sewer at the ocean end by 2 feet, and that the proposal to have two outlets into the ocean, so that the action of the waves should be allowed to expend themselves by going up at the one opening and out at the other, should be adopted. The Paper clearly showed that their advice was sound, both as regards the gradient of the sewer and also the exact form of the outlet, which was 20 or more feet below high water. A similar instance was brought under their notice at the time they were consulted in the case of the northern outfall sewer, which discharged into the ocean about 5 miles to the north of the outlet that had been dealt with by Mr. Peake, and in that case the invert of the sewer at the lower end corresponded with high-water mark, and the two channels dipped down from there to about 10 feet below high-water mark. That was found successful in every respect, and he presumed that the result influenced them in making their subsequent recommendations. They supported the proposal that the flat sewer might be very properly adopted with the small velocity of 2 feet per second, and that the two headings approaching the ocean at different angles from the terminus of the outfall sewer proper should be constructed in the manner described by the Author. Both the sewer and the outlets had been eminently satisfactory. Mr. Davis.

Mr. E. W. Monkhouse asked what type of instrument was used to measure the flow of sewage in the sewer. He gathered from the Paper that it was an instrument with fans to it, like the ordinary current-flow measuring instrument. It would be interesting to know exactly what was used to overcome the clogging effect of the sewage. Mr. Monkhouse.

Mr. Davis said an ordinary small scaled instrument was used such as was employed in river gauging, and then the area of the flow was taken as the other factor. The Paper pointed out that difficulty did arise owing to the sewage being foul, and the instrument could not be used for more than 50 revolutions of the fan. Mr. Davis.

Correspondence.

Mr. T. E. Burrows considered that the construction of this ocean outfall sewer to intercept and convey to the ocean the sewage hitherto dealt with by the sewage-farm as well as the trades-wastes of a large manufacturing area, had filled a want that had been noticeable for some years. The previous existing scheme whereby a large Mr. Burrows.

Mr. Burrows. amount of solids had been dealt with, both by siphoning under Cook's river and even trucking across a bridge to the sewage farm, and occasionally during rainy weather by discharging direct into the river, was anything but a satisfactory method of dealing with that malodorous subject. Complaints had been bitter and frequent during the hot summer months that the sewage farm was responsible for a great deal of unpleasantness in the Illawarra suburbs when the prevailing north-east winds carried the odours to the areas mentioned. The factories at Botany discharged their wastes largely into the waters of Cook's river and Botany Bay. Those discharges at times were so highly charged with chemicals that they killed a great quantity of fish in the river. The old siphon was carried across Cook's river in the form of cast-iron pipes buried in concrete, the concrete bed being supported by piles driven close together. The siphon formed a serious bar to the navigation of the river, as the maximum depth at low tide over it was only $6\frac{1}{2}$ feet. A considerable expenditure had been incurred in aligning the banks and reclaiming large areas of Crown lands below high-water level, but little use or value could accrue to them owing to the shallow depth obtainable. The works described have, therefore, done a great deal of good, and were still capable of further contributing to the sanitation of large areas adjacent to the great city of Sydney, with its population of close on 1,000,000 people. The site selected for the outfall was an admirable one, and experience had proved that the depth below tide-level at which the outfall had been placed was satisfactory from the point of view of safety from wave-action. The latter had been a matter of much doubt at the time the project was being considered, and there had been considerable controversy on the subject. The increased depth of outlet to 26 feet from 20 feet below mean high-water of spring tides was provided as an additional safeguard, and from personal observation he considered the added depth was warranted. The current observations taken at the site of the outfall were of considerable value, inasmuch as they definitely showed that the sewage once discharged into the ocean was carried away by the current, either to the south or the north, and quickly dispersed. The tidal action was negative and had no effect on the current except in the entrance to a port. In that case the nearest port (Botany Bay) was sufficiently far to the south to be beyond the probability of the sewage being carried into it by the flood tide. The current observations referred to also demonstrated that the current close inshore was largely governed by the wind, and was easily reversed by a change in the direction of the air movement. The main engineering difficulty encountered during the construction was the carrying of the sewer through the wet ground near Botany, which was largely met by the construction of the steel-piling coffer-dam, but the removal of water proved to be a considerable item. The water had to be discharged into what might be described as an underground lagoon, through which the construction was being carried, and the 8,000,000 gallons mentioned might be considered as the daily percolation in the trench. The Author had placed before the Institution a clear account of a very valuable engineering work. Mr. Burrows considered the thanks of members generally would be accorded him for a material addition to its records. Mr. Burrows.

With regard to Mr. Bush's Paper, he considered that the description served a useful purpose as a record of the treatment for sewerage purposes of a city with a population of 100,000 persons. He deprecated the inclusion of the collection and discharge of storm-water through the sewerage system of a town of any size, as storm-water should be more satisfactorily and economically dealt with if treated separately. Where overflows occurred during heavy rainfall, the fact that crude sewage was being discharged at various points in the city gave rise to complaints that were in many cases justified. It would also appear that the pumping-stations for dealing with sewage from the lower levels would have some difficulty in coping with the quantity to be pumped when the main sewer was fully charged with storm-water. The point of discharge into the harbour, although some $2\frac{3}{4}$ miles from the centre of the city, was close enough to cause complaints from some of the residents of the odours arising from the vicintity, at low tide or when the direction of the wind was from that quarter. The method of dealing with the reinforced-concrete piles by means of fish-plates might have been made clearer by the Author. It would appear that they were squarely butted together with wrought iron fish-plates only $\frac{5}{8}$ inch thick used for securing them. The thickness of the plates would appear to leave something to be desired both for strength and for corrosion. It would also be interesting to know what amount of abrasion occurred between the concrete ends of the piles as driving took place. With regard to the driving of the reinforced-concrete piles, Mr. Burrows had used successfully a column of sawdust in a steel casing, in which a timber dolly was placed to take the contact of the ram. The scheme suggested that it was one that could easily be brought under the activated sludge treatment at a small cost, and that would largely increase its value from a sanitary point of view, by keeping the effluent which was discharged into the harbour as clean as possible.

Mr. W. E. Cook agreed with Mr. Peake that, although the difficulty of carrying out the work of construction in the wet sand Mr. Cook.

Mr. Cook. section was very great, the chief feature of the sewer was the design of the ocean outfall. He believed that the Author's full consideration of wave-action was no doubt largely due to the fact that in Sydney, even among the sewerage engineers, criticism had been chiefly directed against the flat gradient of the sewer, as it would cause an undue deposit of silt, and also as the wave-action on the precipitous coast at outlet would cause further deposit when the flow was checked or reversed by wave-action in the sewer. Such opinions had proved quite groundless, since the sewer had been found to be so clean that a proposal had been made to discharge the silt and sludge from the screening chambers, both on the southern main and at the low-level pumping-station at Mascot into the east-end of the siphon under Cook's river. Before doing so, however, it had been decided to have a minute examination of the sewer made. After midnight, at a time of extremely small flow, the sewer had been emptied and traversed from Cook's river to the shaft at the outlet, when it had been found that the sewer was absolutely clean. When the Long Bay outfall had been put into operation, the silt and sludge from the southern and low-level pumping-station had been forced by Shone ejectors into a hopper on the wharf at the east end of the siphon, there run into punts, taken out to sea and deposited in deep water. For some time considerable quantities of wool had come from the wool-scouring establishments and an undue proportion had escaped the screens. That had caused great trouble as the wool induced the silt and sludge to bind together in tight masses. By compelling the wool-scourers to screen out the wool effectively on their own premises, this difficulty was overcome. For the year ending the 30th June, 1920, 7,721 tons of sludge and silt had been punted to sea from Mascot. Later the silt and sludge was run into the outfall sewer at Mascot, thus saving the expense of punting. The population dealt with on the 30th June, 1920, at the Long Bay outfall was about 300,000. The corresponding flow was about 8,000,000 gallons per day, of which less than one-fourth came from the southern and low-level sewers. Wave-action was found at all times to be distinctly visible in the chamber near the cliff face, the height to which the water rose being about half-way between the top of the wave outside and the average sea-line at the time. No trouble had been experienced and, in particular, no deposit of silt had resulted. He might mention that 964 cubic yards of silt had been removed from the silt-pits on the old Botany sewage farm at the head of the outfall sewer in the year ending the 30th June, 1920.

He would like to ask Mr. Bush why the entirely separate system was not adopted at Auckland, instead of providing for a flow of one part of foul water and five parts of storm-water before the overflows came into operation, because Auckland seemed to be specially suitable for the separate system. Generally speaking the surface fell fast to the north and the storm-water flowed to Waitemata Harbour by well-defined gullies. No doubt provision for flushing on a large scale would be unnecessary when storm-water was admitted, but the saving of cost over a long length of main outfall sewer would more than compensate for the cost of providing flushing facilities. In the latter case the flushing would be done at the most convenient times, which was not the case when storm-water was relied on. The Long Bay outfall in Sydney, on a gradient of 1 in 3,640, and of a section not so well suited for self-cleansing as the Auckland section, kept itself clean without flushing, whereas the gradient at Auckland was 1 in 3,000. The experience in Sydney showed that it was difficult to ensure an entirely separate system, as, in spite of occasional surprise visits to every house in selected areas, it was found that people did turn rain-water into the foul-water sewers in a good many cases. Some provision must be made for this, but an allowance of 50 gallons per head per day would surely be sufficient. The Author quoted 35 gallons per head per day, as the dry-weather flow while in Sydney, which was very similarly situated and which enjoyed a similar climate, the average dry-weather flow was about 25 gallons, so that, allowing for some trades-wastes, 35 gallons was quite a liberal estimate. The estimated density of population was given as 280,000 on 19,000 acres, i.e., about 15 per acre, so that an excessive dry-weather flow could not be expected. Again, on the low-level area, provision was made for dealing with 100 persons per acre at a rate of 100 gallons per head per day. This provision must surely have been greatly in excess of requirements, even allowing for the fact that the trades-wastes were more likely to come from the low-level pumping-areas near the Harbour than from the sparsely-populated suburban areas. Since overflow-pipes, to provide for the temporary discharge of sewage into the harbour, had been laid a smaller allowance might safely have been made. Mr. Cook.

Mr. H. H. Dare remarked that during the time when he had been associated with the work described by Mr. Peake, the designs had been practically completed and a considerable length of the rock tunnels on the first section, and of excavation and concrete on the second and third sections, carried out. The action of the submerged outlets might be considered to be most satisfactory, and to verify completely the opinion of the designing officers that no detrimental result was to be expected, owing to any surge of the waves along the Mr. Dare.

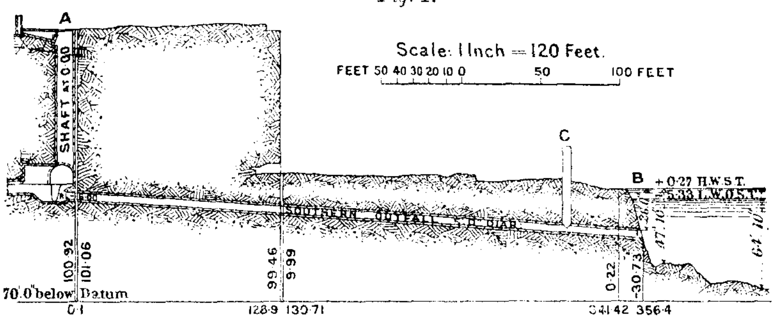
Mr. Dare. sewer checking its discharging capacity. The considerable surge in the temporary shaft on the southern outlet pipe and the fact that the pulsation in the outlet chamber was not affected thereby was of interest, and the experience gained with that shaft should be of value in connection with the design of future works of that class. He was indebted to Mr. C. Simons, resident engineer, for information upon which the following notes regarding the second section were based. Reference was made to the difficulties experienced on the second section in the heavily water-charged sand, which formed part of the area from which the water-supply of Sydney was drawn for many years. As the cutting was completed the water drained down to bed-level, or berm, but the whole of the lower sand-formation, through which the sheet-piled trench 30 feet deep was constructed, still remained full of water. To cope with this a well-cylinder was sunk to form a sump, the sand from the interior of which was removed, partly by pumping and partly by excavation. A considerable length of sheet-piling was then driven and the excavation of the trench proceeded with. Pumping operations were commenced with two 6-inch centrifugal pumps, with which it was possible to deal with the excavation in the upper 10 feet of trench, but, as the trench opened out, the volume of water increased, and ultimately five pumps were required. The angle of repose of the water-charged sand was so flat that additional piles had to be provided for bulkheads to enable the trench to be taken down to the foundation level. Although in the first stages considerable trouble was experienced owing to boils in the sand, this decreased as the trench was opened up and the water drained from the immediate vicinity of the trench, but although the pumps having a capacity of 8,000,000 gallons per day were kept in constant action, the inflow was so great that if any of the pumps failed or stopped from any cause the water immediately commenced to rise. The steel piling was of great service, as, once driven, it moved but little, and pumps, concrete-mixers and tramways for the removal of excavation and for the supply of concrete material were supported on the timber struts. Owing to the difficulty of driving, the sheet piles were driven only about 3 feet below the bottom of the trench, but little trouble was experienced through this cause; it only very rarely happened that a subsidence of the berm took place owing to the sand boiling up under the piles. Every possible precaution was taken to keep the water down to a constant level, but occasionally, owing to the failure of electric current or the choking of pumps with sand, a rise did occur. The volume of water running in the drains between the sewer and piles was very great, and was generally more so on one side than on the other. When for any reason a stoppage occurred, it was sometimes found that the full drain had changed to the opposite side, the stream having evidently cut under the concrete. This was a source of considerable anxiety, since the centre of the sewer invert was, during construction, the weakest part, and if for any reason the sand became scoured in the side drains, especially before the arch was completed, there was danger of the extra weight at the sides causing a settlement, which might result in a longitudinal crack in the green concrete. To guard against this an extra reinforcing rod was provided in the invert. Considering the conditions under which the work was carried out, and the fact that on completion and filling in of the sewer the water immediately rose in the strata to a height eventually of 30 feet above the sewer invert, the number of leaks which developed was surprisingly small. The majority of these were merely pin holes and either took up of their own accord or were easily treated. A few more serious ones occurred and these were dealt with by forcing cement into the cracks by means of compressed air. Twelve months after the sewer had been put into operation the surface of the concrete above the flow line was dry throughout. Mr. Dare.

The third section included a long length of reinforced-concrete sewer above ground. Considerable attention was given to the design of the foundations and expansion-joints, which have proved satisfactory. The tunnel for the siphon under Cook's river was driven through sandstone rock, with a minimum cover of about 13 feet and 18 feet respectively of soft sandstone and shale. The amount of leakage was small and occasioned no difficulty.

Mr. E. M. de Burgh, having had charge on behalf of the Department of Public Works of the scheme during the inquiry by the Parliamentary Committee during the absence through illness of Mr. Wade, and having had charge of the construction of the works for the greater portion of their progress and up to the date of completion, thought that the record contributed by Mr. Peake would be found of value to engineers. Mr. Peake had been associated with the work throughout, and many difficulties had been surmounted in its construction. The sewer, passing from rock tunnel to water-charged sand at various points, and having a very flat grade, required great care in setting out and construction. The fact that the subsidence was practically negligible in the sand sections was highly creditable to Mr. Peake and the staff engaged under his direction. Mr. de Burgh thought that the point of greatest interest to engineers was the ocean outlet. A great deal of evidence had been given before the Parliamentary Committee, which inquired into Mr. de Burgh

Mr. de Burgh. and authorized the scheme, on the subject of the varying pressure which might be exerted by the ocean at the points of outlet, which are situated 26 feet below high water spring tides. Certain engineers, in giving evidence before the Committee, stated that the alteration of pressure at the outlet due to wave-action, would be so great as to cause the sea-water not only to stop the discharge of the sewer, but to flow back into the sewer past the outlet shaft at the point A (*Fig.* 1) producing very serious results. Others again were of the opinion expressed by Mr. Peake: "That the heaping up of the water due to wave action will not cause any additional hydrostatic pressure at the mouth of the sewer, and consequently cannot have any effect in stopping the flow of sewage in the pipes or of causing any influx of the sea-water into the duplicate barrels of the main sewer. On the contrary, the returning water, falling over the cliffs at the outfall,

Fig. 1.



causes a downward and outward suction which will materially help the discharge of the sewage."

Mr. de Burgh was of opinion that the successful operation of the sewer outlet was not due to the fact that the pressure of the ocean at the outlet did not substantially vary. As a matter of fact, it did vary very considerably with every wave approaching the shore, and this was proved by the fact that so long as the working shaft at the point C (*Fig. 1*) (which was at present closed), was open, there were most violent pulsations in that shaft corresponding with the impact of each wave against the cliffs. The success of the sewer depended not on the constancy of pressure at the outlet, but on another principle altogether which was not referred to by Mr. Peake, and was not, so far as Mr. de Burgh was aware, referred to by any of the expert witnesses who gave evidence before the Parliamentary Committee on the subject. The success of the outlet was due to the fact which he was about to explain. Each of the two outlet sewers

Mr. de Burgh.

extending from the shaft A to the ocean at B, was approximately 350 feet in length and 5 feet in diameter. Each of those arms was always full of water, and when the sewer was in operation, there was a certain velocity towards the ocean due to the head at the shaft A discharging the sewage into the ocean. The volume of water contained in each arm weighed about 200 tons. The ocean waves struck the cliff at intervals of about 7 seconds and caused a pressure as evidenced by the surge in shaft C. It was not worth while to discuss whether that pressure was hydrostatic or whether it was due to the waves becoming partly waves of translation with a forward movement. It was sufficient to say that the pressure existed varying from maximum to minimum at intervals of 7 seconds. If there were no flow of sewage towards the ocean and the 200 tons of water in each sewer arm were at rest, it would be necessary for the pressure due to the ocean waves to overcome the inertia of the 200 tons of water contained in each sewer arm and to push that 200 tons of water towards the land into shaft A and up the sewer before it could cause trouble. Time was required to do that, and the wave caused only 3½ seconds of maximum pressure followed immediately by 3½ seconds of minimum pressure. The inertia of the 200 tons of water was too great to admit of the wave pressure producing any substantial movement in that short space of time. The short time during which the variations in wave pressure acted and the inertia of the large volume of water in the sewer arms, were the reasons why, in actual practice, the pulsations in Chamber A were very small indeed. Further, if the sewer were in action and the 200 tons of water in each arm were moving towards the ocean, the wave pressure would not have time to overcome and reverse that motion and so interrupt the discharge of the sewer. The pulsation as actually observed in shaft A was very small, and so far as the satisfactory working of the sewer was concerned it might be neglected. It was a common saying that the seventh ocean wave was always a big one, and if the small pulsations in chamber A were observed during a storm, it would be seen that there was a very slight series of pulsations due to slight alterations in the velocity of discharge and that at intervals corresponding to about from the seventh to the tenth wave there was a slightly larger pulsation, which merely had the good effect of sucking any floating matter in the chamber into the outlet. Mr. de Burgh was of the opinion that the amount of pulsation observed in a sewer of that type would depend entirely upon the length of the sewer arms from shaft A to outlet B, and that the longer these arms were and the greater the consequent inertia of the water contained

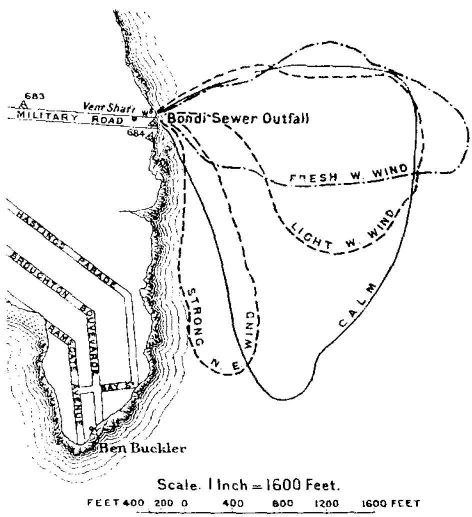
Mr. de Burgh. therein, and also (though this was a trivial matter) the greater the friction to be overcome, the less would the pulsation at shaft A be. Pressure was undoubtedly exerted at the outlet as the result of the ocean waves, but such pressure was of no importance in view of the short period during which it acted and the inertia of the body of water which it had to overcome.

Mr. Halligan. Mr. G. H. HALLIGAN, referring to the Ocean Outfall Sewer, Sydney, remarked that the location and design of the outfall of that sewer presented features which were, in some respects, unique, and it did not appear that the Author had given sufficient credit to the designer for his courage and boldness in recommending the carrying out of so large a scheme when the results must have been, to some extent, problematical. The movements of water below the surface level, under wave action in the open sea, must by the nature of the problem have been largely theoretical, but when the waves impinged upon the shore line, sometimes normally and at other times obliquely, the movements below the surface in repose could only be known by experiment and observation. There were so many disturbing influences in a rocky foreshore, that models could not be made to suit all circumstances, and even if they could have been so made, it was doubtful whether results obtained on so small a scale could be relied upon for more than a rough approximation. The fairly exhaustive experiments which he had carried out under the direction of the late Mr. L. A. B. Wade, had brought out many curious and interesting features, which might well form the nucleus of a separate Paper, but in his own opinion were not conclusive enough to eliminate all doubt as to the effect of carrying out the outfall works in the manner proposed. Mr. Wade, however, had considered that the results were sufficiently convincing, and upon his recommendation the works had been commenced. In view of the fact that the sum involved amounted to nearly half a million pounds, that there would be enormous inconvenience and trouble to many thousands of people should the works prove a failure, not to mention the loss of prestige of the designing engineer, one could not but admire the boldness of the man who had the courage of his convictions under such circumstances. He was not aware that any works comparable to those under discussion as regards the position of the outlet works had been carried out in any part of the world. The outfall in question was on one of the salient points of a coast exposed to very persistent and, at times, violent winds. Waves of from 15 feet to 20 feet in height were not uncommon, and waves of from 30 feet to 40 feet had been mentioned by Mr. T. E. Burrows.[1]

[1] Minutes of Proceedings Inst. C.E., vol. cxl. p. 338.

Dealing with such forces called for much thought and consideration, and some extra caution might well have been excused, even in the most experienced engineer. During the course of the investigations referred to above, it was ascertained that untreated sewage discharged into the ocean, where a permanent current in one direction of from 0·75 knot to 1·5 knot existed, had a very definite limit of flotation distance. The plan (*Fig.* 2) showing the limits of floating putrescible matter from the Bondi sewer outfall, had been largely instrumental in determining the position of the outfall under discussion. That sewer discharged, at times of no rainfall, 11·5 million gallons per day, representing the sewerage from 261,000 persons, and all signs Mr. Halligan.

Fig. 2.



of floating putrescible matter had vanished at half a mile from the outlet in calm weather, and at a much less distance during windy weather. The plan showed that wave action was the determining factor in the disintegration of the sewage, though the consumption by birds and fish must, of course, be considered. The discoloured water extended, during calms, to about double the distance stated, but apart from its objectionable appearance, it did no harm. With a stronger current the objectionable floating matter would extend further, but not in proportion to the strength of the current. He was of the opinion that double the quantity of sewage discharged from the same outlet would not extend much farther into the sea, but would be disintegrated by wave action, or consumed by birds

Mr. Halligan. or fishes before reaching the $\frac{3}{4}$-mile limit. As the nearest beach to the outfall under discussion was more than $\frac{3}{4}$ mile away, it was considered very improbable, if not impossible, for putrescible matter to be deposited upon it, even by onshore winds. The sewer had been then in operation for more than 2 years, and no offensive matter had been deposited on the beach. During the experiments with the model it was found that any obstacles such as small stones and sand placed within the sewer, anywhere between the ventilating shaft and the point of discharge, were invariably drawn out of, instead of being forced up, the sewer, as anticipated by some of the engineers who witnessed the demonstrations. The more violent the wave action became the shorter was the time required to remove the obstacles, and this result was the same when the crest of wave was normal or oblique to the line of sewer. Mainly for this reason he was unable to discover any advantage gained by constructing two outlets pointing in different directions, as recommended by the Committee of three English engineers, to whom the matter had been referred. The amount of the obliquity of the wave-action did not affect the wave-impulse below the surface at the outfall, but it was apparent from the report of the Committee that it had been with the view of obviating the effect of wave-impulse that the second outlet had been recommended.

Mr. Lancaster. Mr. W. D. LANCASTER remarked that Stereophagus pumps had been installed in Auckland instead of the pneumatic ejectors first proposed. He doubted the wisdom of putting down machinery running at from 900 to 1,000 revolutions per minute in deep chambers 32 feet below ground level, even if the high efficiency claimed by the makers of electrical machinery could be obtained in practice. The latter, however, appeared, from the figures given by Mr. H. H. Watkins in the Appendix, to be far from being the case. Fifty stations containing Shone ejectors with capacities varying from 100 to 1,500 gallons per minute had been installed some years ago in Cairo, and, according to official tests made over long periods, an over-all efficiency was obtained, from the indicated power of the steam engine to the pump horse-power in water lifted, of from about 35 to 40 per cent. as had been found to be the case in other installations put down on the Shone pneumatic system. Comparing that with the figures given by Mr. Watkins for station No. 4 where 900 gallons of sewage were raised per minute a height of 32 feet by motors of 29 B.HP., he found that, by allowing an efficiency of 85 per cent. for the engines and dynamos, and 90 per cent. for the electrical transmission, the total over-all efficiency of the installation was as follows :—

HP. in water lifted $= 8\cdot 73$ HP. Mr. Lancaster.

Indicated power of electrical engines $\frac{29 \text{ B.HP.}}{0\cdot 85 \times 0\cdot 90} = 37\cdot 9$ I.HP.

(For driving dynamos.)

Total efficiency therefore was 23·1 per cent.

The over-all efficiency at the four stations was 25·71 per cent. taking the depths at centre lines as the actual lifts. But the probability was that the actual lifts were less and consequently the efficiency would be lower. Ejectors would, therefore, have given higher mechanical efficiency and moreover required far less attendance and supervision, being absolutely reliable for many years; that was a very essential feature for such machinery, ministering as it did so largely to the health and comfort of the inhabitants of the drained areas.

Reference was made in the Paper to the storage arrangements at the pumping stations. Such an objectionable feature was unavoidable with pumps when dealing with sewage, but was unnecessary with ejectors. A Shone ejector for raising 900 gallons of sewage per minute only discharged its contents once a minute and thus acted as a powerful automatic flushing tank, whereas the continuous discharge of the Stereophagus pump produced no such action. The inlet and outlet pipes of the ejector were 12 inches in diameter with large single flap valves, and would freely admit anything solid floating in the sewer. The Stereophagus pump inlet appeared to be only 6 inches in diameter, and although it contained an ingenious cutting apparatus for masticating all solids, that could evidently not be done without considerable expenditure of energy, and there was always the danger that the solid body might be too hard or too tough for the cutting apparatus in the pump, more especially when the pump was just starting from rest. Mr. Lancaster was therefore of opinion that pneumatic ejectors were preferable to electrically-driven pumps for sectional drainage, and that they were more economical, more reliable, and required far less attendance than any other form of pumping machinery yet proposed for that purpose.

Mr. J. Mitchell remarked, with regard to the heaping up of the water on a lee shore during a storm (referred to by Mr. Peake), that, while this was a phenomenon the existence of which could hardly be doubted, its direct measurement seemed to be quite impracticable. Having, during several consecutive years, plotted the observed tide-levels at a port against those predicted, he had been greatly struck by the extraordinary discrepancies between the two curves—discrepancies sometimes several times as great as the 10 inches mentioned by the Author, and as often positive as negative. Having regard Mr. Mitchell.

Mr. Mitchell. to the very great influence of the wind in its intensity, direction and duration, upon the height of the tide, and to the fact that the determining wind was in many cases one operating at a place far removed from the point of observation, little help could be looked for from tidal observations.

Mr. Osborn. Mr. A. F. OSBORN wished to point out that the method of sewage disposal adopted for the southern and western suburbs of Sydney had been so successful that the New South Wales Parliament in 1911 had sanctioned the construction of a similar, though much smaller, scheme for the suburbs of Vaucluse and Watson's Bay. The district comprised an area of about 1 square mile—the northern part of the peninsula on the eastern side of Port Jackson (Sydney Harbour).

The slopes of this peninsula confronting the harbour were undulating and residential, but the side confronting the Pacific Ocean consisted, for the most part, of precipitous cliffs rising to a height of 250 feet above the sea. The sewage was discharged below one of these prominent cliffs at a point 20 feet below high water. The range of spring tides was only about 5 feet 6 inches on that part of the coast. The nearest beach suitable for bathing was nearly 3 miles distant. Almost the whole of the area served by the Vaucluse outfall sewer could be drained by gravitation. One small low level area occurred at Watson's Bay. It was already more or less densely populated. It could be served by pumping into the head of the gravitation sewer. The scheme provided for a much larger population than the present one, as Vaucluse was only partially settled, although served by a tramline and steamers, and supplied with water and electric power. Thirty persons per acre was the number provided for on the area served by gravitation, and twenty per acre on the low-level area. The volumes provided for in the sewers were: for sewage, 75 gallons per head per day, one half flowing off in 6 hours. Rain-water was admitted to the sewers from 200 square feet of roof or yard per head from 2 inches of rain evenly distributed over the 24 hours. On the low-level area the system was entirely separate with a sewage discharge of 50 gallons per head per day, one half of the total to be lifted by the pumps in 6 hours. For a distance of 2,400 feet from the outfall the main sewer was excavated in tunnel through hard sandstone, the invert being from 20 to 270 feet below the surface. Gelignite was used for the blasting. Along that length shafts were sunk at intervals of about 400 feet, up which the excavated material was brought in cages raised by winches which were worked by electric power supplied by the Sydney City Council at 415 volts, at a cost of $1\frac{1}{2}d.$ per unit, and transmitted by overhead cables to each shaft.

Mr. Osborn. Shafts Nos. 3 and 5 were filled in after the tunnel had been excavated, lined and packed. The others were lined with concrete and retained as manholes and ventilators. The lining of the sewer consisted of reinforced-concrete oviform pipes, except the length down-stream of the shaft nearest the outfall. That section, 207 feet long, was lined with concrete. The 20-foot length nearest the outfall was bell-mouthed and reinforced with steel rods. The importance of pilot holes when excavating a submarine outfall was proved when one of the holes, drilled to find the exact position of the face of the cliff, discovered a cave which extended 10 feet landwards. The hole which revealed the cave was only 2 feet long, so that the tunnel had a somewhat narrow escape of being flooded before the sewer was ready for such action. The end of the tunnel was successfully blasted in a similar manner to that described by Mr. Peake. At the bottom of the first shaft, 207 feet from the outfall, a chamber was excavated and lined with concrete to form a wave trap.

As Vaucluse was then only sparsely built over and the flow of the sewage would consequently be small for some years to come, a flushing chamber was also constructed at the first shaft, by which 13,000 gallons of water could be released, by opening a penstock, under a maximum pressure of 50 feet head of water.

Regarding Mr. Bush's Paper, he did not notice any mention of the range of tide at the outfall. He wished to ask Mr. Bush to give that information as an addition to his very interesting Paper.

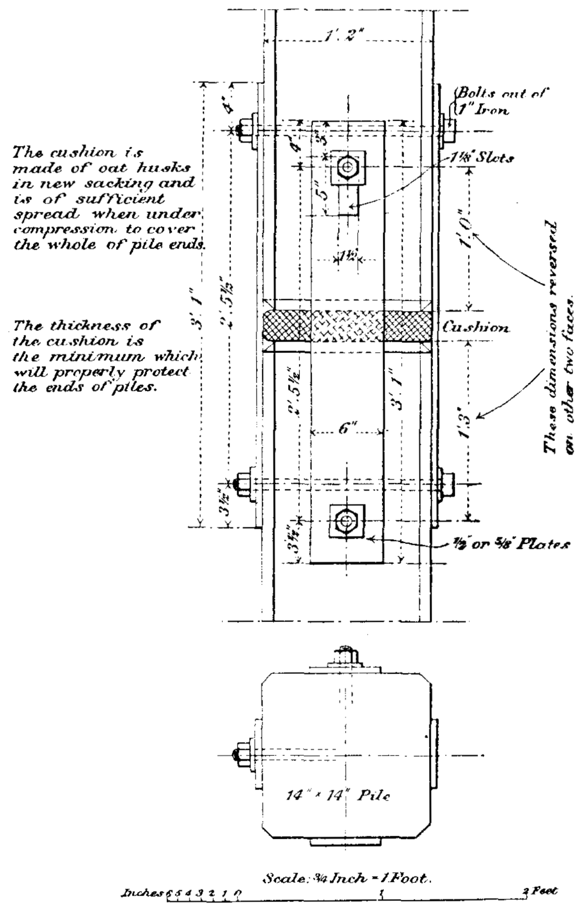
Mr. Bush. Mr. Bush, replying to the Discussion and Correspondence, desired to thank the members for their references to his Paper. He regretted the absence of Mr. G. Midgley Taylor, for it was partially in fulfilment of a promise made to him when he visited Auckland, that the Paper had been written, and he desired to acknowledge the valuable way in which Mr. G. M. C. Taylor had supplemented the information in the Paper, especially in regard to the actual point of outfall, and for the emphasis placed on the fact of the completion of the work below the estimate.

In reply to Mr. Martin, he would point out that the only length of completely reinforced sewer was that across Hobson Bay, shown in the plate over the legend "on piles," in Figs. 3, Plate 5. This sewer was designed to act as a box girder carrying the sewer and its contents, when full, a total load of 54 tons between the piers spaced at 20-foot centres, and the reinforcement was placed where it would be most effective for that purpose and for resisting the bursting pressure of the liquid inside, and wave action outside the sewer, consistent with adequate protection of the steel from the chemical action of sewage on the inner face and salt water on the outer face.

Mr Bush. Dealing with the point raised by Messrs. Burrows and Cook as to the inclusion of storm-water in the sewer, reference to the Paper would show that the existing sewers in the City of Auckland had been designed for and were carrying sewage and storm-water, and the construction of an entirely separate system would have involved not less than 50 miles of sewer on the separate system, and the re-drainage of 8,000 or 10,000 separate premises in the city alone as then existing, independent of sewers and houses in the suburban districts. That would have far exceeded the extra cost of providing a sewer with a capacity of 210 gallons per head per day, as against 100 gallons per head, which is the proper provision for a separate sewer in a colonial city situated as Auckland is. The areas to be pumped were all to be sewered on the separate system, rain-water being rigidly excluded, but an actual census of those areas showed that in the more developed portions there were already as many as 80 persons per acre employed during the day-time in the various offices, shops, warehouses, hotels, etc., while buildings as high as 100 feet were projected, some of which have since been erected, and the consumption of water per head per day was 55 gallons. Under these circumstances the provision of 100 gallons per head and 100 persons per acre was, in the Author's opinion, fully justified. In regard to the possibility of a nuisance being caused by the discharge of crude sewage from overflows, sewage that was diluted with five times its bulk of storm-water could scarcely be termed crude sewage, and, as stated in the Paper, every overflow was fitted with screens of $\frac{1}{2}$-inch mesh. No such nuisance had been created, nor was its creation deemed to be a remote possibility. The difficulty anticipated by Mr. Burrows as likely to be experienced at the pumping stations in times of storm, would not be likely to occur, for the reason already given, as to the exclusion of storm-water from sewers whose contents required to be pumped. There had been remarkably few complaints as to odours from the outfall. Shortly after the formal opening of the work, but before the Author had connected any sewage therewith, a complaint was received from a resident in the vicinity. Subsequent to this, there had been two or three complaints from the residents of a suburb about 2 miles to the east who travelled to and from the city by ferry-steamer, which called at the Orakei wharf, 1,000 feet south-west of the outfall, and passed almost immediately over the outfall. There, during the discharge of sewage, there was naturally a slight odour, for sewage was under any circumstances an offensive substance, and the problem of its disposal was always to so carry it out as to cause the least possible offence or nuisance. This, the Author believed, had been accomplished in the case of Auckland. Mr. Bush.

With reference to the reinforced-concrete piles, the Author hoped *Fig. 3* would make the method adopted quite clear. A second pile was imposed on the top of the first, but with a

Fig. 3.



Main Sewer. Section No. 2. Details showing Method of Splicing Poles.

canvas bag filled with oat husks placed in between the two to absorb the shock of driving, which was effected by means of an ordinary drop ram of 2 tons weight, falling through a height of 8 or 10 feet upon a wooden dolly 3 to 4 feet in length placed on the top of the pile, which was also cushioned with

Mr. Bush. a bag of oat husks. The fish-plates served to keep the top pile in alignment, but the actual load was transmitted through the head of the lower pile. Extensive corrosion in light mud is not considered as likely to occur. The amount of abrasion on test piles driven with the oat-husk bag as a cushion was found to be insignificant, but with other materials which were tried it was so marked as to render their use out of the question. The Author had no precedents to guide him, and had to take his courage in both hands and do what he did, or otherwise either scrap the piles already made and make longer ones, involving the erection of a new pile-driver and pontoon, or adopt the slow and laborious process of building up lengths of 6 to 8 feet at a time, letting the same mature, then drive the pile down and repeat the process until the extra 30 to 40 feet had been driven.

In reply to Mr. Lancaster, the figure of 32 feet was that of the centre-line of pumps below the ground surface, the actual height from the centre-line of the pumps to the discharge point of the rising main being 45 feet, while the brake horse-power of motors installed must not be taken as the minimum necessary to deal with the maximum load. The Author was familiar with the Shone and other types of ejector, and had two under his control, operated by automatic electrically-controlled and -driven air-compressors, but he would point out that the object of the Paper was not to discuss any particular method of raising sewage, the Appendix being added at his request to supplement the information as to the scheme generally outlined in his Paper.

In answer to Mr. Osborn's question, the maximum difference between the highest and lowest recorded tides was 13 feet 5 inches, the ordinary difference being approximately 8 feet.

Mr. Peake. Mr. PEAKE, in reply to the Discussion and Correspondence on his Paper, observed that reference had been made to the effect of the inertia of the column of sewage in the outlet-pipes in neutralizing the inward pressure caused by waves striking the cliff at the outlets. In the period between his first and final design for the sewer outfall, the late Mr. L. A. B. Wade must have been aware of the effect of the inertia referred to, as Mr. J. A. Pollock, Professor of Physics at the Sydney University, in giving evidence as to the proposal before the Parliamentary Standing Committee of N.S.W. had stated :—" One must bear in mind that that pressure (caused by a wave at the outlet) exists for an extremely short time and it is very questionable whether that pressure exercised for such a short duration would be sufficient to set that great mass of water (in sewer pipes) in motion, even if should it be continued for a considerable time, it might move the water back in the sewer." Mr. Wade had Mr. Peake. also available during the same period the Presidential address of the late Sir William Matthews to The Institution in 1907, in which Sir William had stated "the depth to which wave-action extends is much greater than was formerly believed to be the case," and then quoted instances where wave-action had been shown to have extended to depths of 20 to 30 fathoms. Mr. Wade was therefore aware from this and other information, that one of the premises upon which the design was prepared was in error, namely, that wave-action is practically imperceptible at a depth below sea-level equal to the height of the wave; and it was with his concurrence that the soffits of the discharge pipes were lowered from 20 feet below spring high-water, as recommended by the English Advisory Committee, to 26 feet below that datum, in order to provide for wave-action extending to a greater depth than he had at first allowed for.

The questions whether, in lowering the openings to that depth, they had been taken to a level where the hydrostatic pressure is little affected by the passing wave, or whether the varying pressures upon the outlets were caused by hydrostatic pressures or by forward movement of the waves due to the rise in the bed of the ocean, or partly by one cause and partly by the other, were problems still unsolved. It was noticed shortly after the break through into the ocean, that the pulsation at the shaft-chamber was less at high-water than at low-water, but this gave no help to the solution of the above questions, as with the greater depth, both the wave-action and the variation in hydrostatic pressure would be reduced. Some attempt was made to compare the vertical movements of each wave at the shaft sunk on the reef 30 feet back from the outlet of the southern conduit (Shaft "C" in Mr. de Burgh's comments) and at the Cliff Shaft. Owing, however, to the difficulty of measuring with any reasonable degree of accuracy the range in shaft "C," the investigation had to be abandoned. As stated in the Paper the approximate measurements of the respective rises and falls in these shafts bore a ratio of about 12 to 1.

It had been remarked by Mr. Cook that the height to which the water rose (in the shaft) was about half-way between the top of the wave outside and the average sea-line at the time. This would appear to convey an idea that the height of the wave in the Cliff Shaft was half the height of the ocean wave causing it, which was not the case. Notes taken of the movement under similar conditions of weather at high-water and low-water had unfortunately been mislaid. The movement was so much less at the former level, that

Mr. Peake. the Author had designed the outlets for the Northern Suburbs Outfall Sewer, now under construction, with the soffits 30 feet below high-water of spring tides. This sewer was designed to serve North Sydney and its suburbs, extending from Manly to Parramatta, a distance of 22 miles, and drained an area of 177 square miles. The sewer was of sufficient capacity to serve a population of 1,100,000, and, at the outlet end, its internal dimensions were 13 feet 9 inches by 8 feet 9 inches. The design of its outlet was similar to that at Long Bay, the site selected being even more suitable for that form of outlet. The conduits into the ocean bifurcated at the shaft-chamber at an angle of 60 degrees, so that there was little probability of the maximum pressures upon the outlets synchronizing. The shortest conduit was 432 feet long, and from the experience gained at Long Bay it was anticipated that the pulsation at the Cliff Shaft would be negligible.

In conclusion, the Author wished to thank all those who had contributed to the discussion and correspondence upon the Paper, and trusted he had not overlooked any comments which called for reply.