various problems were common to both stations, but had been treated in quite different ways. Sir Henry Japp had already referred to the thorough way in which the underground conditions at Battersea had been studied, and he thought that *Figs. 2* of the Paper by Messrs. Berry and Dean, which showed the contour of the surface of the London clay, were most instructive. They afforded an excellent illustration of the pitfalls—he might almost say the potholes—which an engineer might fall into through drawing conclusions only from a small number of boreholes, even when they were made with the greatest care. At Battersea seventy-three boreholes and eight inspection pits were put down, the latter being probably equivalent to three or four times their number of boreholes. Owing to that adequate investigation, a large part of the foundations could be put directly on London clay, but for the foundations below —20 O.D. 17-inch Vibro-piles were used, and he understood that about 1,500 were required. The watertightness of the steel sheet-piling enclosure was remarkable; when once the water-level had been lowered the total leakage, 300 gallons per hour, was only equal to about a quart per linear foot per hour. A small number of large piles were used at Battersea, but a large number of small piles at Dunston. The Dunston station was required in a great hurry, and it was largely due to the absence of deep foundations, and to the use of short piles, that the work had been completed in the remarkably short time of 20 months. The work at Battersea was pushed ahead well, but took 50 months. In the Papers on the Battersea station full particulars of costs were given, but in the Paper on Dunston costs were not mentioned at all. He hoped that Mr. Anderson would be able to give some figures, because, although the Dunston station had been built at a tremendous pace, he did not believe the costs would compare unfavourably with those of Battersea.

Dr. Lowe-Brown.

Glancing at the Paper on Dunston, it might be thought that the site had not been properly explored, as only two test piles had been put down, but exploration had actually been going on for 20 years. Borings had been put down all over the site before the original station was built; certain difficulties were experienced during construction, but the completed work stood up for 20 years, so that the information available was really very considerable. It would appear that the engineers not only learned to place reliance on short piles driven down to the gravel, but they also learned the danger attending deep excavation in the ground in question. That was referred to, Dr. Lowe Brown

although briefly, on p. 5 of the Paper. He had looked up the plans of the old station,[1] and had found that the turbine-house was placed on the riverward side of the station and the suction-chambers in the turbine-house itself, so that he presumed that that was the place where the trouble had been experienced with the deep foundations. In designing the new station deep foundations were avoided as far as possible, and when they could not be avoided altogether they were kept as far away from the turbine-house as possible. The turbine-house was placed away from the river, the nearest deep excavation being 300 feet away from the turbine blocks, and the circulating-water pump-house on the river bank at about double that distance. Foundation-work at the site was not at all easy, but the strata were fairly level, though they varied in thickness from 12 feet 6 inches to 6 feet 6 inches. The engineers were to be congratulated on having made the best of the conditions that they could. Turbo-generators needed very stable foundations, and the engineers seemed to have been able to meet all the requirements. He hoped that Mr. Anderson would give the piling formula which had been used and which appeared to have been most successful. No tests were made on the piles, but the driving of each pile was recorded. Since there were 6,300 concrete piles and 1,700 timber piles, that must have involved a tremendous amount of work, but still more remarkable was the speed with which they were driven—three hundred and fifty per week, or fifteen per pile-driver per day. Mr. Anderson referred to the way in which the ground was churned up by the piles; he would like to know if that affected any of the piles which had already been driven, if redriving tests were made, and if observations were made of the settlement of the piles under the dead load. He would also like to know if any raking piles had been driven at Dunston—he did not think they had, but the top 30 feet of the piles was in very soft and unstable material, and he thought it would have been safer if some had been used. The stability of the old power-station did not show that they were unnecessary, because the old building had certain deep foundations which would help to stabilize it laterally, whereas the new power-station had none. He would also like the Author to say why the creosoted piles had been adopted—was it because they had been used with success on the old building?

It was interesting to note that at the Dunston station the difference between the cost of brickwork and the cost of patent glazing had been equated against the extra cost of ventilation. The temperatures appeared to be satisfactory both in summer and winter.

[1] "Dunston Power-Station of the Newcastle-on-Tyne Electric Supply Company," *Engineering*, vol. xcii (1911), p. 7.

Dr. Lowe-Brown.

At Battersea the intake-culverts had been built in tunnel at low levels and the pumps were in a suction-chamber placed in the power-house, the discharge-culverts being also placed at low level. At Dunston, on the other hand, as in the case of so many power-stations designed by the same engineers, the pumps were placed on the river-bank and both the delivery and discharge pipes carried at a high level. That was probably due to the urgency of the work and to the nature of the ground, but he would like to have a comparison of the costs of carrying out the work in that way and by tunnel. Were there any additional expenses for maintenance, and was the pumping greater? The engineers favouring the low-level principle laid great stress on the importance of siphonic return, and in the present instance it was possible that the siphonic return might not be available at low water, so that the pumps might have to be made more powerful.

Mr. Braine.

Mr. C. D. C. BRAINE said that in view of certain doubts about the design of pressure-tunnels, the application of purely theoretical considerations to such tunnels might be of some interest. In the case of the cast-iron-lined pressure-tunnels of the circulating-water system at Battersea, if the surrounding ground were to be relied on to prevent them bursting it would have to resist the very small movements which took place in the linings when the tunnels were filled. That movement might not exceed 0·01 inch on the diameter in the case under discussion. London blue clay, through which the tunnels were mostly driven, was generally far too plastic to resist deformations of that order, especially when it had been disturbed by tunnelling operations. The maximum water-pressure in the tunnels appeared to rise to about 1½ ton per square foot, and he would be a bold engineer who would place a load of 1½ ton per square foot on a clay foundation and guarantee that the settlement would be less than 0·01 inch; yet that was, apparently, relied on in the case under discussion. Mere weight above a tunnel did not necessarily mean that small movements could be resisted, as was borne out by tests which had recently been made on a tunnel almost identical with those at Battersea, and which showed that a clay surround offered no apparent resistance to an internal bursting pressure. There was, however, an additional factor to be taken into account. During construction, the temperature in the tunnels would have been about 70° F. and the temperature of the iron perhaps about 50° F. The temperature of the water, however, when first admitted to the tunnel, would have been about 35° F. to 40° F., and the contraction in diameter of the iron due to the falling temperature would have been about 0·015 inch. The iron would therefore have pulled away from

Mr. Braine. the clay, despite the internal load on it. It was thus clear that for some time at least the lining would have carried the full internal load, for the ground was then not even in contact with the iron, and if the clay were stiff several days might elapse before it closed on the iron. A still greater variation in temperature might easily arise when the tunnel was in use. The total bursting force on one ring of segments might be, say, 28 tons, giving a direct stress in the cast iron of about ½ ton per square inch. That stress would only produce an elongation of the tunnel circumference of about 0·03 inch, or about 0·01 inch on the diameter. Such deformations were so small that they would cause only hair-cracks in the lining which would be difficult to see when the tunnel was emptied. Rupture due to secondary bending stresses in the flanges would probably occur should the diameter be increased by, say, 0·03 inch. The weakest parts of the ring were the longitudinal joints. If 1-inch diameter bolts were used the stress in them would be 8½ tons per square inch at the bottom of the thread, which seemed high when it was considered that in time the bolts would probably deteriorate owing to water percolating through the joints. The segments were apparently machined, so that any extension of the bolts would allow of water entering; unless the bolts were tightened up sufficiently to produce at least that tension in them they would stretch when the load came on them. If they were just taut initially the total elongation in the circumference due to that tension would amount to about 0·006 inch, about one-half the stretch occurring in the segments. It was therefore most important that those bolts should be pulled up very tightly. When the tunnel was under internal pressure the pull on the flanges was eccentric and caused them to bend, and the secondary stress developed thereby was about 4¼ tons per square inch at the root of the flange. To that should be added the primary stress of ½ ton per square inch, so that the total tensile stress at the root of the flange was no less than 4¾ tons per square inch, nearly double what was customary for cast iron. The secondary stress could have been greatly reduced if the longitudinal flanges had been stiffened by webs similar to those on the circumferential flanges. "Reeling" the joints was no guarantee that the stresses he had mentioned would be eliminated (although it probably reduced them), because all the holes were slotted, and the degree of assistance obtained was dependent only on friction between the rings. It was therefore unreliable, more particularly so in the present case because the tunnel would tend to "breathe" as the tide rose and fell and because the machining of the joints probably gave slightly less friction between segments than might otherwise have been the case. The remarks he had made seemed to receive support *from the following remarks in the Abstract of a forthcoming* **Mr. Braine.** Paper by Mr. Ravenor[1]: "In dealing with a compressible material it will be appreciated that its resistance to compression may be less than its resistance to motion, and in the case of clay this is always so until the condition of liquid mud is approached." That was particularly interesting because it appeared to bear out his own belief that clay would not usually resist very small movements such as occurred in pressure-tunnels. He felt, therefore, that such pressure-tunnels should be designed to be safe even if the whole of the cover of the ground above them were to be removed. Where tunnels were driven through water-bearing gravel the conditions were, of course, fundamentally altered, and different conditions would apply. Mr. Gerald Haskins's Paper on the failure of the Sydney pressure-tunnel,[2] and the discussion which followed it, showed how greatly opinion varied on the design of pressure-tunnels; he hoped, therefore, that the Authors would see fit to deal with the question of cast-iron-lined pressure-tunnels in their reply to the Discussion.

Mr. Anderson, in reply, remarked that Dr. Lowe-Brown had **Mr. Anderson.** referred in generous terms to the remarkably short time of 20 months in which the construction work of the Dunston power-station had been completed, and had observed that the probable reason for that was that a large number of short piles of small sectional area were used rather than a small number of long piles of large sectional area. It appeared (from those and other remarks) that the impression had been gained that short small piles had been selected for the sake of speed in driving. That, however, was not the reason; the site-conditions themselves had compelled the use of short small piles. The length of the piles had been naturally determined by the depth below ground-level of the gravel strata and by their thickness. Bore-holes made as early as 1908 had disclosed that below the strata of ballast was a considerable depth of alluvial strata which could not be relied upon to carry any appreciable load. It was actually to test those alluvial strata that the two test-piles had been driven, and he thought that the results given in Appendixes I and II showed that it would have been most unwise to have driven piles through the ballast. The results of those tests, coupled with the knowledge gained during years of foundation-work on the site in connection with the original station, had determined the use of 12-inch-square piles.

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[1] Sessional Notices Inst. C.E., Session 1934–35, p. 114.

[2] "The Construction, Testing, and Strengthening of a Pressure Tunnel for the Water Supply of Sydney, New South Wales." Minutes of Proceedings Inst. C.E., vol. 234 (1932), p. 25.

Mr. Anderson. Pile-driving formulas were the subject of a controversy which might never be settled by a solution applicable to all conditions, and it was for that reason that he had not given the formula in his Paper. Again, as a result of years of experience with pile-driving at Dunston it was found that the well-known Sanders formula gave the most satisfactory results. That formula deduced the safe load from the kinetic energy of the hammer, and was $L = \frac{WH}{8d}$, where L denoted the safe load in tons, W the weight of hammer in tons, H the drop in inches and d the set of the pile for the last blow in inches. Although the site had been consolidated by the pile-driving operations, and the driving became more difficult as the number driven became greater, no re-driving tests had been made. The only tests for settlement had been carried out on the turbo-alternator foundation-piers by means of oil level-gauges, which had been placed in selected positions around the foundation prior to the erection of the machines; observations taken during the erection period showed that no settlement took place. The timber piles used for the circulating-water mains and stores building had been creosoted as an additional precaution against deterioration, although the site was not permanently waterlogged. No raking piles had been driven, as the buildings were constructed on what might be considered as one heavily reinforced raft, which would give great stability.

Dr. Lowe-Brown had remarked upon the remoteness of the new station from the river bank and on the fact that the turbine-house had been turned away from the river. During construction of the original station, serious trouble had been experienced owing to the deep excavation for the circulation-water-pump wells in the turbine-house causing sand to flow from beneath the turbo-alternator foundations, and thereby causing settlement; for that reason the deep excavations in the latter work had been kept as far away as possible from the turbine-house. Other very important reasons for the change in orientation of the power-station were, firstly, the need for providing for a future store for river-borne coal, so that coal could be fed directly into the boiler-houses from the future coal-handling plant, and, secondly, the fact that the bulk of the load from the power-station was to be transmitted southwards.

From the discussion it appeared that the impression had been given that the difference between the cost of brickwork and the cost of patent glazing had been equated against the cost of ventilation. That, however, was not the case. He had meant to convey that the speed and cost of building the external walls with brickwork relieved with stone and precast-concrete courses, and glazed with large ornamental steel sashes (or windows), had been equated against

Mr. Anderson. the speed and cost of providing an external covering consisting of a plinth brick wall surmounted by patent glazing, making allowance for the probably necessary cost of mechanical ventilation.

The locating of the power-station at some distance from the river-bank, together with the orientation of the station, necessitated some modifications to the circulating-water inlet-system, as compared with the system installed in the old station, the alternatives consisting of a pump-house at the river-bank with mains at either high or low level, or deep pumps in the turbine-house with low-level inlet-mains to the pumps. Owing to previous trouble already explained, the latter alternative was decided against. The centrifugal pumps are placed at such a level that they are drowned at all stages of the tide in the river, therefore avoiding special priming arrangements; their level was thus determined by the lowest possible tide. As the water had to be raised to the top of the condensers whatever the level of the pipes leaving the pumps, speed and economy decided that the pump-discharge pipes should be at high level, just below the ground surface, as the joints in the pipes were thereby readily accessible. The return or outlet system had been designed as siphonic at all states of the tide.

He regretted that he had not been able to obtain permission to give particulars of the costs of the station.

Mr. Berry. Mr. BERRY, in reply, said that the President had referred to the danger of placing big power-stations in the centre of London and had suggested that their flue-gases might have serious effects on the buildings surrounding them. He would emphasize, however, that as far as the Battersea power-station was concerned, a completely satisfactory certificate had recently been received from the Government chemists confirming that the gas-washing was so successful in eliminating noxious elements in the gases coming from the chimney as to render those elements practically negligible. The washings were filtered and returned into the Thames in a condition which, he believed, the Port of London Authority admitted to be better than that of the water when first taken out of the Thames. That difficult problem having been solved by the London Power Company, there was no reason why the station should not have been erected near the centre of gravity of its load, thereby effecting a very great saving in transmission-costs.

The process of gas-washing had been fully treated by Dr. Pearce,[1] but Mr. Berry was in sympathy with Dr. Lowe-Brown's suggestion that details with regard to the materials used in the construction and lining of the flues, towers and chimneys for gas-washing would be

[1] See footnote (1), p. 57.

Mr. Berry. of interest. When the construction of the north tower had been begun, use had necessarily been made of such materials as had proved most satisfactory under tests made up to that time. It had been found that those materials were not altogether satisfactory, and in the case of the south tower, which had been begun later than the north tower, various improvements had been introduced. There was still room, however, for further improvement, and better methods still had already been incorporated in a tower, chimney and flues recently constructed at the Deptford power-station. He hoped that Mr. Bartlett would be able to present a Paper at some later date giving full details of all the experience which had been obtained.

Mr. Dean. Mr. DEAN, in reply, observed that the answer to the President's question with regard to the siting of stations in towns or in the country depended essentially on the primary factor of transmission-costs. Estimates had been published giving the relative costs which would have been incurred had the Battersea and other town stations been located in positions well outside their distribution-areas. Those showed that a distant site was wholly uneconomic. With regard to the Battersea chimney-towers, it should be emphasized that they were an entirely new development; therefore, when the design had been started, it was impossible, since experimental work was still proceeding, to visualize the ultimate washing process, so that the study of ordinary practice at chemical and similar works did not provide a safe basis on which to finalize the design. Very many materials had been tried with varying success, and the ultimate principle of construction was to provide a succession of protective materials, each of which would give a line of defence against possible attack, and to blend the whole protection into a reasonable structure. As Mr. Berry had already stated, those original combinations were already in a sense almost obsolete.

Dr. Lowe-Brown had referred to the speed of construction of the Dunston power-station, which had been put into commission in 20 months, whereas Battersea had taken 50 months. It had to be remembered, firstly, that the superstructures in particular of the two stations were totally different. Another factor was the speed at which the station had been required to be put into commission, and yet another factor in speedy construction—in his opinion most important—was the extent of detailed information which it was possible to obtain about the electrical and mechanical plant before the constructional engineering work of a large generating station was started. It was not easy to give that information, but the better those particulars were known at the beginning, the faster the station could be built. Regarding relative costs, the location of Battersea was totally different from that of Dunston. Battersea was visible for a great distance around; it was in the centre of London, and with a lively memory of the statements made by opponents of its construction about 5 years ago, he could not bear to contemplate what would have been said had the Battersea station been built with glass sides and a flat roof. He thought that the favourable opinion which had been generally expressed as to the essential dignity and fitness of the station had fully justified the supreme interest of the London Power Company in the æsthetic side of the whole construction, although some considerable increase of cost above the practicable minimum had been incurred. Mr. Dean.

Mr. Bartlett, in reply, observed that Sir Henry Japp had criticized the order in which the cofferdam work had been carried out (the dredging having been completed before the cofferdam was started), and had said that it was stated in the Paper that it might have been better if the dredging had not been taken down before the cofferdams were built. Actually, however, the Paper only stated that much time would probably have been saved. The Authors had considered that question beforehand, and had come to the conclusion that it would have been very much more expensive to carry out the cofferdam work first, because it would have left very little dredging—only that outside the cofferdam. It would have hardly been worth while to bring the dredger, the transport of which constituted the greater part of the expense of dredging, through the bridges to the site. Furthermore, the cost of excavating inside the cofferdam was very much higher than the cost of dredging. Mr. Bartlett.

He did not agree with Sir Henry Japp's suggested reason for the "blow" which occurred in the third cofferdam. He did not quite understand how settlement below the cofferdam could have caused it, because the lines of cleavage would have run across the cofferdam. If the tunnel had been running parallel with the cofferdam there might certainly have been a line of cleavage, parallel with the piles, through which the water might have found a way and have eventually caused the collapse of the piles, but he did not see how it could happen in the way Sir Henry suggested, at least without warning. The Authors had no doubt that the primary cause was the absence of a bottom frame of timber inside the cofferdam. The bottoms of the piles were 13 feet 6 inches below the excavated bottom, which was at − 17·5 O.D., but the lowest frame of timber was at −4·0 O.D. The contractors were placing an additional frame at − 17·00 O.D. at the east end of the cofferdam at the time when the blow occurred. That frame was shown in dotted lines on section AA, Figs. 3, Plate 4. According to calculations, the deflection of the bottom unsupported length of pile at the exceptionally high tide which occurred prior

Mr. Bartlett. to the blow was $\frac{3}{8}$ inch, assuming the bottom 6 feet of piles to be fixed in the clay. The frequent change in deflection due to tidal conditions would not only loosen the ground, but would also allow the water to penetrate lower and lower behind the piles, ultimately causing the pressure at the back of the piles to become so great as to overcome the passive resistance of the clay inside the cofferdam. It was a point of interest to state that the piles had been driven first, and the tunnel had been scheduled to be driven in compressed air.

Mr. Braine had produced figures purporting to prove that cast-iron lining was not suitable for the circulating-water tunnels, but he had possibly forgotten the fact that the tunnel-lining had been grouted under a pressure of 100 lbs. per square inch, which should give an initial compressive stress in the clay and in the cast-iron lining that would greatly reduce the theoretical tensile stress in the cast iron when water-pressure was applied.

Mr. Cadwell. Mr. CADWELL, in reply, referring to Sir Henry Japp's remarks concerning the excavation of the screening-chamber, stated that the reinforcing in the walls was arranged in bands, as shown in section CC, Figs. 4, Plate 4. That arrangement greatly simplified the work of the contractors. Straight bars were used throughout, and the spacing of the bands facilitated the operations of placing concrete and simplified the timber falsework.

Dr. Lowe-Brown had referred to the pumping-chamber being near the station. It was originally intended to place the pumping-chamber nearer to the river-bank, but it was finally located as shown in the drawings for purely mechanical reasons.

Mr. Braine was in error in comparing the Battersea culverts to the pressure-tunnels to which he referred. The latter were required to withstand pressures of from 166 to 250 lbs. per square inch, whereas the maximum pressure at Battersea under the highest estimated tide would only be 24 lbs. per square inch. Mr. Bartlett had already referred to the pressure-grouting of the tunnels, and Mr. Cadwell was of opinion that the premises stated by Mr. Braine did not in fact arise.