Discussion.

The PRESIDENT, in proposing a vote of thanks to the Author for his Paper, said he was sure the members would congratulate Mr. Galbraith and the Author on their successful solution of a very difficult problem. The experience which other engineers had had of the nature of the foundations at Southampton must certainly have caused them to face with some anxiety the design and execution of the works described in the Paper. It would be within the memory of many members that serious failures occurred in the earlier work at Southampton, and it was therefore very gratifying to note that the present undertaking had achieved such satisfactory results. There was one point in the Paper on which he would like to have further information; he would like to see some comparison made between the design in the former case, when failure occurred, and that which had been so successful in the present instance. Such a comparison, if the Author could give the particulars, would enable very useful deductions to be made, and would add materially to the instructiveness of the Paper. It would also be useful to hear something about the pressures on the bases of the walls, and the sectional areas of the walls. The Paper dealt chiefly with the difficulties of construction, which seemed to have been grappled with very successfully. The President

Mr. T. SIMS thought the work must have been a source of great anxiety to the Author on account of the serious difficulties he had to contend with in connection with the foundations. Although he was responsible for some large engineering work not many miles from Southampton, he had not had the pleasure of going over the works described by the Author, and therefore the few remarks he proposed to make must be of the nature of questions rather than criticisms. Turning to details, the first question that occurred to him was, what had determined the level at which the excavation ceased and dredging was resorted to in the wet dock? It was stated that the excavation was carried down to about 30 feet below the coping-level, and part of it some few feet deeper. By that time the walls of the dock had reached a very advanced stage, so that the bank which had laid dry the area of the wet dock was able to be breached, dredgers were let in, and the rest of the deepening was carried out in the wet by dredgers. He realized that the original Mr. Sims.

Mr. Sims. level of the wet dock was not sufficient to let dredgers in. It was at about mean-tide level, and therefore it was necessary to excavate some feet in the dry, in order to give flotation to the dredgers. Assuming that 5 or 6 feet were allowed from the coping down to high-water level, and 13 feet for the range of tide, making 19 feet in all, and allowing for the draught of the dredging vessels, which might be anything between 12 and 16 feet, somewhere about the level adopted for relinquishing excavation and taking to dredging would be obtained, and it might be that that consideration had fixed approximately the level at which dredging began. On the other hand, it might have been a question of the cheapest way to continue the deepening. All the material had to be taken to sea, whether it came from the excavation or from the dredging, and it seemed rather an open question which would be the cheaper method of continuing the work—whether, in fact, it might not have been cheaper to do it by dredging. At all events, that was the stage at which dredging was resorted to. Again, as the walls of the wet dock had been carried up mainly to coping-level, it might have been felt that it was impossible to go very much deeper without giving some water support to the face of the walls, and that might have been the reason for letting the water in at the stage at which the bank was breached. It would be interesting, however, to know what considerations had led to the change from excavating to dredging. He had no doubt the question of the stability of the walls had been continually in the Author's mind throughout the whole of the work. Most engineers who had had much to do with retaining-walls would agree that the real difficulty was not so much the question of the stability of the wall—its resistance to overturning—as the more uncertain question of the supporting power of the earth upon which the wall was built, especially at the toe of the wall. In addition, there was the uncertain element of the danger of the wall sliding. In that connection it was impossible to trust very much to the formulas in text-books; it was necessary to be guided by local circumstances and experience. Both those conditions appeared to have been very fully provided for by the Author, who had adopted a splendid toe to his walls to distribute the pressure there, while in some cases it was reinforced, so that every precaution had been taken in regard to pressure at that point. He also thought the Author must have felt fairly comfortable, as far as the question of sliding was concerned, with a slope of 1 in 8 from the front to the back of the wall. The only criticism that occurred to him was that it might have been advisable to step the bottom of the wall as well as slope it, so as to give the

Mr. Sims.

wall a better grip on the earth upon which it stood. With regard to portion C, which had been constructed in the heart of the bank, he felt he would be on dangerous ground if he attempted to criticize the method of construction, because evidently the difficulties had been very great; but he thought it would occur to some that the method was very elaborate—not only the system of curtain-walls and arches, but also the reinforced structure at the back of the wall, to relieve the wall from pressure. That plan was admittedly costly and slow, and it occurred to him to ask whether it would not have been possible to build the wall by making the foundations in box dams, with spaces at intervals, driving sheet-piles between the concrete masses—very much as had been done in connection with the caisson foundation trouble in another section of the work—and finally surmounting that foundation with a wall of ordinary section. From the general description of the work he gathered that in some cases the dock walls had been carried to their full height for certain lengths, and that further trench-work had then been opened out at the scar end of the wall, another section or length thus being added. In view of the somewhat treacherous nature of the foundations, he wished to ask the Author whether any settlement-cracks had been observed at the junction of the completed section and the one added more recently. It looked as though such cracks might have been feared under those conditions. He did not notice in the Paper any mention of power-capstans for handling the ships. Perhaps, however, the large liners which used the dock were handled entirely by means of their own capstans? The only other point that occurred to him was that very few details were given of the cost of the work. Perhaps they had been omitted advisedly, but if the Author were at liberty to give a little further information under that head, it would be interesting.

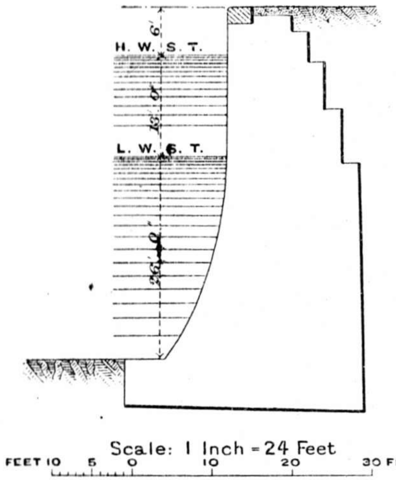
The Author.

The AUTHOR stated that, in accordance with the President's suggestion, he had placed on the wall a section of the wall of the Empress dock, which was built about 20 years ago, and gave considerable trouble.[1] The dock was built in the dry, and before the water could be let in, two out of the four walls which surrounded the dock overturned. They did not overturn forwards about the toe, but backwards about the heel. Certain calculations of the stability of this wall were given in the Appendix to the Paper, and the constants used in that Appendix were there applied to similar calculations made for the wall for the White Star dock, and it was shown that although apparently the Empress wall

[1] Minutes of Proceedings Inst. C.E., vol. cxxi, p. 127.

The Author. was a massive one, the later wall was more stable. That was attributable, for the most part, to the fact that, whereas the base of the first wall was practically level, the base of the later one was sloped from front to back as much as practicable.

Fig. 14.



Mr. Palmer. Mr. Frederick Palmer thought the Author was to be warmly congratulated on having solved the problem how to build stable dock-walls at Southampton. With hardly an exception, in previous walls there had been some movement, and with that experience before him the Author must have had a very anxious time, not only in designing but particularly in constructing his dock-walls and awaiting the results. That the results had proved the sufficiency of the design was a tribute to the Author's skill and to the courage of his opinions. The calculations given in Appendix I showed that the difference between stability and instability lay within comparatively narrow limits: he mentioned that because the figures seemed to prove that the design adopted was in no way extravagant. Some years ago there was considerable discussion in the Institution on the question of the decomposition of cement concrete exposed to the influence of sea-water, and it would be useful to know if the older walls at Southampton showed any deterioration from that cause. It was held by many experienced men that if the mass of the work could be protected by a waterproof skin, no damage would arise, and it had become a somewhat common practice, where a comparatively weak mixture was specified—such as the 8-to-1 concrete in the case under review—to require a much richer outer surface. That point was doubtless considered fully when the new walls at Southampton were designed, and it would be instructive to learn whether the Author's experience of unprotected concrete there had induced him to dispense with the outer skin of higher quality. A question had already been asked as to the determining factor in fixing the depth of 30 feet below quay-level for excavation by steam-navvies, and perhaps in replying the Author would state whether, when fixing the depth, he also considered the possibilities of sinking monoliths, as an alternative to building the walls in timbered trenches. Such a method would have avoided the risks necessarily involved in the employment of timbered trenches, and would probably have cost no more. That it could have been used successfully seemed fairly well established by the ease with which the reinforced-concrete caissons described in the Paper were sunk, notwithstanding the fact that the total loading, even when the resistance due to skin-friction was entirely ignored, was less than 2 tons per square foot of bearing-area. A heavier loading of the caissons would certainly have facilitated the process of sinking. A few remarks on the general lay-out of the Southampton docks might not be out of place, although bearing only indirectly on the questions raised by the Paper. A glance at the plan (Fig. 1, Plate 1) could not fail to give the idea that a valuable area of 240 acres—all the more valuable, perhaps, because no expansion seemed possible—had been frittered away. Probably reasons of a financial nature had prevented the construction of a large dock at the time when the Empress dock was under consideration, but, with the wisdom which was so easily attained after the event, one could see that if, instead of this peculiarly-shaped dock, there had been built a dock, say, 500 feet wide, opening from the river Test, and with the quay-walls more or less parallel to the east and west walls of the Empress dock, accommodation would have been afforded which, while providing for the needs of that time, would have been capable of extension inwards from time to time to meet the demands for more and longer berths. Including the site of the old inner dock, the east quay of such a dock would have given straight berthage of more than 4,000 lineal feet, and the opposite quay more than 3,000 feet. The value of long straight quays, or of quays susceptible of development in straight lines, would be apparent from a brief study of the enormous growth in the size of steamers. The record of the White Star line was a striking example of that increase. In 1871 the old "Oceanic," 420 feet long, was launched. In 1880 the largest vessel in that fleet was the "Britannic," 455 feet long. In 1890 the "Teutonic" came first, with a length of 565 feet. In 1900 a new "Oceanic," more than 700 feet long over all, came into existence, while at the present time there was the "Olympic," launched in 1911, with an over-all length of 882 feet. A new "Britannic" was under construction, and, as her tonnage would exceed that of the "Olympic" by 4,000 tons, her over-all length would be little, if at all, short of 900 feet. In other fleets the 900-feet mark had already been Mr. Palmer.

Mr. Palmer. passed, for the "Aquitania" was 902 feet, and the "Imperator" nearly 920 feet over all, so that the Empress dock was fast falling into disuse, whereas a dock on the lines he had suggested would have accommodated the old "Britannic," and would have been capable of extension to berth the new. The quays of the White Star dock, excluding the jetty at the river end, were about 1,600 feet long, and were it not for the fact that practically every inch of available space had been covered, one would wonder whether the Author in his design had erred on the side of making the berths much too short for two present-day vessels, or had been bold enough to anticipate the coming of the 1,500-foot vessel. Unfortunately, the adjoining Trafalgar dry dock, which very soon after its completion had to be lengthened and widened to take vessels of the "Olympic" class, was now barely large enough for the new "Britannic," and would have to be extended again when the next advance in the size of vessels took place. Then there was the commercial aspect. The White Star dock, with its equipment and dredged channel, must have cost about £750,000. The cost of the dry dock, with the additional expenditure incurred recently, probably stood at well over £350,000, so that for accommodation which in the near future would suffice for only two berths, the interest-charge at 4 per cent. would alone amount to £44,000 per annum, excluding working-expenses and dredging. Provision for those leviathans must, of course, be made, and in incurring that heavy liability the London and South Western Railway Company had shown that the passenger-traffic between England and the United States should not be diverted from Southampton for want of adequate facilities.

Mr. Moncrieff. Mr. J. M. MONCRIEFF wished, in the first place, to join in the approval and congratulations which had been expressed with regard to this excellent Paper. One feature in it in particular was admirable, namely, the order in which the information had been put forward, which was of great assistance to those who wished to discuss the subject. He had no personal desire to be a critic of the various points raised in the Paper; but the very purpose of the meetings of The Institution was criticism and discussion for the benefit of the profession generally, and he hoped it would be understood that his criticisms were offered in that spirit. The Author had done well to recall the character of the ground at Southampton in which dock-works had to be carried out; and his description of the strata in which the walls had been built showed that nothing less than the best engineering and contracting talent could be expected to deal with them successfully.

Mr. Moncrieff.

With regard to the general features of the dock-walls, the Author was to be congratulated upon his design, in that he had provided such liberal support to the wall in the matter of the toe. Mr. Moncrieff had been much struck, when reading descriptions of other dock-works, by a curious neglect of the great benefit to be derived from a good toe in front of the main wall. He could not understand, however, why the Author should reinforce the toe with "old" rails. He presumed that meant discarded rails which had had their day in railway service, and might therefore be assumed to be considerably less reliable than they were originally. It seemed to him that the toe of the White Star dock wall was worthy of being reinforced with new material. In any case, the cost of the reinforcement could not have been appreciable in relation to the importance of the safety of the wall. He was in the habit of using rails as reinforcement to concrete in dock-work, and in all important cases he had always used new, slightly defective rails, supplied under a clause in his specification which required that no defect should be of such a nature as to diminish the efficiency of the rail as a tension member. He believed the Author was right in his view as to the desirability of having a good slope on the base of the wall. That slope was especially effective in the case of walls built nominally "in the dry," for the simple practical reason that the surface of the foundation was much more easily drained and kept free from water, which ran to the lowest point of the excavation at the extreme back, where the intensity of the pressure would be least when the wall was fully backed and was performing its duty of holding up the earth behind. He noticed that the Author drew attention to the fact that the offsets at the back of the wall were made wide, in order to ensure that the weight of the earth backing should bear fully upon them. He wondered if that precaution had been taken because of a remark made by the late Sir Benjamin Baker to the effect that it was a mistake to count upon the assistance of the earth resting upon offsets, and that he had found cases in which a distinct space existed between the earth backing and the top of the offsets. Mr. Moncrieff had never been able to see the force of that contention, because, even if such a space did exist, it seemed to him that something must have supported the earth. Very little consideration would show that that supporting agent was actually the friction between the back of the wall and the earth; and, that being so, the wall must have taken its share of the weight of the backing immediately over the offsets. The Author's description of the sealing of the enclosed bank was of great practical interest, and it recalled an

Mr. Moncrieff. experience of Mr. Moncrieff's own. A short time ago he was constructing a dry dock, and borings showed that he would have to deal with clay overlying a bed of sand and gravel. The greater portion of the bottom of the dock would be, and was, in a clay bed, but near the entrance the clay bed was practically cut through and the sand was met with. On the river foreshore the sand and gravel were overlain by a blanket of mud, and the coffer-dam had to be constructed on that foreshore. Accordingly he designed the bottom of the dock as an arch capable of resisting the full hydrostatic pressure of the tidal water outside. When the dock was being constructed a large sump was provided to drain the works inside the dam, but the pumps in that sump really had little to do, as the quantity of water to be dealt with during the construction of the dock was very small. Of course he received, as dock-engineers usually did, advice and criticism from irresponsible people, who told him that it was not necessary to construct the dock-bottom to resist water-pressure, as it was evident from the state of the excavations that there would be no such pressure. He need hardly say that those views had no influence upon his procedure, as the critics had lost sight not only of the necessity of providing for the conditions existing while the excavations were drained by a large sump, but also of the fact that when the coffer-dam was withdrawn the blanket of mud overlying the gravel would be pierced; and, moreover, the dredging-operations to give the necessary depth of water to the dock-entrance would remove a large part of this blanket of mud, when the river-water would be free to percolate through the gravel and pass under the dock-bottom. That actually occurred, and on the removal of the coffer-dam and opening of the dock it became apparent that water from the river had really found its way under the dock-bottom: it must have been under very considerable pressure, as it penetrated through the joints in the arch of the dock-bottom and also rose partly up the dock-walls—although, he ought to say, in very small quantity. He mentioned that incident in order to emphasize the necessity of providing not only for what might be found in the excavations but also for what might happen to the structure when the temporary works were removed on its completion. He was glad to see that the Author showed in the Paper the details of the timbering of the trenches, which was a matter of great interest both to the engineer and to the contractor. He had met many engineers who had but a slight acquaintance with the timbering of the trenches in the works for which they were responsible, and that ignorance should not be possible. He knew well from his own experience, however, how easy it was to go over works under construction and look at them without actually *seeing* them. It was very desirable that engineers should go down into large timber trenches whenever they had the opportunity, and should note the sizes and disposition of the timber and the character of the ground for which such timbering had been provided. With regard to the concrete, it was surprising to find such wide divergence of opinion among dock-engineers as to the proper proportions of concrete for almost precisely similar work. The perusal of a number of dock papers one after another would make that divergence very evident. He noticed that the sand and gravel for the mass and block work were used without screening and regrading, and that the proportions of the concrete for the wall in portion A were 8 parts of unscreened ballast to 1 part of cement. He would have thought that with so weak a mixture it would be all the more desirable to make sure that the cement was given a fair chance to make substantial mortar—which after all was the really important part of concrete in sea-work. Referring to *Fig. 6*, showing the volumetric analysis of two samples of the gravel ballast, and accepting the Author's classification of everything passing a $\frac{1}{4}$-inch mesh as being sand, then—without the 10 per cent. of additional sand—the percentage of sand appeared to have ranged from 22·3 per cent. to 46·9 per cent., and the addition of the 10 per cent. only corrected those figures to 28·6 per cent. and 52·2 per cent. It would seem, therefore, that the mortar in the Author's concrete varied very much in strength; in fact, some parts of it would be little more than half the strength of other parts, and, roughly speaking, the concrete would appear to have varied between 1:2:8 and 1:4:8, or perhaps 1:4:7. That, again, was entirely on the assumption that the two samples were completely representative of the worst extremes, and it would be interesting if the Author would say whether he had given the worst samples or whether there might perhaps have been even greater variations. He agreed with the Author that the great advantage of regrading was that the concrete was more uniform in quality and more watertight, but he could not agree with the suggestion that gravity walls did not need to be specially watertight. He very much wished that could be taken as correct, but he did not think the destructive action of sea-water on porous concrete, of which there had been a considerable number of instances, should be lost sight of. He would not like to say that he would never be a party to the use of unscreened ballast for the walls of wet docks, but he certainly would not wish to feel that it would be possible to have such a wide variation in the mortar. In the case of dry docks, he thought screening and regrading were absolutely essential. Instances of the gradual deterioration of

Mr. Moncrieff.

Mr. Moncrieff. concrete had been under his observation for a number of years, and he might perhaps be allowed to describe briefly one case, that of a small dry-dock entrance built of Portland-cement concrete rather more than 20 years ago. A few years ago he was asked to advise as to the walls in the immediate neighbourhood of the gate-anchorages. One wall had literally grown $3\frac{1}{2}$ inches vertically in 19 years, as was shown by the fact that the anchorage-ring around the heel-post head had been lifted from its seat by that amount, and was gradually losing its hold of the heel-post. He at once had the anchorage-bars cut free from concrete and the anchor-ring dollied down into place. In the present year he had had to repeat the operation, as the ring had risen again by about $2\frac{3}{4}$ inches, making a total vertical rise of about 6 inches in about 22 or 23 years. The other entrance-wall had undergone a similar process of growth, although to a less extent, and in that case also the anchorage-ring had had to be set down into place in order te preserve its hold upon the gate. In describing the difficulties in trench-excavation, the Author remarked that when the bottom of the trench was in clay there was a distinct tendency for it to rise. That tendency did not appear to have occurred in the sandy bottoms. If that was so, and assuming Rankine's theory of earth-pressure to be correct, then either the clay was lighter than the sand, or it must have had a flatter angle of repose, and any foundations in such clay ought, according to that theory, to be at a greater depth than those in the sand. Was that, however, true, and did Rankine's theory really apply? The Author's description of the difficulties in the trenches and of the various expedients adopted to overcome those difficulties was very valuable and interesting. So, also, was the description of the sinking of the concrete caissons; and Mr. Moncrieff would like to know whether the divers, when using the high-pressure jets to loosen the sand in the pockets, actually worked with the kentledge of rails on end standing overhead when there was a rush of sand into the caisson. If that was the case, he thought the divers must have been very brave and probably also very frightened. The $3\frac{1}{2}$ cwt. per square foot given by the Author as the skin-friction on the surface of the caissons might be compared, as a matter of interest, with the following results of a large number of records which Mr. Moncrieff took more than 20 years ago, when sinking a number of wrought-iron cylinders under air-pressure through a great depth of fine sand mixed with silt and clay, and finishing in clay and boulders. The maximum value of the skin-friction occurred not at the greatest depths but at the shallow depths. The deepest cylinder was sunk to 71 feet 6 inches below high water, and was 62 feet into the ground. At a depth of 20 feet into the ground the average friction was 1·46 cwt. per square foot, while at a depth of 62 feet into the ground the average friction was only 1·08 cwt. per square foot. There again the results did not confirm the ordinary theory of earth-pressure, although the material was about as good as could have been chosen to test the matter. According to theory, the average pressure on the skin of the cylinder, and therefore the frictional resistance, at 62 feet, should have been very much higher than it was at 20 feet. He was not losing sight of the disturbing influence of the escaping air past the cutting edge of the cylinder. The method adopted for the foundation-trench for the wall of portion B at Southampton was very interesting and, he thought, courageous. Would the Author repeat wall B with the same methods, even though block work were adopted for the hearting in place of mass concrete? He confessed that he was unable to follow entirely the theory of the special design of the wall in portion C and its piled platform behind. Did the piles really relieve the wall of the earth above the platform without causing the earth underneath to press more hardly on the back of the wall? It seemed to him that in the first instance, without the piles and platform, the earth above the level of that platform would rest upon the earth beneath it; and, in the second case, with the piles and platform, the superincumbent earth simply rested upon a mixture of piles and earth, which mixture of piles and earth really had no power of resisting lateral pressure. All the piles shown in the section were, practically speaking, above the line of slope of repose (2-to-1) assumed in the calculations in Appendix I. The Author did not say whether those piles were driven before the lower trench was formed or after the wall was completed. The stability-calculations in the Appendix were very interesting as far as they went, but he hoped the Author would give them in much fuller detail, or rather give a diagram setting forth the directions and amounts of the calculated overturning forces. He noticed particularly that there was no mention of any friction on the back of the wall, although the friction on the base was, quite properly, taken account of. Were the weight of the earth and the slope of repose only assumptions, or had they been the subject of measurement? If they had been assumed, why not assume the entire section of wall, as urged by the late Sir Benjamin Baker? He could not see how the fact of the Author's wall standing could prove the accuracy of his assumptions in regard to weight of earth and slope of repose. The fact of the wall standing, however, did

Mr. Moncrieff.

Mr. Moncrieff. show that he had been successful in dealing with bad ground, and of course that was what was really wanted. Referring to the section of the wall of the Empress dock, which he understood had failed, or partially failed, he presumed the calculations in Appendix I with regard to this wall had been worked out in precisely the same way as the calculations were subsequently worked out for the wall of the White Star dock. Both sets of calculations, presumably, were directed towards the same result, namely, determination of the maximum pressure on the foundations at the toe of each wall. It would be of great value to have figures for the pressure under the toe of the Empress dock wall to compare with those in the Appendix for the toe of the White Star dock wall, and he suggested that the Author should give a complete stability-diagram showing all the forces considered for the Empress dock wall also. A knowledge of the mode of failure of this Empress wall was of the greatest importance, and it would be extremely valuable to dock-engineers to know whether this wall actually failed in consequence of the intensity of the pressure under its toe or from some other cause. It was only by full knowledge and understanding of the calculations employed, of the materials met with in the foundation and in the backing, and of the actual mode of failure, that any judgment could be arrived at which would be correct and serviceable to those in the profession who were responsible for the design and execution of similar works. Further, it was by analysis of such instances as had been given by the Author that engineers might be enabled to build up something of a reliable nature as a basis for a true theory of earth-pressure, concerning which there was so much that was obscure and beyond present knowledge.

Sir John Griffith. Sir JOHN P. GRIFFITH thought the Paper was a very fitting introduction to the Session, following so closely on the interesting Address given by the President. To those who, like the President and himself, had been associated with dock-work all their lives, points naturally arose in considering the plans which were rather outside mere questions of engineering. He confessed he was disappointed at not finding in the Paper something more about the cost of the work than the cost per lineal foot of three sections of the wall. Many years ago, Mr. Dalmann, of Hamburg, one of the most eminent North German engineers of his day, who visited the Port of Dublin to see some of the large block-laying work then in progress, invited him to visit Hamburg, and stated that Hamburg dealt with a larger tonnage of shipping per lineal foot of quay than did any English port. That was rather startling to him as a British engineer, and he took it very much to heart. He visited

Hamburg on several occasions and learned much there, but Mr. Dalmann's unit of tonnage dealt with per lineal foot of quay, associated with income per lineal foot of quay and cost per lineal foot of quay, fixed itself in his mind as an important unit in discussing economic problems connected with ports. The result had been that in his own work he had endeavoured for many years to impress on the Board he served that it was of the utmost importance to deal with the maximum tonnage per lineal foot of quay. In the early days of his connection with the Port of Dublin the interests of the port were very much in the hands of merchants and not shipowners. The merchants were desirous of utilizing the ships as stores as long as possible, and they endeavoured to deliver their cargoes direct from the ship to the consumers. The result was that ships lay alongside the quays to the last day of their charters. The quays of Dublin were consequently not remunerative, and the question arose whether it was not important for the Port as an authority to see that the quays were used to the greatest advantage and the ships discharged as rapidly as possible, instead of wasting money on extending the quays. He had made those remarks simply to impress on the members the importance of the unit he had referred to. In using that unit it was necessary to embrace in it not merely the cost of the bare wall, but also that of the dock, the equipment, and the channel, which, of course, gave a much higher figure. Instead of the Author's most costly quay-wall working out at £117 per lineal foot, its cost, including those items, would probably be about £170 to £200 per lineal foot, and it was necessary to look for a return on that figure. It was in that connection that the words in the President's Address were of so much importance. It was important to know the cost of the dock described in the Paper. It belonged to the category of docks constructed by railway-companies, with which the President had dealt in his Address, and which competed with ports controlled by trusts who had to make their harbours pay. It might be said that his remarks did not refer to engineering matters; but really they bore on them. In certain lectures that had been delivered recently at the Institution the importance of financial considerations to the engineer had been shown, and he had only mentioned the figures he had quoted for the purpose of impressing on the members how important it was to endeavour to construct ports economically. He had hoped to be able to deduce from the Paper figures which would have shown whether the railway port at Southampton was worked on economical lines, or whether it

Sir John Griffith.

Sir John Griffith. was worked—as the President had put it in his Address—in the interests of the railway, charges which should fall on the shipping being defrayed at the expense of the railway in general; but the Paper did not give that information, and if it were possible for the Author to add it, or to present another Paper embodying those very interesting particulars, it would be of great value to The Institution. The three classes of wall mentioned in the Paper interested him greatly, because to a certain extent they went over ground which he had traversed on an extended scale in the Port of Dublin. Most of the work in Dublin had been done departmentally, and he had therefore been face to face with many problems which, as a general rule, fell to the lot of contractors. He had been much interested in the drawing the Author gave of his trench-timbering, Fig. 5, Plate 1, because he knew well the dangers of that trench—dangers that the Author had referred to perhaps rather too lightly. He would have liked the Figure to show how the timbering had been braced diagonally. Diagonal bracing—not only horizontal but vertical—was one of the most important points in those deep trenches. It was greatly disliked by anybody who had to carry out such work, because it was troublesome, and because it interfered with the lifting and lowering of material. Most of the trenches excavated in Dublin had been close to an open thoroughfare, the quays being not much more than 80 to 100 feet in width from the house-front to the face of the wall. The quay-walls had to be built from a foundation about 40 feet below the quay-coping, the traffic in the street and the houses beyond having to be maintained. The engineers had often spent very anxious periods while the work was in progress, and the necessity of taking out the sections in short lengths, to which the Author had referred, had been brought home to them vividly. With regard to the wall (Fig. 8, Plate 2) with block work at the back and at the front, in which so much diving work had to be carried out, all engineers acquainted with that class of work knew that it was extremely costly. His predecessor, the late Dr. Bindon B. Stoney, M. Inst. C.E., was, as many of the members knew, the author of a system of block-laying that had not been equalled in any other part of the world. The blocks contained 5,000 cubic feet of masonry each, some of them being 31 feet high. The full section of the wall from the foundation up to low-water level, or a couple of feet above low-water level, was formed by such blocks, and the superstructure was built by tidal work. If they had had to build a wall of the Southampton type in Dublin, what they would have done—and had done on several occasions—was, instead of excavating the trench by means of divers, to excavate it by steam bucket dredgers. The trench was not carried quite to the back of the wall, but to about two-thirds of the width of the base of the wall itself and was extended well beyond the front, the object being to lay a base of concrete on which the quay-wall would rest, with the resultant pressure of the filling of the wall passing centrally into that concrete base. He only mentioned that as an example of what had been done in Dublin in a similar way, to show how the necessity for economy had forced itself on the minds of the engineers there. It would be readily appreciated that the dredging and the deposition of the concrete formed a cheap method, because it was possible to utilize the block-setting appliances for lifting boxes containing 50 tons of concrete and depositing it in the trench. No greater advantage could be looked for in depositing concrete in in water than laying the largest possible quantity at one time. The smaller the quantity the more it suffered. He could quite appreciate the Author's reference to each little layer of concrete being covered with silt or injured by tidal currents. The results obtained in Dublin showed that a perfectly firm and solid base of concrete could be deposited, on which the large concrete blocks were laid, the concrete being levelled by means of a large diving-bell. The appliances in Dublin would not have laid blocks 10 feet in length of the section of the Southampton wall, because a block of that section would weigh about 800 tons; but there would have been no difficulty in laying the blocks in two tiers and working with 100 ton blocks. By that means the saving in the cost of the wall, even including the cost of the plant, would have been very material. The other section of wall described by the Author was the pier-and-arch type. The only example of that type of wall on a large scale with which Sir John Griffith was acquainted was constructed in the port of Hamburg about 30 years ago. In that case the wall was built on piers, but they were not sunk solid; they were sunk as what might be called caissons of masonry on curbs at intervals, and down to their foundations, and the curtain-wall was built between. A very extensive section of the quays was built in that way, and proved entirely successful. One other modification made in Dublin was that walls with vertical faces had been adopted recently. Every wall in the Author's work had a batter of about 1 in 10. Present-day vessels had perfectly square bilges and perfectly vertical sides, and some were even wider at the bilge than at the deck. Consequently, they nearly all rubbed along the bilge against a battered wall. He noticed that in Fig. 12, Plate 2, dummies were marked, but dummies between a wall and a heavy ship where there was a rise of tide or any swell were things that shipowners

Sir John Griffith.

Sir John Griffith. detested. It was almost impossible to avoid damage to the vessels under those circumstances, and he would even be afraid that with only a concrete face the wall would suffer very materially. The practice in Dublin, even to the present day, wherever vessels rubbed, was to use ashlar faces, and he would not be inclined to advise a departure from that practice.

Mr. Cruttwell. Mr. G. E. W. CRUTTWELL remarked that the feature which distinguished Southampton from the generality of seaports was the fact that the docks were open to the tide instead of being closed with lock-gates, as in most ports. He desired to say a few words on that subject, as he had often been asked why the docks at Immingham had not been made tidal, like those of Southampton. What was suitable and proper for Southampton would be unsuitable and improper for many other places. As the Author pointed out, Southampton had two important natural advantages, namely, the moderate range of the tide—at springs about 13 feet and at neaps about 9½ feet—and the small amount of silt contained in the tidal water. Those two features, he presumed, had rendered the tidal dock at Southampton an economical and practicable scheme. In the case of the Immingham dock, which was opened in 1912, a large number of calculations were made with a view to determine the relative merits of a tidal dock and a closed dock. At Immingham there was a rise of 19 feet at springs and a little less than 16 feet at neaps, and the dock being situated on the Humber, the amount of silt in the water was naturally very large. Both those circumstances were strongly against a tidal dock. After going into the matter very carefully, it was found that the dock as at present constructed—consisting of a main turning-basin 1,100 feet square, and a single arm, about 1,250 feet long and 350 feet wide, leading out of one of the corners of the turning-basin—without taking into consideration any contemplated extensions, would involve an extra capital outlay of no less than £106,000 for carrying the excavation of the dock and the dock-walls to such a depth as would afford the same depth of water with the tidal scheme as had been obtained with the closed dock. Eventually, when the four arms of the dock were completed, an extra capital outlay of £414,000 would have been involved. But that was not the worst feature of a tidal scheme on the Humber, because the quantity of silt to be removed was enormous. Instead of having anything like the Author's quantity of 9 to 12 inches of silt to remove in the course of a year, in the tidal entrance to the Immingham dock no less than 6 inches, and sometimes 1 foot, had to be dredged in a week; and in the course of the year an average of about 25 feet of silt

Mr. Cruttwell.

had to be dredged in the aggregate. Of course, if all that silt were to get into the dock very heavy expense would be incurred in its removal. It was found that the extra cost of dredging the silt, as compared with the cost of working the lock, would have amounted, with the single-arm basin now constructed, to more than £6,000 a year, and for a basin with four arms the cost would have been very much more, the annual cost of maintenance dredging being about £14,000 more than the annual cost for working the lock. Notwithstanding the extra first cost of carrying the dock-walls and the dock-excavations about 10 or 12 feet deeper than they would have had to be taken if a closed dock had been constructed, he reckoned that roughly about £250,000 had been saved on the first cost at Southampton by avoiding the construction of a lock entrance. If the Author had gone into such calculations perhaps he would kindly state what the actual difference in cost would have been. Again, at Southampton, owing to the small quantity of silt, the annual cost of dredging would be very much less than the annual cost of maintaining the lock, so that the two comparisons showed how widely the conditions differed, according to the situation of the work. Referring to the section of the quay-walls at Southampton, he also would much prefer to see the face of the walls vertical. In all the docks with which he was connected he was in the habit of making the walls vertical, or with a very small batter. Timber fenders placed along dock-walls to keep the bilges of vessels from rubbing against the concrete must be especially objectionable in the case of a tidal dock, where vessels were continually rising and falling with the tide. Was any difficulty experienced at Southampton in loading and unloading the cargo due to that cause, and was frequent adjustment of the warps and ropes necessary to suit the rise and fall of the tide? He believed there was not much variation at Southampton; but, where the rise and fall was considerable, it would be a very disturbing factor in dealing with the traffic. The only other point to which he wished to refer was the curtain-wall in Section C of the work, to which Mr. Moncrieff had already called attention. It had struck him also that it could hardly act as an independent wall. Was it not rather relied upon as a kind of horizontal retaining-arch between the monoliths than regarded as an independent wall between them? If it was regarded as an independent wall he agreed with Mr. Moncrieff that it was quite inadequate to withstand the pressure.

Mr. Meik.

Mr. C. S. Meik had read the Paper with great interest, all the more because he happened to have been fortunate enough to go quite recently with the Author over the whole of the works

Mr. Meik. described in the Paper. Southampton was very favourably situated in the matter of land communication, but it could not be said to be so well situated in regard to access from the sea. The deep-water channel from Southampton to the Solent was 8 or 9 miles long, and the dredging of that channel was a very serious matter, which would probably handicap Southampton in the future if vessels continued to increase in draught as they were doing at the present time. The Author said that the channel was mud, and that the soft bottom obviated damage in case of a vessel touching; but Mr. Meik was under the impression that there was rock at one place in the channel. It was familiar to the members that at Southampton the channel was under the Harbour Commissioners, while the docks belonged to the Railway Company; that position was rather to be deprecated, as it was not desirable to have two authorities for one port. A question to be borne in mind was whether the depth of the channel, 35 feet at low water, was sufficient. The "Olympic" had a maximum draught of 35 feet, and her sailing draught from Southampton never exceeded 33 feet, it being impossible for her to get out of the channel at low water when she was fully loaded. There were ships with a deeper draught than the "Olympic." The "Mauretania" and the "Lusitania" and the big German liners also drew 36 feet, so that 35 feet was hardly sufficient for the very large vessels that now traded across the Atlantic. With reference to what Mr. Palmer had said about large vessels, Mr. Meik thought the largest vessel in the world was the "Vaterland," which was fitting out at Hamburg. She was 930 feet long, 98 feet beam, and 36 feet draught. The increase in draught was therefore becoming a very serious matter to dock-engineers. It was already an expensive matter, as the Author stated, to provide accommodation for vessels of the "Olympic" class, and if deeper vessels were built in the future there were very few ports in the kingdom that could accommodate them. He thought it would be of material advantage if some prominent shipbuilder could be induced to read a Paper at the Institution on these large vessels, giving information as to the size and draught of vessels for which accommodation would have to be provided in the future. In the White Star dock the Author had provided a depth of 40 feet, which was 5 feet more than in the channel; and even with some deepening of the channel, 40 feet ought to be sufficient for the next 25 years. He noticed that the Author had only given 6 feet of freeboard on the wall above high water, which he considered might have been increased with advantage for a ship of the size of the "Olympic." For ordinary traffic, Mr. Meik.

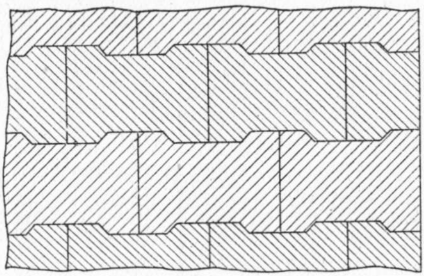
such as the loading of cargo-steamers, a plumb face was of great advantage; but shipowners would not allow large vessels such as the "Olympic" to come against a quay-wall; they insisted upon some dummy being put in between, lest the vessels should rub against the face of the wall. He thought there would be more likelihood of damage to a ship of that description in a swell if she were lying against a vertical quay-wall than if she were kept off by dummies, such as those used at Southampton and in other ports where vessels of this kind were dealt with. In docks for vessels of the smaller class, such as he had carried out himself, he had always adopted a plumb face because it was desirable to get the vessels close to the quay-wall. Another problem which engineers had to consider in connection with large vessels was the provision of the necessary sheds. That point did not arise so prominently in the case of big passenger-ships such as the "Olympic," because they did not carry much cargo: he supposed 2,000 tons was about as much as the "Olympic" brought into Southampton, and a single-deck shed would deal with that without any difficulty. But when large cargo-vessels carrying 10,000 tons, and possibly more, of miscellaneous cargo had to be dealt with, a single shed was quite inadequate. The traffic people said that a shed 120 feet in width was as wide as could be worked conveniently from one berth; therefore, when large quantities of cargo were being dealt with, one, two, three, or four floors were required. About 3,000 tons of miscellaneous cargo was as much as could be dealt with on the floor of one shed 500 feet long. He had recently an opportunity of inspecting several large ports, with a view in particular to examination of the shed accommodation, and he was very much struck with the different ideas that prevailed in these ports. At Liverpool, for instance, the sheds were close to the quay-wall, and the cargo went straight into the shed from the ship, there being no railroad between the shed and the ship. The same state of affairs existed at Manchester, although he noticed there that in the most recent type of shed rails had been laid between shed and ship. Possibly all these arrangements had their good points, but the diversity of practice was rather confusing to an engineer who wished to find out what was the best thing to do. With regard to the enclosing bank, in two recent docks which Mr. Meik's firm had constructed sand dams had been relied upon entirely.[1] Large areas had to be reclaimed, and there was a considerable width available; and the dams were quite successful in keeping

[1] See, for example, Mr. R. Henderson's Paper, "Burntisland Harbour: Construction of the East Dock," Minutes of Proceedings Inst. C.E., vol. clviii, p. 120.

Mr. Meik. out the water. The outer portion of the embankment was made of rough rubble, and the inside of sand, the width varying from 70 to 100 feet, according to the fineness of the sand.

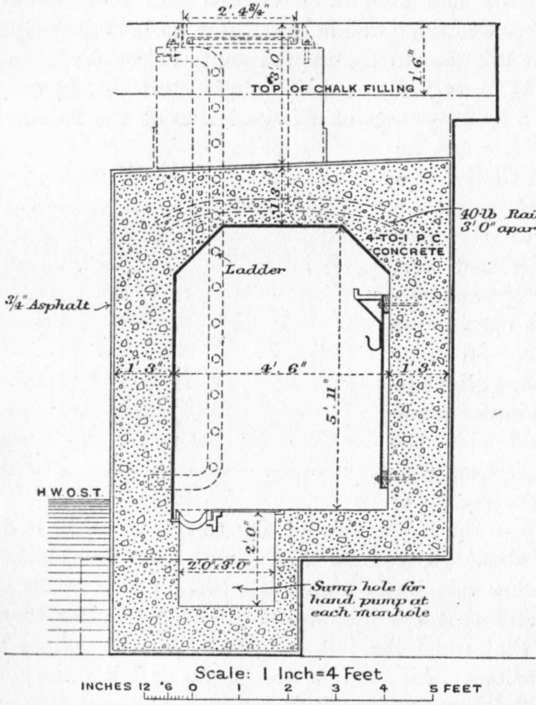
Mr. Walmisley. Mr. A. T. WALMISLEY thought that all who had read the Paper must commend the care displayed by the Author in avoiding, in the execution of the works, any settlement of the natural ground, which contained a large proportion of shifting clay and running sand. In his opinion the timber in the trench (Fig. 5, Plate 1) was excellently arranged. The importance of filling up a pot-hole immediately it was discovered, as stated on p. 50, was emphasized by an incident that occurred in the North of England: sheet piling had been driven at the toe of a concrete wall in which the width of the base was about one-third of the depth from the level of high water, and the drawing of that sheet piling, coupled with simultaneous dredging-operations in the adjoining river, caused the clay to be softened, with the result that the wall was undermined and cracks were produced in it. If the pot-holes had been filled when the piles were drawn, the result would have been very different. At Southampton the timber piling below ground-level for the walls built in water had been left in, and he read the statement on p. 61, that great care was taken to avoid settlement of the ground, as referring not only to the work there recorded but to the whole of the contract. With respect to the mass-concrete base to the wall shown in Figs. 3 and 8, Plate 2, he entirely agreed with the Author's remarks about block concrete. Concrete blocks had the advantage of being set before they were put in water-bearing strata, but with mass concrete, however carefully mixed, there was a certain risk. For instance, in one place, the Author referred to dry lumps that did not unite with the lumps next to them. He also said that fresh water was used in mixing the concrete, because it was feared that if salt water were used the steel reinforcement might become corroded. Mr. Walmisley thought the use of either sea-water or fresh water was entirely a matter of convenience, though, of course, clean sea-water only should be used. He knew of instances where contractors had preferred to pay for fresh water by meter rather than incur the expense of pumping the sea-water to the site. The important thing with concrete was, in his opinion, to have sufficient water to produce a stiff pasty conglomerate which would be non-porous when set. If the concrete were at all porous, the use of sea-water might affect the concrete in a far more prejudicial manner than by causing rusting of the surface of the steel reinforcement. Chemists stated that if the salts in sea-water combined with any uncombined lime in the concrete, swelling and disintegration might take place; and sea-water might penetrate between the dry lumps that were found not to unite with the other lumps. The walls described in the Paper were excellent from the point of view of stability, although he certainly preferred the face-line of the wall in the Empress dock—curved vertically and widening out towards the base. He did not believe that the curved face of that wall had anything to do with its failure; and he preferred that profile to the apron step combined with the wall, though in the case of the retaining-wall for the reclamation of $11\frac{1}{3}$ acres to form a site for a marine station on the harbour side of the Admiralty Pier, Dover, he had adopted a vertical wall of concrete blocks, having timber fendering and a base equal to half the height. The vertical face was due to the requirements of the continental mail-steamers. With regard to a wall being watertight, he once had to go down to a landing-stage on the east side of the Admiralty Pier at low water, when he noticed that there was a little more water on the west side of the pier than on the east side, and the water was pouring through open joints in the pier. In order that this point might be appreciated it was necessary to add that the transverse section consisted, in the centre of the pier upon the shore side of the turret, of chalk and shingle filling for about 13 feet in width, with concrete blocks 24 feet thick on either side up to high-water level, above which was mass concrete; and that the face-stones of the Admiralty Pier had no dowels, so that when the joints worked loose sometimes the face-blocks came out. Air got into the joints at low water, and when the tide rose (there was an 18-foot 9-inch range of tide at Dover) the air was compressed in the joints, and forced the face-blocks out. That showed the importance of dowelling. When Messrs. Coode, Son and Matthews carried out the seaward extension of the Admiralty Pier, they put in blocks right through the section, which were properly dowelled on the face. The Author said it was not essential that his walls should be absolutely watertight, and to prevent the face-blocks from coming out, he had introduced a turned-up end, a kink (Fig. 8). That was an admission that the Mr. Walmisley.

Fig. 15.



Mr. Walmisley. face-blocks might come out if they were not secured in some way. At Gibraltar a form of H-block had been used, which was self-dowelling and also interchangeable (*Fig. 15*). The idea was conceived by Mr. Charles Colson, M. Inst. C.E., late of the Admiralty. The Author had very properly provided a trench for water-pipes and cables. The late Mr. H. H. Wake, M. Inst. C.E., who built the Roker and South piers at Sunderland, provided a passage right through the centre of each of those piers. The passages were

Fig. 16.



6 feet high, one being 4 feet and the other 5 feet wide, so that it was possible to walk through them from end to end above water-level. That suggested to him, when it became necessary to widen the Admiralty Pier in order to make a site for the station for the South Eastern and Chatham Railway, to make a passage of 24 feet, 6 feet high by 4 feet wide, right through the pier, to convey War Department cables underground, as well as any other cables and pipes that might be required by the Dover

Harbour Board, down the pier, instead of having to take up the sets upon the surface of the pier every time it was desired to get at mains or cables. *Fig. 16* showed the details of this conduit. Mr. Walmisley.

Mr. ADAM SCOTT observed that many of the points which had occurred to him had been touched upon by previous speakers, but he desired to make, in the first place, a few remarks with regard to the position of Southampton. Southampton had many advantages—perhaps more than any other port in the kingdom. It was almost perfectly sheltered, and it had a moderate range of tide, which did away with the necessity of impounding the water; while vessels had easy ingress and egress at all states of the tide, and fairly deep water in the approach-channel from the Solent. Notwithstanding that, he did not think Southampton was an ideal port for huge liners, for whose accommodation, chiefly, the dock described in the Paper had been built. Among the first necessities for a port dealing with the traffic involved in the use of such large vessels were, first, that it should be near to open water; secondly, that it should have deep water; and, thirdly, that it should have shelter. The disadvantage of Southampton was that even a distance of 5 miles up from the Solent was too much, because in the hurry of the present day, and in the race of the large liners, time and money were everything. He had no doubt that the Hamburg-Amerika vessel, the "Imperator," could go up to Southampton just as easily as the "Olympic." The reason why she did not go was probably that she would lose at least half a day by doing so, and nowadays every hour was valuable. Bearing on that subject, at least indirectly, was the very important question of the development of ocean-going vessels at the present day and the provision of accommodation for them. Large liners were in a class by themselves, and a very restricted class. While they were few in number it was feasible to deal with them at a few of the principal ports, and it was only the principal ports which could attempt to do so. Altogether there were only eight vessels owned and built in the United Kingdom which exceeded a net registered tonnage of 20,000 tons; there were four exceeding 30,000 tons, and only two exceeding 40,000 tons. In view of the number of ships in existence, it would be seen how very few of these large ships there were in comparison with the enormous mercantile tonnage of the country. But it was not those large vessels chiefly that had to be dealt with; most ports had to consider more the intermediate class of vessel, and a great development had taken place also in the smaller classes of vessels. He had carried out recently certain investigations into that matter, and had found that vessels below 3,000 tons were gradually Mr. Scott.

Mr. Scott. decreasing in number, and would probably soon disappear to a large extent from ocean traffic; but above 3,000 tons—say, 3,000 to 8,000 tons principally, and up to 10,000 tons—they were increasing largely. It was in that class of vessel that engineers and the generality of ports were chiefly interested. In the past the increase in the dimensions of vessels had been greatest in the matter of length, next in width, and least in draught; but he was inclined to think that in the future probably the beam and the draught would increase in greater ratio than the length, if the large liners increased in length much beyond what they were at present. The disadvantage to a port of being so far inland was strikingly exemplified by the recent case of Queenstown. There the difficulties and the dangers of going inside were such that the Cunard Company had now refused to allow the "Mauretania" and the "Lusitania" to enter the harbour at all. Those ships were now allowed to call off Queenstown only when the weather permitted of their taking the mails on board from a tender. That must be a serious loss to Queenstown; and it must be a loss to Southampton when a liner such as the "Imperator" did not go up to the dock. Nowadays vessels were being built more and more for special trades and purposes, and in consequence special accommodation had to be found for them. The dock under discussion appeared to be very convenient in shape, with the turning-basin outside. It had also a good length of quayage for its water-area. So far as the method of handling the cargo was concerned, there was not much to be said, because the quantity of cargo dealt with was very limited, consisting more or less of small packages, none of which were of any great weight. The bulk of the cargo was sent off almost direct from the ship's side, so that the sheds and the quays were cleared within a day or two. That being so, he did not think the accommodation in the matter of sheds could be taken as a basis for any other case. The accommodation provided gave about 10,000 square feet of shed per hundred lineal feet of quay, which was a very small allowance; but, as he had already said, the cargo was dispatched almost immediately. Exports which came in one day were probably all loaded by the next day or at any rate within two days. A few days ago he saw a steamer loading in the dock. She had four cranes working, besides, he thought, about half-a-dozen of her own derricks loading into perhaps eight or ten hatches; but he doubted if they were putting on more than 200 or 300 tons per hour—a very small amount. The sheds seemed to be very convenient for their purpose, and although as a rule he was not in favour of the railway-lines being within the sheds, he thought that in the present case they answered their purpose well, especially for perishable goods. He would like to ask why on the west side of the dock the balcony was flush with the face of the shed, while on the east side it overhung. Further, on the west side the balcony was not used at all; there were no travelling stages, and it therefore seemed to him that the stairs within the shed took up much space and were rather in the way. Perhaps it might have been intended to provide stages for both sides and to use the stairways on the west side also for passenger-traffic. There were large numbers of men engaged in handling the various packages, running here and there, not only out of the shed but along it, and a series of run-ways within the shed would, he thought, have been a great saving of labour. With regard to the different types of walls and the system of construction adopted, in the case of wall A, built in the dry, he did not think the contractors could have done better. He did not know whether they had been allowed to choose their own method of construction; that was usual, and probably had been so in this case. Wall A was a moderately cheap wall. Wall B was manifestly a case for block work entirely—especially interlocking blocks—instead of mass-concrete hearting. It would have been a better and cheaper wall if that method of construction had been adopted. He thought also that wall B might have been reduced considerably; it was much stronger than wall A. There was, he thought, 5 tons excess in the case of A and 17 tons in the case of B, on the safe side. As to the cost of the walls, he thought the Author had been in the happy position of having practically a free hand. Walls B and C were certainly not cheap: he did not say they were not economical, but he considered their costs very high. With regard to the method adopted in putting in wall C, he thought that if concrete caissons had been used for the whole depth, instead of piers and arches, the result would have been a much cheaper and an equally good wall. However, the Author had clearly achieved his object in reducing the pressure on the ground under the piers by adopting a reinforced-concrete platform. It had to be remembered, in connection with that point, what the conditions actually were. First of all the piers were put in, then the curtain-walls, and after that the arches. The wall was then really taking the pressure from behind almost to the full height—certainly up to the springing of the arches. The piles were driven through compact sand to a dead set, and some of them had to be cut off. If the sand was retained and there was no possibility of its getting away, it formed a very good foundation. If it Mr. Scott.

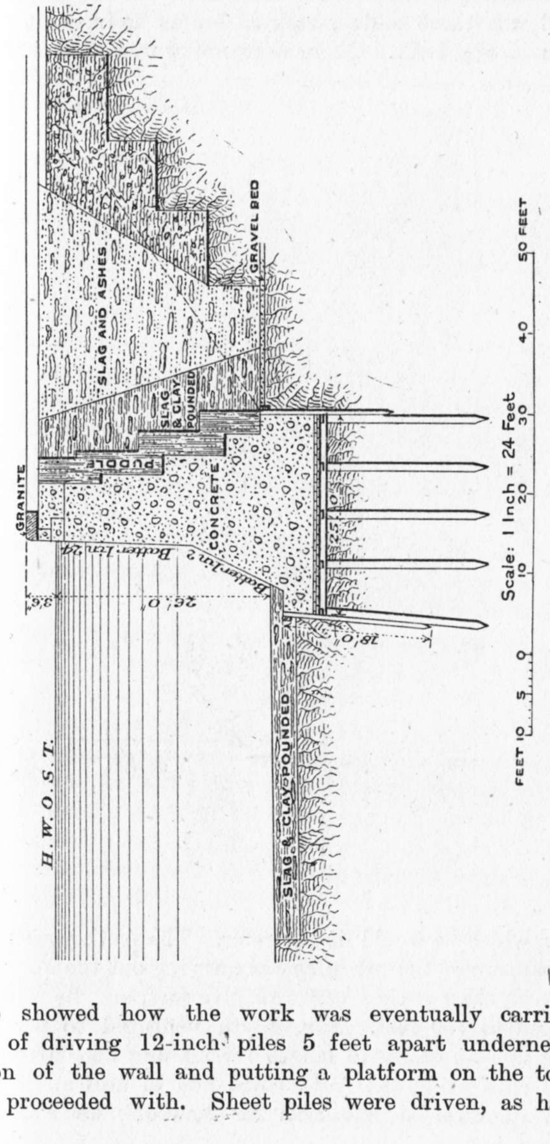
Mr. Scott. were disturbed it would run, but in this case he did not think there was any possibility of its being further disturbed; there could be no marked movement of the sand behind without serious movement of the wall itself. The sinking of the concrete caissons reminded him of some similar work he had to do a good many years ago for a quay-wall on the Tyne. In that case the caissons were 37 feet deep, 30 feet long, and 20 feet wide, with a well 20 feet by 10 feet. They were sunk through 19 or 20 feet of running sand and mud. Over and over again the well was filled to a considerable depth by inrushes of sand. When the caissons were got down they reached a good, hard, gravelly foundation. In sinking them they were weighted with old rails and kentledge blocks, the greatest load being 350 tons. With walls 5 feet thick all round, he was able to continue sinking with the weights on. In the present case at Southampton he did not think that had been possible. So far as he could gather from the Paper, it had been necessary to take off the load again before sinking could be resumed. He had read the Paper with great pleasure, and had found it one of the most interesting of its kind that had been read at the Institution for a long time.

Mr. Blyth. Mr. B. Hall Blyth congratulated the Author not only upon the admirable Paper he had put before The Institution, but also upon the splendid way in which he had carried out his very difficult work at Southampton. He found a strong likeness between the work at Southampton and work which he had carried out at Grangemouth. There also the formation was soft mud and a bed of gravel ranging from 12 to 15 inches in thickness. The toe of the wall at Grangemouth was made long, for precisely the same reason that the Author had adopted a long toe at Southampton. Again, on p. 58 it was stated that at one time it was intended to increase the supporting-power of the ground by driving bearing-piles under each pier; and the same thing occurred at Grangemouth. In all those particulars the conditions at Grangemouth, where he constructed the dock in 1879, were precisely similar to the conditions at Southampton. His firm specified that the dock-walls were to be built with sheet piles in front and 12-inch bearing-piles 5 feet apart underneath the whole front, covered with 6 inches of timber in two layers of 3 inches each. The front row of sheet piles had been driven, and a start had been made on the driving of the main bearing-piles, when he received a telegram one morning asking him to go to Grangemouth to see what had happened. On arriving there he found that the sheet piles which had been driven in front of the wall were standing up like a fan, in consequence of the

Mr. Blyth.

driving of the bearing-piles. It was manifest that the original design of the foundation of the dock-wall must be altered. He had brought with him tracings, one of which (*Fig. 17*) showed how the walls were intended to be constructed, and the other

Fig 17.



(*Fig. 18*) showed how the work was eventually carried out. The idea of driving 12-inch piles 5 feet apart underneath the foundation of the wall and putting a platform on the top of it was not proceeded with. Sheet piles were driven, as had been

Mr. Blyth. originally intended, in front of and behind the wall below the level of the gravel bed. He believed the foundation of the wall was about 7 or 8 feet below the gravel bed. But instead of the piles being put in vertically they were put in horizontally, and the wall was built upon a platform of timber 12 inches thick. That was done in 1879; the wall was there to-day, and, as far as he knew, it was as good as when it was built. There were one or two other matters in the

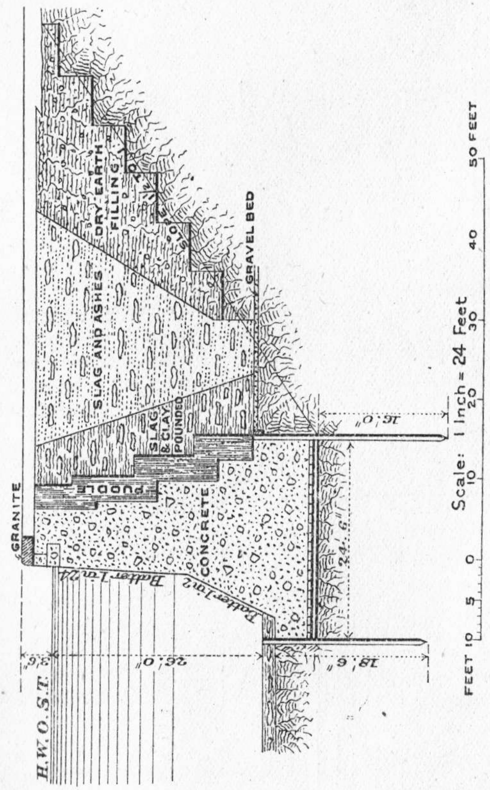


Fig. 18.

Paper to which he would like to refer. The Author seemed to have been disappointed that when he was carrying out the work in lengths of 260 feet, the trenches began to give way, and he had to curtail the length to 100 feet. Mr. Blyth ventured to say that even 100 feet was an excessive length for sinking deep trenches in the material with which the Author had had to deal at Southampton. On the question of materials for concrete, he had stated his views on previous occasions.[1] The Author seemed to him to have adopted too small an aggregate; a large part of it had to go through a 1-inch screen, which Mr. Blyth considered unnecessarily small. His own specification was—and always would be as far as he personally was concerned—about 2 inches to 2½ inches for the aggregate of concrete. He had made concrete from slag, from whinstone, from gravel, and from freestone. He had invariably found that slag exercised some chemical action on the concrete, and occasionally it failed. Gravel and whinston he put together because they both had, if he might use the expression, a kind of "greasy" surface. Whinstone particularly had a greasy surface, while gravel was rounded, and neither seemed to have the "bite" it ought to have on the cement. On the other hand, properly-broken freestone adhered absolutely, particle by particle, and a conglomerate was obtained in which it was hardly possible to distinguish the stone from the cement. If a block of concrete made with whinstone were split, it would be found that the fracture left the stone quite untouched, and the same applied to concrete made with gravel. But if a block of concrete properly made with freestone were split, it would be found that the stone and the cement broke together with a perfectly clean fracture. He held a very strong opinion on one point in connection with the use of concrete in sea-work. Many engineers were much in favour of specifying displacers—or "plums" as they were called by contractors—in such work. After many years' experience he had determined never to use displacers in concrete. If they could be put in according to the engineer's specification, that was, one displacer not being nearer to another than 12 inches, and if it were possible to ensure that the concrete was rammed tightly around the displacers, well and good; but that meant an amount of supervision that no engineer and no company could afford to give. Therefore, if an engineer desired to have concrete that he could depend upon, he should not consider the 2s. or 3s. per cubic yard that would be saved by adopting displacers, but should have his concrete made with stone, sand, and cement. The only other matter to which he wished to refer was that he thought his friend Mr. Moncrieff had rather cast a slight upon engineers in saying that many of them never studied the timbering of the trenches in which their walls were built. He hoped Mr. Moncrieff did not really mean that, because every engineer who had a deep trench to excavate, such as had been made at Southampton, studied very carefully the method of timbering it. Mr. Blyth.

[1] Minutes of Proceedings Inst. C.E., vol. clxxii, p. 63, and vol. cxci, p. 140.

Mr. Wilson. Mr. MAURICE F. WILSON remarked that he had been much interested in the Paper for two reasons: first, because he spent a good deal of time at Southampton many years ago in connection with the construction of the Prince of Wales dock, and secondly, because the Paper had been presented by an old friend who was with him at Southampton in those days. It had given him great pleasure to hear that the Author had brought his work to so satisfactory a conclusion. In regard to its general design, he did not think the Author could have done better. To begin with, the space at disposal was confined; there was the Trafalgar dock already built on one side, the Empress dock on the other, and the old works lower down on the landward side; and he thought the Author had made the best use of the remaining space. The only question he desired to ask in that connection was whether it was necessary to make such a long guide-stage at berth No. 42. If it was not necessary to make it that length, he thought it would have been just as much use for helping ships into the dock if it had been cut off about half-way round the curved portion of it. As it was, it must interfere with the use of berth No. 41; at all events, it confined the space very much and must render it rather difficult to get ships in and out. The Author mentioned that the guide-stage might be used as a lay-by berth; but, if ships were lying on the outside of the stage, Mr. Wilson did not see how it could be used effectually as a guide for helping ships in. Another point that had been raised was whether a lock entrance should have been constructed. With a moderate tide such as occurred at Southampton it was clearly not necessary to have a lock. There was plenty of water in the estuary, and it could easily be deepened if required. He thought the very peculiar tide which occurred at Southampton had not received all the attention it deserved. The Author spoke of a second tide following the first tide about 2 hours later; but, as a matter of fact, the tides at Southampton were even more complicated. In addition to the two tides, there was what was called the "young flood." After the water had risen for about $2\frac{1}{2}$ or 3 hours there was a pause, generally for about 1 hour, which took place when the water was about 4 feet above the level of low water. From that time all through the double high water until it ebbed again to that same level there was a depth of more than 40 feet of water, so that there were only about 3 or 4 hours throughout the whole tide when there was less water outside than there was in the dock. The disadvantage of dredging the channel to a less depth than the dock was therefore not really very great. One speaker, in alluding to the question of the draught of ships and the depth of the

White Star dock, had asked whether sufficient allowance had been made for the greater draught of the ships that would be built in the future. In the vessel shown on the diagram there was not much water under the keel—certainly not enough to allow for much future expansion—but it must be remembered that those exceedingly large ships were very few in number. Personally he thought it was very doubtful whether for some time to come ships were likely to increase much in draught. The United States, which must have kept very clearly in view the developments of shipping in the future, had fixed the depth of water over the sills in the Panama Canal at 40 feet; and a similar depth applied to the Ambrose channel at New York. He thought therefore that the Author had been wise in fixing upon that depth, and that he would have been unwise if he had advised his Company to incur the additional expense of a deeper dock. He was rather surprised to notice that the Author had battered the face of his walls 1 in 10, because the general opinion was now held that with straight-sided ships the walls should be vertical, otherwise large fenders, or camels, or something corresponding with them, must be used to keep the ships' bilges away from the walls. With regard to the general design of the wall, he agreed with several speakers in the advantage of a wide toe, but he thought the Author had gone a little too far in designing a toe which needed reinforcement. In building a gravity wall such as that described he would much rather have a toe which would stand by itself, like an inverted corbel; and if he could not get depth enough to obtain sufficient thickness in the toe, he would rather put the extra width behind. The Author also made a strong point of the adoption of a slope of 1 in 8 for the base of the wall. He quite agreed that it was very necessary to get a good hold on the foundation, especially in ground such as that at Southampton, where the Author had before him the example of the slipping of previous dock-walls. He did not see, however, that there was any particular advantage in the large fall from the front to the back, provided a good hold on the ground was obtained. The Author would remember that when they were together at Southampton the Empress dock walls were strengthened by means of a toe of cylinders sunk in front, and a wall built on the top of them. That had kept the walls perfectly secure, and he did not think they had moved since the work was carried out. He desired to say also a few words on the timbering of the trenches. Apparently a nasty accident very nearly occurred at one end of berth No. 46. In his description of it the Author stated that the first thing noticed was the move- Mr. Wilson.

Mr. Wilson. ment of the central piles to the south. That brought up again the question of using central piles in trenches, which always seemed to him a very objectionable procedure if it could, by any possible means, be avoided; because a knuckle-joint was obtained in the middle of the strut, just at the very place where it should be rigid. Although a 44-foot trench was wide for a single strut, he believed there were means by which such struts could be stiffened and prevented from buckling, and he thought it would have been preferable to incur any extra expense in that way, rather than run the risk of the trench shutting up, which must have happened if the central piles had given away. He did not quite follow whether Mr. Moncrieff in criticizing the concrete, meant that it was porous or too poor. As, roughly speaking, anything that would go through a $\frac{1}{4}$-inch mesh had been classed as sand, the average proportion of sand in the Author's concrete would apparently be about 36 or 37 per cent. In the Admiralty Harbour works at Dover two kinds of shingle were used; one was a natural shingle and sand, in which the sand was in excess, and the other was clean shingle having no sand at all. About 50 per cent. of sand passed the $\frac{1}{4}$-inch sieve in the sand-and-gravel shingle; about one-third of the other shingle was added to it, and that brought down the proportion to about the average used by the Author. In carrying out those works at Dover many thousand blocks were used, a large number of which had to be cut from time to time for various purposes, and in not a single one was any honeycombing visible; they were absolutely solid. He was therefore sure that the Author's concrete must be perfectly solid if it had been made in anything like the same proportions, which appeared to be the case. With regard to the use of concrete under water, he agreed with the view that it would have been far preferable if wall B could have been built of concrete blocks. There was a great objection to depositing mass concrete under water: it was always liable to disturbance, and any movement of the water must wash out a certain amount of cement; in fact, everything that happened, from the moment the concrete was lowered under water, tended to weaken and deteriorate the concrete in some way. The fine scum or deposit produced under those circumstances was very often found, especially in depositing concrete under water, but he was surprised to hear that the deposit was found where there was a stream running in the tideway, and that where concrete was laid in perfectly still water no deposit was met with. He would have expected the effect to be that the current would wash away the fine scum of cement and sand, and that it would be present where the cement was deposited in still water. Recently he had been sinking some cylinders for a wharf-foundation. A concrete seal was made at the bottom of the cylinder, about 8 feet thick, the cylinders were pumped out, and the seal stood for about 3 days, so that it got thoroughly hard. On the top, on pumping out the water, there was found in some cases several inches of deposit, due, he presumed, to the fine stuff being drawn out of the cement while it was passing through the perfectly still water of the cylinder and then settling afterwards. He thought a peculiar and even extraordinary feature of the work described in the Paper was the quantity of trenching done under water. He would like to know if that was cheap or economical. It had already been suggested that caissons, monoliths, or something of that kind, might have been used with more economy, and it would be interesting to know from the Author whether that was the case, because the works as carried out seemed to him to be very expensive. The Author had made an excellent job of the work, and he was very pleased to congratulate him on his success. Mr. Wilson.

Mr. JAMES M. DOBSON thought, in view of the formation and nature of the foundations, that the work reflected great credit on the Author and the contractors who had brought it to such satisfactory completion. Fine silty sand, so highly charged with water that the slightest movement caused it to run, was about as unsatisfactory a foundation as an engineer could possibly have. The greatest care had to be exercised in dealing with such material, otherwise something was sure to go wrong. Personally he had had a great deal to do with treacherous material of that sort. In one dock for which his firm acted as consulting engineers a bore-hole was put down alongside an adjoining existing dock, and the boring showed, after piercing the surface, nothing but red sand, river mud, and grey sand, for about 28 feet 6 inches below the coping; then there was a thin layer of bastard clay, and, when that was pierced, there was nothing but red sand down to 53 feet 6 inches below coping-level, or 37 feet 6 inches below datum. At high water the water stood in the bore-hole within 9 feet of the coping. The bottom of the wall of the existing dock was 22 feet below the coping, and between the bottom of that wall and the hard clay there was nothing but 15 feet 6 inches of red sand fully charged with water. The average level of the hard clay in the new dock was 40 feet below datum, and whenever and wherever the water that was pumped was connected in any way with that sand, it naturally drew it away. There were a few points in the Paper to which he desired to call attention. With regard to the walls, he quite agreed that a sloping base was advantageous, but there was a limit even to the degree of Mr. Dobson.

Mr. Dobson. slope, and there were cases where, no matter what it might be, it would not prevent the wall from slipping forward, and other means of counteracting that tendency had to be adopted. In the south dock of the East and West India docks, for which the late Sir John Hawkshaw was the engineer, two portions of the wall at the back of the Millwall dock slid forward, though the wall was obviously strong enough, because it remained vertical.[1] These portions of the wall were founded on conglomerate or natural concrete resting on clay, and when the water was let into the Millwall dock the walls with the conglomerate slid forward bodily on top of the clay, so that no degree of sloping could have stopped them from going forward. The late Sir James Brunlees had described a similar accident at the Avonmouth dock,[2] where 80 yards of wall were forced forward 4 feet. This was attributed to the fact that the wall had been built over an ancient channel, in which the deposited layers of material were softer and more slippery than the rest of the foundations. He quite agreed with the Author's view that if wall B had been built entirely of blocks between dock-bottom and low-water level, probably a rather better and cheaper structure would have been obtained, and in support of that opinion he would refer to a quay-wall recently built under his firm's direction in the extension of a harbour in India. That wall was built in a natural depth of 22 feet below low water, increased by dredging in a trench to between 32 and 34 feet. The bottom of the trench was levelled, and 2 to 4 feet of rubble was deposited in it. The wall had then a depth of 30 feet below low water, and 14 feet above that level, the rise of the tide being about 6 feet; the total height was therefore 44 feet, the same as that of the Author's section at berth No. 49. The wall he was referring to was built almost entirely of block work, placed in position by a crane working on the top of the wall as it was brought along, stage by stage. The estimated cost of that wall, including backing, fenders, bollards, and plant, was £34 per lineal foot; and although he had not received details, he had no reason to suppose it had been exceeded. The estimate was based on the actual cost of a wall already built in the same place, the only difference being that that wall was not quite so high. The Author's statement that the cost of walls at Southampton 30 feet and 25 feet high below low water averaged £72 per lineal foot was not very definite; but assuming that the 25-foot wall cost three-fifths of the 30-foot

[1] Minutes of Proceedings Inst. C.E., vol. xxxiv, p. 171.
[2] *Ibid.*, p. 175.

wall, its cost would work out to £54 per lineal foot, or £20 more than the cost of the block-work wall to which Mr. Dobson had alluded. There was one other point to which he wished to refer. The Author stated (p. 43) four great advantages that Southampton had over many other ports. In speaking of silting, he presumed the Author was referring more to the past than to the present, because the fact of deepening the channel would necessarily increase the silting, and although there would be no additional silting in the older docks, which were only 26 and 27 feet deep, the fact that the White Star dock was 40 feet deep and the channel 35 feet deep meant that that dock would act as a kind of catch-pit, so that there must be more dredging. And there was another reason why he maintained there would be more dredging. When, on the 10th April, 1912, the ill-fated White Star ship "Titanic" left Southampton on her maiden voyage, three tugs were employed to tow her out of the dock. She was then taken very slowly along the quay. She first came opposite the "Oceanic," and then opposite the "New York," which was fastened to the quay with twelve hawsers. When she was abreast of the "New York" it was apparent that that vessel's hawsers were being strained, and that she was being drawn by suction towards the "Titanic," a liner of no less than 60,000 tons displacement. The ropes attaching the ship to the quay broke; immediately the "New York" began to veer round towards the stern of the "Titanic," and she was within 15 feet of it when, fortunately, she was stopped. That, in his opinion, showed that the suction due to such enormous vessels would have the effect of drawing down the mud much more than had been the case hitherto, with a channel only 30 feet deep, navigated by ships of one-fourth and one-fifth of the tonnage of the "Titanic." Some years ago an incident of the same kind occurred in the Mersey, when the new Isle-of-Man steamers commenced running. At first they went down the river at a very high speed, and the swell caused by them was so great that it actually forced open a pair of dock-gates. If he remembered rightly—the President would correct him if he was in error—the Commissioners subsequently restricted the speed of those vessels. He mentioned that point to show that if a small steamer caused so much swell that the gates of a dock were forced open, very serious effects would be produced when steamers of 60,000 tons displacement went close alongside mudbanks. There was no doubt that, following the awful disaster to the "Titanic," the conditions in large ships, as far as safety was concerned, had been greatly improved, and at the present time the safety of passengers and crew was very fully considered. He wished to

Mr. Dobson.

Mr. Dobson. suggest whether, as engineers, the members could not learn from that disaster something which would largely help to reduce some of the evils to which he had called attention. Southampton had great advantages over many other ports, but it possessed disadvantages as well. For instance, to the shipping-companies which owned these enormous vessels, the journey up the channel to Southampton meant a long run, over a great part of which they could not go at full speed—a costly run, and a loss of time; and when it was realized that these ships burned 4,000 to 5,000 tons of coal on a voyage between England and America, it was apparent how serious was a day's extra expense incurred in order to reach a particular port. The depth of the channel was 35 feet at low water, while the mean draught of the "Olympic" was 34 feet 7 inches, and when fully loaded 35 feet 7 inches. No boat would come up the channel with only a foot of water under her keel, because all these vessels "drew down" to a certain degree. Therefore he could not see how these ships were going to be worked up a channel having only a depth of 35 feet, should they arrive at low water, and it was not fair to take anything but the maximum draught; moreover, he was confident that the shipping people would say that with a deeper channel they could work the big vessels to much greater advantage. Again, these large ships not only required plenty of depth, but also plenty of water-area, and he urged that engineers must look the question fairly in the face. It was useless to say the ships were too large already and should not be built any larger; in the opinion of many that might be so, but shipowners and shipbuilders thought otherwise, and these large ships, in his opinion, had come to stay. It was therefore essential for safety that they should have plenty of water, both in depth and in area, in which to manœuvre, and the only thing that could be done was to provide proper and sufficient accommodation for them—harbours where they could go in and out at any state of the tide and in any weather—instead of trying to jam them all into one port; they needed accommodation without risk of sinking each other or running aground.

Mr. Fitz-Gibbon. Mr. G. FitzGibbon remarked that the Author did not say whether, before determining the manner in which the walls were to be constructed, any trial pits or cylinders were put down in order to ascertain the exact positions and character of the strata to be passed through and founded on; but it would seem that the nature of the ground varied considerably in different parts of the site, as shown by a comparison of Fig. 4, Plate 1—where mud and peat were indicated down to a level of about 35 feet 6 inches below coping-level, then a 6-foot layer of ballast down to 41 feet 6 inches, followed by clay—with Fig. 5, in which gravel was shown down to about 39 feet below coping-level, followed by about 5 feet of greensand and 20 feet of loamy clay. It would be very interesting if the Author could add to his Paper elevations or longitudinal sections of the east and west walls, showing the different strata met with in carrying out the work. No great difficulty seemed to have been encountered in getting in the south end of the west wall near the enclosing bank, although the bottom of the trench would appear to have been about 75 feet below coping-level, or about 33 feet below the toe of the sheet piling at the front and back of the enclosing bank; but he was inclined to wonder why that sheet piling had not been driven down through the bed of ballast into the underlying clay. On the other hand, the last 100-feet length at the south end of the east wall appeared to have been very troublesome. He supposed the trench for the south end of berth No. 43 was carried down through the porous material and the mud and peat below it, and the Author said that the excavation was carried down to about dock-bottom level without any great difficulty—which was very fortunate, considering the nature of the material passed through and the proximity of the trench to the enclosing bank. He was not sure that he correctly understood the Author about that depth, as later in the Paper it was mentioned that about 3 weeks afterwards, when the excavation had been carried down to dock-bottom level, two large "blows" occurred. It naturally occurred to him that the difficulty in completing the south end of berth No. 43 had been at all events increased by admitting water to the dock before the foundation was got in, and he would like to know why the admission of the water had not been delayed for a time. Perhaps there had been some good reason for not doing that. It would seem that the walls of the dock generally had been completed and fully backed, and it might have been thought advisable to give them the benefit of the support of the water in front. Unless, however, they had shown any signs of requiring that support, he would have been strongly tempted to trust them until the last length of foundation was in. About 7 years ago, when taking part in the discussion on Keyham Dockyard Extension,[1] the Author mentioned that the White Star dock then about to be constructed at Southampton would probably be one of the deepest, if not the deepest, in the world; and, although several very large dock improvements had been carried to completion during the last few years, he thought the Author might Mr. Fitz-Gibbon.

[1] Minutes of Proceedings Inst. C.E., vol. clxxii, p. 55.

Mr. FitzGibbon. still be congratulated upon the fact that his wall was one of the highest in the world. He believed there were only eight dock or tidal-harbour walls built as berths for the accommodation of large vessels which measured 50 feet or more from dock-bottom or footings to coping, namely: Quebec, ocean-liner berth, footings to coping, 66 feet; Southampton, White Star dock, bottom to coping, 59 feet; Montreal, Vickers dock, footings to coping, 58 feet; Dover, new quay-wall, footings to coping, 57 feet 8 inches; Keyham Dockyard extension, basin-bottom to coping, 55 feet 6 inches; Heysham Harbour, bottom to coping, 55 feet; Liverpool,[1] dock-bottom to coping, 50 feet 6 inches; Cardiff, New South dock, dock-bottom to coping, 50 feet. The Quebec and Montreal walls consisted of a concrete superstructure on timber crib-work sunk in deep water on to gravel and sand, after the usual Canadian practice, which was certainly an expeditious and economical manner of constructing harbour- and dock-walls in deep water: no heavy plant was required, and a wide base was provided, capable of carrying exceedingly high walls on even a sand foundation, which obviated the necessity of carrying the foundations down to abnormal depths by means of monoliths or columns until a hard stratum was reached. The dock at Montreal, which had been constructed recently for Messrs. Vickers, to the designs and under the direction of the firm of which Mr. FitzGibbon was a member, had several exceptional features. It was 1,000 feet in length and 500 feet in width, and was constructed on a site reclaimed from the bed of the River St. Lawrence. It had to provide accommodation for a floating dock 600 feet long and 135 feet wide, and of a lifting-capacity of 25,000 tons, which had a draught of 27½ feet when light, and required a depth of water of 53 feet when sunk. A portion of the dock had therefore been dredged to 53 feet below extreme low water in the river, or 81 feet below coping-level, which made it by far the deepest dock in the world. The extreme rise of the water of the St. Lawrence at Montreal was 25 feet 4 inches. The timber cribs were generally 200 feet in length and 45 feet wide at the base, and it was found possible to float out three such cribs and sink them in 30 days, a level bed having been prepared previously in a trench excavated in sand and gravel by the dredgers.

The President. The PRESIDENT remarked that every speaker had concurred in offering sincere congratulations to the Author on his excellent Paper, and on the very interesting discussion it had aroused; and he was sure he would have the sympathy of the Meeting if he

[1] See next page.—SEC. INST. C.E.

extended those congratulations to their old friend and Member of Council, Mr. Galbraith, who was consulting engineer for the work, and who had hoped to be present and offer some remarks on it himself. Unfortunately his health did not permit of that, but the President was sure it would be the wish of the members that the Author should convey to him their hearty congratulations that the evening of his career had been crowned by such an interesting and successful work, and that it had given rise to so long a discussion at the Institution. Before commenting on the work he desired to correct one statement made by Mr. FitzGibbon, with regard to the dock-walls at Liverpool. The latest dock-wall constructed there was 61 feet in height from the toe to the coping, and there were other walls in course of construction which would have a total height, from the footings to the coping, of 63 feet 6 inches. The President.

As to the work itself, two points which struck him were, first, the way in which it had been carried out, and, secondly, the design of the walls. It was with considerable diffidence that he offered any criticism on the first point, because it was impossible from the mere reading of a Paper to understand all the surroundings of the work. The Author had had the advantage of being on the spot throughout the whole time, and no doubt he had studied all the difficulties which might be anticipated or which were met with, and had adapted the best means to the end in view; but in looking at the work and in reading how it was carried out, it had occurred to him that 5 years appeared to be an excessive time for it to occupy. He thought that perhaps 3 years should have been sufficient—at all events, for the wall work and the excavation. It was apparent that the long time taken was due largely to the successional character of the operations, none of which overlapped. There was first of all the lowering of the surface to 30 feet below coping-level; then the trenching operations; then the building of the outside walls; and then the cutting of the bank and the dredging of the bulk of the excavation. That meant that the operations had to wait one upon the other. Could not the work have been carried out by beginning at the south end of the dock and working inwards, following up the construction of the walls by dredging? The trenches could have been made secure against any inflow of water by drawing the timber and filling in between the dumpling and the face of the wall. He had had a somewhat similar work to carry out in the form of a branch dock out of a main dock at Liverpool, where he had to retain water in the dock, and that was the method he adopted there. He did not say, of course, that the circumstances were the same, the

The President. conditions of the foundation, etc., being much simpler than in the Author's case; still, the plan he had suggested would have had the advantage of getting over the difficult part of the foundations from the very start, and would have enabled the operations of building and excavation to go on together; and in that way considerable time would have been saved. He was also of the same opinion as several other speakers in regard to the monolith or caisson work for the outer walls. The cost of one of the walls was put at £117 per lineal foot, or £351 per lineal yard, and even if it were put at the price of breakwater work, about £2 per cubic yard, that would give a cross section of more than 170 square yards, so that a very substantial work might have been made, he thought, at a much less cost than the outer walls that were built in water.

The Author. The AUTHOR, in reply, desired first to express his thanks for the kind reception accorded to the Paper and for the gratifying manner in which it had been discussed. To him the subject was, of course, of the deepest interest, and he was delighted that it had called forth so many instructive remarks from engineers who had had experience of difficulties similar to those encountered at Southampton. He thanked the President also for his kind remarks about the consulting engineer, Mr. Galbraith; it would give him great pleasure to convey to Mr. Galbraith the members' congratulations on the completion of this work, in which he had taken the keenest interest.

Turning to the various points raised in the discussion, he would deal first with those which concerned the general lay-out of the docks. Mr. Palmer had rightly pointed out that if only the predecessors of the present generation had been endowed with prophetic gifts and could have foreseen the developments which would take place in shipping, they would have laid out the docks very differently. As far as the White Star dock was concerned, however, as Mr. Wilson had remarked, it might be said that they had made the best use of the small space at their disposal. No comparison of the relative capital and maintenance costs for a tidal and a non-tidal dock, such as had been suggested by Mr. Cruttwell, had been prepared for Southampton, but it was obvious that with the small range of tide there, the most economical arrangement was to have an open dock. An entrance-lock to admit ships at all states of the tide would have cost a very large sum, and moreover it would have destroyed two of the five berths in the dock itself. The replies to Mr. Cruttwell's further questions were in the negative. The fact of the dock being tidal involved, of course, a slight extra lift for the cranes, but even with the "Olympic" it was found that with a height of jib of 60 feet above the quay, cargo could be easily lifted on or off the deck. The mooring-ropes were always carried either forward or aft, so that the tidal rise caused no serious inconvenience. Mr. Wilson had asked why the jetty at berth No. 12 had been made so long. As mentioned in the Paper, a portion of this jetty had already been constructed, and it needed only a short additional length to convert it into a useful lay-by berth. It was true that this berth could not be used when a ship was entering or leaving the dock, but it often happened that such a berth was required for laying a ship by for a short time, e.g., when waiting to go into dry dock. With regard to the design of the works for portion A, the limit of open excavation was carefully considered before the contract was let, and it was decided that the most economical level at which to effect the change of method would be at 30 feet below coping-level. Had the trenches been started at a higher level, the cost of the wall would have been much greater: on the other hand, had they been started lower, the saving would have been little or nothing, as although the trench-excavation would have been reduced somewhat, the open excavation and filling would have been greatly increased, owing to the necessity of making a flat slope behind the back of the wall. Moreover, time would have been wasted by lowering the starting-level of the trench-excavation, because a second cut would have had to be made with the steam-navvies before the sinking of the trenches could be commenced. He agreed with Mr. Meik that for an enclosing bank such as had been used in this case sand was an excellent material, and those who had read of or seen the temporary works carried out in connection with the Assuan and other dams on the Nile would doubtless have been impressed with the usefulness of the sand dams employed there. Unfortunately, at Southampton the lump-chalk bank had been constructed before the White Star dock-works were contemplated, and the sheet piling driven on both sides of the bank served to make the best of a very porous bank. In reply to Mr. FitzGibbon, the reason why the sheet piles surrounding the box dams were not driven down farther was simply that they would not go, the gravel bed which they partly penetrated being so hard that the piles crushed rather than go farther. The water was admitted into the northern portion of the dock as soon as possible, in order to ensure that that portion should be ready for the reception of the "Olympic" on her maiden voyage in June, 1911. Moreover, it was doubtful whether, even if the admission of water had been delayed, the trouble which occurred in the box dam at the south end of berth No. 43 would have been avoided. The weight

The Author. was not removed while the caissons in this box dam were being sunk, since there would have been no advantage in doing so. The weights were secured, so that they could not slip, even if the caissons sank rapidly or irregularly. When the divers were working inside a caisson, there was no rush of sand into it, as sufficient weight was placed on it to keep its cutting edge well buried. With reference to Mr. Palmer's suggestion that for the quay-wall for portion A it would have been better to sink monoliths or caissons, he would point out that although large caissons had never been sunk at Southampton, a number of small ones had been used there from time to time, and invariably it had been found that the gravel and fine sand were very difficult and expensive materials to sink through. Caissons or monoliths were very suitable under such circumstances as prevailed at Keyham or Avonmouth, where they had to be sunk through soft mud or clay to a hard bottom, but it would be realized from the description given in the Paper of the sinking of the under-water caissons, that the skin-friction in the Southampton sand was very high. Moreover, caissons did not lend themselves to the construction of a wall with a wide toe and a sloping base, such as was needed at Southampton, and for these reasons they were not adopted. In reply to Mr. Hall Blyth small stones were undoubtedly essential for reinforced-concrete work. With gravel concrete small stones were advisable in positions where it was essential that the concrete should be free from voids, as the larger stones sometimes formed a rubbly mass which it was difficult to surround with finer material. Otherwise, no doubt, excellent concrete could be made with large stones. Mr. Moncrieff had also criticized the quality of the concrete used, and evidently he considered that there was considerable danger of its being attacked by sea-water in such a way that it might swell and disintegrate. He would only say that at Southampton there had been no experience of such disintegration taking place, although it was well known that this trouble had occurred elsewhere. The walls of the Trafalgar graving-dock, constructed about 8 years ago, had recently been cut away in order to widen the dock, and it had been found that, although the concrete was of a similar mixture (8-to-1), on the whole it was in excellent condition. There were a few rough places where the sea-water had penetrated, but even there the concrete was not seriously disintegrated or damaged. It was true, as Mr. Moncrieff had pointed out, that the proportion of sand in the natural ballast varied to some extent, but this was not of great importance in ballast like that used at Southampton, where both sand and stones gradually diminished in size from the largest to the

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smallest. He agreed that the fact of the White Star dock wall having stood did not prove the accuracy of his assumptions in regard to the weight of earth and the slope of repose. The late Sir Benjamin Baker had pointed out, in his famous Paper [1] on "The Actual Lateral Pressure of Earthwork," that Rankine's formulas for earth-pressure gave results which were undoubtedly on the high side. This fact might induce an engineer to use these formulas with confidence, were it not that it was impossible to assign correct values to the constants in them. No one could say with certainty what was the slope of repose of the backing at Southampton, or what was the coefficient of friction at the base of the wall. But, as explained in the Appendix, the Author had assumed certain values for these constants, and had thus obtained values for the forces which tended to overturn the wall, or push it outwards, as well as values for the forces which tended to keep it safely in position. He had repeated the process for other walls at Southampton, some of which had stood and some of which had moved. The results showed that the White Star dock wall appeared to be more stable than some of its unsuccessful predecessors. He claimed that the fact that the wall had stood proved that his assumptions were sufficient —not necessarily that they were accurate. They were probably inaccurate, but on the safe side. The wide steps at the back of the wall had been adopted in order to ensure, as far as possible, that the full weight of the earth above should bear upon them. No doubt actually an arching effect resulted, which caused the earth above any step to bear partly upon the back of the wall, and partly on the earth behind the wall; but it seemed to him that with a wide step this arching effect was less likely to take place than with a narrow step, and that therefore the earth above the wider step was more likely to contribute to its stability. In reply to Mr. Moncrieff's objection, old rails had been used as reinforcement because they had been obtainable at about half the price of new ones, and in such a condition that they were quite good enough for what was required of them. Mr. Wilson, on the other hand, had objected to reinforcement, and had suggested that if the toe of a wall were so long as to need reinforcing, it would be better to shorten it and to reduce the weight on the foundations by thickening the wall. Of course it would have been possible to adopt that alternative, but the expense would have been very much greater, and in view of the fact that reinforcement of the type adopted could be put in without any trouble or delay, it seemed to be by far the

[1] Minutes of Proceedings Inst. C.E., vol. lxv, p. 140.

The Author. best thing to do. Mr. Sims's suggestion of a step in the foundation of the wall was a good one, and a long length of quay-wall having such a step had been built at Southampton from Mr. Galbraith's designs. The only objection to it was that where the ground was at all wet the step was difficult to make; it had to be timbered, which caused expense and delay, and even then it was not altogether satisfactory. On the whole, the slope was to be preferred under the Southampton conditions. With regard to Mr. Wilson's view that there was no particular advantage in the large fall from the front to the back, provided a good hold on the ground were obtained, it was true that if the foundations were taken deep enough a slope was not required; but after consideration, the Author had come to the conclusion that, for a wall on sandy clay, the slope from front to back was by far the most economical way of ensuring stability. This might be accounted for thus:—In order to move a wall having a horizontal base, it was necessary to force forward the earth in front of its toe, but in order to move a wall with a sloping base, or with a step in its base, it was necessary to force forward the earth underneath the wall. Now the earth underneath the wall offered far more resistance than the earth in front of the toe; so much so, that a wall with a sloping base would conceivably travel up the slope rather than push forward the earth underneath it. In the case of the White Star dock wall, the base sloped down from 10 feet below dock-bottom to 15 feet below that level. Assuming the values given in Appendix I for the coefficient of friction and the slope of repose, it could be shown that this arrangement offered greater resistance to horizontal movement than if the base were carried down to 15 feet below dock-bottom throughout—a conclusion based, of course, on theoretical considerations, but, the Author contended, rational and in accord with experience. No doubt the curved profile of the Empress dock wall which Mr. Walmisley admired looked very nice on drawings, but it was expensive and difficult to construct, and there seemed to be little or no advantage in a curved over a straight face. Certain settlement-cracks had shown themselves near the scar ends of walls which had been built up to their full height, but these cracks had never opened more than about $\frac{1}{4}$ inch, and had given no trouble since the adjoining lengths of wall were built. With reference to Sir John Griffith's request for a drawing showing the diagonal struts placed in the trench, it would be difficult to illustrate them, as they had followed no special system. It might be said, however, that the diagonal struts were of two kinds: vertical diagonals were inserted to prevent the middle piles from rising, The Author. and horizontal diagonals were inserted to prevent the middle piles from moving bodily towards one end of the trench. He was inclined to agree with Mr. Wilson that these middle piles might have been dispensed with altogether; there had been the greatest difficulty in driving them down to the bottom of the trench. It was not easy, however, to arrange any other method of preventing the struts from buckling; and, moreover, these centre piles were useful in taking the weight of the travelling cranes which lifted excavated material. Passing to the design of the wall for portion B, the under-water trench had been criticized freely, and Sir John Griffith had suggested that an open trench excavated by dredger would have been better. With an open trench it would have been impossible to obtain the deep foundation and the sloping base (which the Author regarded as being so important at Southampton) without very heavy expense, and such a trench filled with concrete would have been much more costly than the one adopted. It was true that a good deal of divers' work was required in the construction of this trench, but that work was of a simple character, and was carried out rapidly and without interruption. The Author had long known and appreciated Dr. Bindon Stoney's admirable work with 400-ton blocks at Dublin. Such blocks, however, would not have been suitable for the White Star dock. It would not have been worth while to purchase the special plant involved for so short a length of wall, and the making and setting of the blocks would also have presented many difficulties at Southampton. All the blocks there were provided with joggles, which were shown in Fig. 8, Plate 2, although not specially mentioned in the Paper. He agreed with Mr. Walmisley that there was no objection to mixing submarine concrete with sea-water. At first he had been inclined to oppose this practice, on account of the white powder which formed directly concrete was immersed in sea-water, and was seen clearly when the concrete was dried. It was probable, however, that this chemical action was purely superficial. The Associated Portland Cement Manufacturers, Limited, who supplied the whole of the cement used on the works, had been good enough to carry out some experiments on cubes of concrete made with sea-water and with fresh water, and kept both in sea-water and in fresh water. The results indicated that there was apparently no disadvantage in mixing with sea-water. He still preferred, however, to use fresh water for reinforced-concrete work, so as to minimize the risk of rusting the steel. The President and Mr. Wilson had observed that the cost of this wall was higher than it should have been, and it should be mentioned, The Author. in this connection, that the cost stated in the Paper, £117 per lineal foot, included the preliminary dredging and filling behind the wall. These two items alone amounted to £10 per lineal foot. Of course, a large part of the expense was due to the foundations; but when it was considered how difficult it was to design satisfactory foundations at Southampton, it would probably be conceded that the wall was economical under the circumstances. Mr. Dobson had compared the wall at berth No. 49 with one he had built in India, which was 44 feet high and had cost £34 per lineal foot. But the wall at berth No. 49 was 54 feet high, not 44 feet, and the cost included excavation and filling, as well as the deep foundation-trench necessary to prevent the wall from slipping on the sandy clay. The design of wall adopted for portion C had been much criticized, and several speakers considered that it would have been better to adopt caissons. As already mentioned, however, caissons were difficult to sink at Southampton, and moreover the danger of sand running in under the cutting edge, which Mr. Scott had alluded to, would have been a very serious drawback at this site. Probably, as mentioned in the Paper, a satisfactory alternative would have been to sink steel caissons under compressed air, as had been done so successfully at Havre. There was no doubt, however, that this process would have been much more expensive than the one adopted. Probably Mr. Sims's suggestion that box dams should be adopted was more economical. It would, in fact, be a modification of the scheme actually carried out, the only difference being that the piers would be made wider and the arches smaller, and possibly that would be an advantage. The Author was unable to agree with Mr. Moncrieff's suggestion that the platform behind the wall was of no value. As explained in the Paper, that platform was constructed with a view to reduce the pressure on the pier-foundations. It was impossible to set down in figures the exact amount of relief given, but it could hardly be disputed that the effect of the platform was that the weight of superincumbent earth was carried down to the feet of the piles, and hence that the horizontal thrust due to this weight was imposed on the wall at or near its base, instead of higher up. Consequently the overturning moment on the wall was reduced, and the pressure on the toe of the wall was diminished accordingly. Moreover, it was well known that even isolated piles driven into the ground reduced the tendency of that ground to slip. Therefore what Mr. Moncrieff termed "a mixture of piles and earth" was undoubtedly a better backing than earth pure and simple, and gave relief to the wall. This relief was gained at comparatively small expense, as, of course, the piling work did not involve any deep and difficult sinking of trenches, and moreover at this site a good many of the piles happened to be already driven, as they formed the foundation of a building which existed before the works commenced, and which had been demolished. With regard to equipment, a good deal had been said on the subject of dummies. At Southampton no objection to them was raised by the shipowners, and the Author thought they were advantageous on the whole, as they prevented damage to the ship or to the wall. The only drawback was the cost of their maintenance. Their chief advantage was that they permitted of a batter being given to the face of the wall, which allowed the wall to be built with a broad base, without an excessive toe projection. That, as already explained, was an important matter where foundations like those at Southampton had to be built upon. In reply to Mr. Sims, no power capstans had been provided. Some years ago, when fitting out the Empress dock, power capstans were installed, but they were never used. The ships preferred to make use of their own winches for warping. Referring to Mr. Scott's observations on the sheds, the first shed had an overhanging balcony, but this was found to interfere with the loading of trucks on the railway underneath it, and therefore the other balconies were kept back. Run-ways in the cargo-sheds could be introduced at any time, but the Author had not yet seen any system of run-ways which would be of assistance in handling the miscellaneous cargo dealt with at Southampton. Several members had asked for further information as to the cost of the works, but to set out fully the cost of the quays and their equipment, and to compare this cost with their earning-power, as Sir John Griffith had suggested, would be a good deal beyond the scope of the Paper. Mr. Palmer had offered some figures for the total cost which the Author was not in a position to confirm or dispute. He would like to point out, however, that the works described in his Paper included not two berths, as Mr. Palmer had suggested, but nine, namely, five inside the dock, and four outside. Some of these were short berths, but, on the other hand, they were all useful. The President had suggested that the construction of the work might have proceeded more rapidly, and seemed to think that the various walls were built one after the other, but that was not the case. All the operations had proceeded simultaneously, although the Paper described them separately for the sake of clearness. The contract was let in October, 1907, and the "Olympic" was berthed at quay No. 44 in June, 1911. Of course, the adjoining quays were not finished and equipped until after this date, but in view of the difficulties encountered, it might be said that the rate The Author.

The Author. of progress was good. A good deal had been said about the suitability of the dock to accommodate larger ships. Mr. Scott was right in supposing that it was quite possible for the "Imperator" to enter the dock, but his suggestion that she would lose half a day by doing so was misleading. The "Imperator" had hitherto picked up her passengers by tender at Cowes, which was only $\frac{1}{2}$ hour distant from Southampton. The ships which entered the docks generally needed coal, water, or cargo, as well as passengers. The Author agreed with Mr. Meik that it would be useful if some shipowner could be induced to read a paper on the dimensions that were likely to be given to ships within the next few years. Meanwhile it might fairly be claimed that the White Star dock would meet all requirements for many years. It should be borne in mind that the increase in the size of ships did not always cause a dock to become obsolete. The old outer dock at Southampton, which was built in 1840, was still as busy as ever. Moreover, the London and South Western Railway Company had purchased 400 acres of land on the east bank of Southampton Water, where it would be possible to make docks to accommodate any ship that was likely to be built. It would be agreed that their enterprise in this matter was worthy of all praise.