

done by scoops with that done by steam-navvies at Newport to the Mr. Scott. disadvantage of scoops, but Mr. Scott would point out they were adopted at a time when it was quite impossible to work steam-navvies on the soft mud, it being absolutely necessary to adopt some method that would obviate the use of locomotives and wagons. As soon as the steam-navvies could be put on the surface of rock they were adopted and the use of the scoops was discontinued, but it must be remembered that there was about 40 feet of mud overlying the rock. With regard to Mr. Gibb's suggestion as to poling-boards, Mr. Scott could only endorse what Sir John Jackson had said on the subject and assure Mr. Gibb that nothing but disaster would have resulted had they been tried in the deep trenches at Keyham. In reply to Mr. Binns's question as to dredging a portion of the mud before the closing of the dam, there was a special stipulation in the contract that this was not to be done on any consideration whatever, and no doubt the Admiralty engineers had good reasons for the stipulation: had it been otherwise the contractors would have proposed to dredge a very large quantity—probably as much as 2,000,000 cubic yards—before closing the dam.

Correspondence.

Mr. JOHN S. BRODIE observed that it was not quite clear what Mr. Brodie. was meant by the "segments" of the concrete columns under the outer wall, and a little further explanation would be appreciated. The average depth of concrete under the centre part of the floor of the docks and lock was given as 14 feet, and under the side parts 12 feet 6 inches. Considering that, underlying this, there was fairly solid rock, the depth of concrete stated would appear to have been excessive. With regard to the use of limestone from local quarries in making concrete blocks, and otherwise in concrete, it was surely extremely hazardous to risk limestone subject to contact with water, in an important work of this description.

Mr. M. RATCLIFFE BARNETT thought that unless there had been some Mr. Barnett. other special reason than that mentioned in the Paper for building the south cross dam on the line shown, it would have been preferable to build it so as to pass through the centre of the entrance to the tidal basin. This would have enabled the north arm of this basin to be built clear of the coffer-dam altogether. Would not the same

Mr. Barnett. purpose have been served by building first that portion of the main coffer-dam which curved round the south arm of the tidal basin, thereby saving the cost of this cross dam altogether? The difficulty in connection with the sewer diversion might have had something to do with the course adopted, but the cross dam itself seemed to be somewhat of a hindrance to the work of the north arm. Perhaps in this case it had been a question of choosing the less of two evils. It would be interesting to know whether, in building the cement-sheds, any consideration had been given to the question of adopting mechanical means of turning the cement to aerate it, as had been adopted in other works where a much smaller quantity of cement was used. Possibly the largeness of the quantity to be dealt with on this work had militated against the use of mechanical turning. From the description of the concrete cylinders it was clear that, where the mud had extended down to the rock, it had been entirely removed from under the columns and replaced with concrete. As regarded the portion of the foundation where the gravel bed was met with, it would be inferred that the gravel had not been removed, in which case there must be a pocket of gravel left under each column, of the same shape as the column. Having regard to the great depth of the overlying mud, there could, of course, be no risk of this gravel being washed out. This case, however, seemed to be one where the method of grouting deep-sea foundations under pressure, advocated and used by the late Mr. W. R. Kinipple, M. Inst. C.E., at the St. Helier Breakwater, Jersey, and elsewhere, could have been adopted with advantage. When the concrete in the pockets between the columns had been put in to above the level of the bottom of the columns, the gravel under the columns could have been grouted up solid with cement, through pipes put down in one or all of the three circular wells in each column, the wells being thereafter filled with concrete. The foundation of the wall would thus have been made solid throughout. This would, in his opinion, have been a distinct advantage, as the area of the columns formed a considerable portion of the foundation-area of the wall.

Mr. Carey. Mr. A. E. CAREY observed that the site of the dock-extension works at Keyham somewhat resembled that of the free port at Copenhagen. In both cases the site had been largely reclaimed from land subject to submergence. At Copenhagen there was little tidal effect and the variation of water-level was due almost entirely to wind-action. The sinking of cylinder foundations through mud to so great a depth as 100 feet was a matter of special interest by reason of the departure of such cylinders from the vertical. In constructing recently some concrete caissons for a quay-wall, where large

volumes of water had to be dealt with, Mr. Carey had set them Mr. Carey. back from the intended line of the work and concreted them in mass concrete in front to the true line. This method would not, of course, have been applicable to so deep a wall as that described. One point of novelty in the details of working was the behaviour of the coffer-dam, as described by Mr. Scott. The movement of this dam bodily and the arrest of its movement by weighting it, were features of interest. Mr. Carey had recently constructed a timber dam 700 feet long across a river-breach, which had for years been neglected and the substratum of which was in part a quaking, boggy clay. Behind and under the shelter of this dam a new length of river-wall 1,000 feet long was constructed. This was built of clay puddle with a slope of 2 to 1 on each side and faced on the river side with chalk pitching. When almost completed there was some tendency for a portion of the wall to slip inwards, towards the excavation, and this movement was arrested by a method somewhat similar to that described by Mr. Scott, namely, running a slope of filling along the edge of the excavation and thus weighting the toe of the wall. The Brown scoops, if apparently somewhat crude, seemed effective; but the actual cost of the work per cubic yard would be a useful addition to the Paper, if Mr. Scott would furnish this figure.

Mr. C. Colson remarked that the credit for the inception of the Mr. Colson. Keyham extension northward was due in a very large measure to the late Mr. Scamp, who was Deputy Director of Works during the construction of the Keyham Steam Yard and Factory. Soon after the completion of those works, he reported on the future inevitable extension of the yard, and in doing so pointed out that the only direction in which such an extension could be carried out was to the north: at the same time he recommended, in view of this fact, that the whole of the area between the Keyham yard and the Weston Mill Lake should be acquired for naval purposes. This report was ultimately acted upon, and Mr. Scamp took great pains to investigate the physical characteristics of the site, and its possibilities, favourable and the reverse. As one result of this careful investigation he foresaw the difficulties likely to be encountered owing to the unstable character of the material overlying the slate rock, and emphasized the necessity of reaching the solid rock in founding all permanent works. In referring to the material underlying the mud as "rock" it had to be borne in mind that the surface of this slate rock, known locally as shillet, proved to be very disintegrated and altogether unstable as a foundation; and therefore the whole of this rotten shillet had to be removed down

Mr. Colson, to the solid rock. This was especially important in the case of the dock-floors, in view of the concentrated dead weight on the keel-blocks, which, in the case of a large battleship, amounted to a maximum of about 80 tons per lineal foot at some points in the ship's length, and might in the near future reach, if not exceed, 100 tons per lineal foot. Later investigation emphasized the earlier views as to the nature of the mud, but did not reveal the whole of the facts. On all large works, especially of such magnitude as those under discussion, bottom conditions, revealed only as the site opened out, brought about unforeseen checks and difficulties, some serious, others of a minor character. It was not surprising, therefore, that the Keyham Extension Works were not exempt from such contingencies, the most important being due to the great depth of mud and the extreme irregularity of the rock surface. The principal change brought about by the development of unfavourable conditions was in the method of reaching the rock in the outer west and north walls. Many schemes were discussed, among others rectangular caissons, and triple columns. The result of very careful consideration was an arrangement of triple columns differing somewhat from the earlier triple columns introduced by the late Mr. Deas. It was believed that columns of this newer form, while requiring no guide-piles, presented greater possibilities of control in sinking than any other form of concrete monolith. Other favourable features were that they afforded facilities for examining the bottom and ensuring a sound seating of the column on the slate rock. Further, in view of the developed conditions, it was deemed desirable to establish a sound connection between the front and the back rows of columns. The plan of the columns was therefore so designed that the mass concrete in the irregular central pockets had a dovetail grip on the columns, and so established an effective tie between the two rows. Figs. 9, Plate 1, showed a distance of 10 feet between the columns longitudinally. This dimension was not as originally intended, but was the result of experience, the original idea having been to sink the columns practically close together. It was found, however, at an early stage of the operations, that the effect of sinking was to increase the density of the mud immediately surrounding a column. Consequently the adjacent column met with unequal resistance, which created difficulties in sinking; further experience demonstrated the wisdom of increasing the distance between the columns to 8 or 10 feet and sinking them in alternate positions as described in the Paper. By adopting this course the difficulties in sinking were reduced to a minimum, while a substantial saving of

costly columns was effected. Owing to the increased density Mr. Colson. of the mud, no abnormal difficulty was experienced in clearing the 10-foot space between the columns by ordinary excavation and timbering. In sinking the columns the most important element of resistance to be overcome was of course the skin-friction, which was augmented by the roughness and irregularity of the concrete surfaces. It was possible that the sinking might have been somewhat accelerated had the outer surfaces of the columns been rendered; a smooth surface would have reduced the skin-friction and possibly have saved a little time, but the cost would have been augmented. With regard to the piling which was put in over a larger area to support the filling, he might refer to an occurrence some years ago on a large work with which he was connected, and the effects of which were no doubt still visible. The work was on a site somewhat similar in character to the Keyham site—a reclamation with a considerable depth of mud. The filling required to make up the area to coping-level was deposited directly on the mud, the surface of which, to a depth of a foot or two, had hardened considerably. Before long it was observed that the walls, which were on piled and cross-timbered foundations and of ample stability in all respects, were gradually moving forward on the foundation-platform. It was evident on examination that the movement was due not to the ordinary stresses to which a retaining-wall was subject, but to a severe horizontal thrust, the result of the weight of the filling, which was about 10 feet deep, acting on the soft mud. With regard to the method of constructing the dock-floors, it would, he thought, be admitted that horizontal beds or joints in concrete covering a large area, and subject to upward hydrostatic pressure, constituted an element of risk; therefore, in view of the width of the dock-floors, the method adopted had been to deposit the concrete in the form of blocks constructed in situ, the idea being to obviate all horizontal joints in the mass and to arrange the blocks with radial longitudinal joints and in such sizes as to constitute an arch. The requirements of the original design, as to the number of such blocks in the width of the dock-floors, were departed from to some extent, as it was found that with the facilities provided by the contractors a larger block could be formed in a given time than was anticipated; but the principle was preserved throughout. With regard to the method adopted for working the caissons and dock-machinery and for general purposes, if steam could be distributed from a central power-station without condensation in the pipes, it would probably afford the most economical method of applying power; but given a large area, a long length of main, and

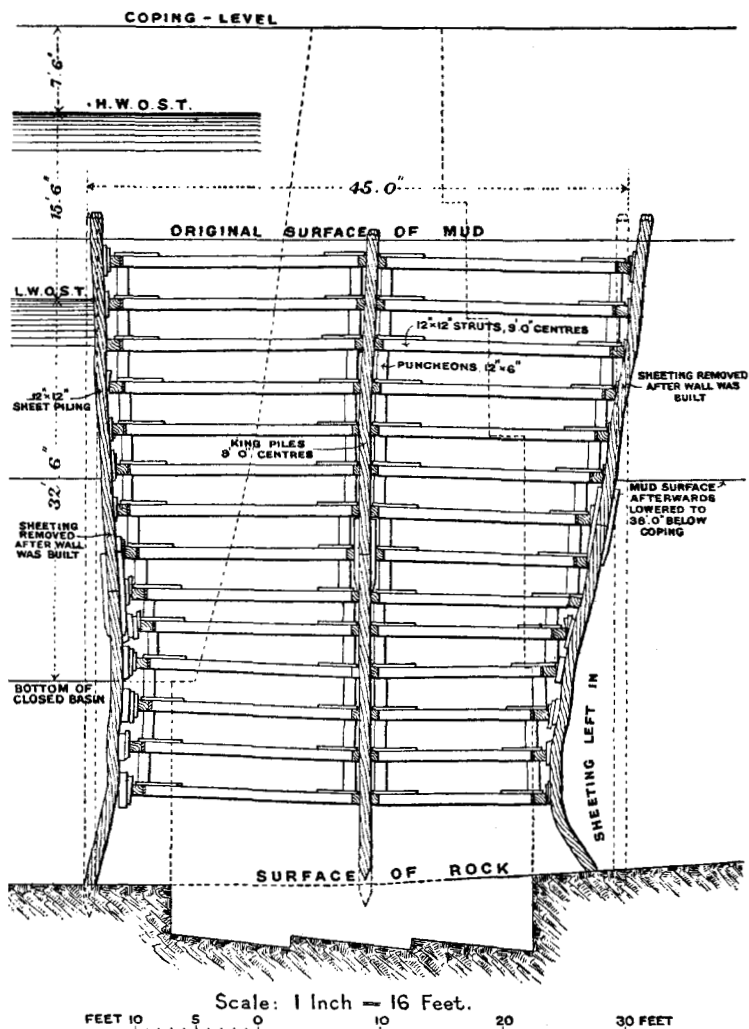
Mr. Colson. an intermittent demand, such a method was not feasible. The hydraulic and pneumatic systems of distribution appeared to run each other fairly closely in the matter of efficiency. The result of observations on the practical working of both systems appeared to be that, with continuous use such as obtained more in a commercial dock than in a large naval establishment (as, for instance, the use of numerous cranes for the manipulation of cargo), the hydraulic system would be the preferable one as regarded economy; but with a number of machines spread over a large area, some of them at a considerable distance from the source of power, and all working more or less intermittently, the requirements were on the whole more economically met by the pneumatic system, one particular advantage being the reserve of power—depending, of course, upon the size or number of the receivers provided—that was available during the time the pumps were standing, through any temporary cause. The following report as to the working of the pneumatic system at Keyham might be of interest:—

“From the first the plant has worked most satisfactorily. It is used for working caissons, dock and basin penstock-valves and capstans. It is also used for working pneumatic tools on ships in dock and in the shops. The air-main has proved perfectly tight, and except at one or two points, where, owing to a slight settlement of the ground, a pipe has fractured, has given no trouble. A pressure of 100 lbs. per square inch is maintained in the receivers, of which there are six, each of 300 cubic feet capacity. Under the heaviest demands on the plant there is very little fluctuation in the pressure in the reservoirs. The loss due to friction in the mains is small. At the extreme distance from the power-station in the north-east and north-west corners of the closed basin the pressure is 98 lbs. per square inch, while between the docks the full pressure is maintained.”

Mr. Sadler. Mr. HENRY SADLER submitted a cross section (*Fig. 1*) of the trench for the north wall of the closed basin, taken through a point about 150 feet east of the north-west corner of the basin. This section gave an interesting illustration of the difficulties contended with in the sinking of the deep trenches. The 12-inch sheeting was originally driven perpendicularly from the surface of the mud, as shown by the dotted lines. The profile of the wall as built was also shown by dotted lines. The depth of the mud at this place was about 54 feet. After about five frames of timber had been put in, the upward movement of the mud in the trench lifted the centre or king-piles, which in their turn raised the struts out of the horizontal at their intersection with the centre piles. Had this lifting been allowed to continue, there was no doubt that a similar collapse of the trench would have occurred to that which happened at the north-east corner, where the mud was still deeper. Excavation

inside the trench was, however, then suspended, while the mud Mr. Sadler. surface on each side was lowered 20 feet for a width of 100 feet, in

Fig. 1.



accordance with the instructions issued before the trench [was commenced. After this had been done, excavation inside the trench was resumed, and the succeeding struts were put in, with a decided

Mr. Sadler. dip below the horizontal at their intersection with the centre piles, as shown in the section. This arrangement constituted a powerful toggle-joint, interposing resistance to any further tendency of the centre piles to lift. The remainder of the excavation was completed without mishap, but a considerable quantity of extra stopping timber was required to choke back the mud in the spaces between individual sheet-piles which had become very much buckled. The pressure was so severe that the ends of the struts were in many places squeezed into the walings to the extent of quite $1\frac{1}{2}$ inch. The cross section shown was not an extreme case, as buckling of the sheeting occurred to about the same extent in parts of the trench for the west wall of the closed basin, where the original depth of the mud was still greater, and notwithstanding that the surface had been lowered before excavation was commenced. In order to interpose greater resistance to the upward thrust of the centre piles, diagonal struts were in some cases inserted, raking upwards and outwards from the centre.

He also contributed the following additional notes upon the caissons provided for closing the various entrances, which formed an important feature of the undertaking. The eight sliding caissons and the three ship or floating caissons were designed in the office of the Civil Engineer-in-Chief, and constructed under contract by the Thames Ironworks, Shipbuilding and Engineering Company, under the direction of Mr. A. M. Alexander, M. Inst. C.E. The eight sliding caissons were divided into two types:—Three, designated as A, B and C respectively, were of similar dimensions, and were provided for the entrances to graving-docks Nos. 4 and 5. The other five, marked D, E, F, G and H, of larger dimensions but all alike, were provided for the entrances to graving-dock No. 6, the lock and the west entrance from the Hamoaze to the closed basin. In the details of construction the three smaller caissons were identical, and the details of the five larger caissons were also alike, except that C, E, and G, situated respectively at the tidal-basin entrances to docks Nos. 5 and 6 and the river-entrance to the lock, were each provided with a pair of culverts and sluices, to assist, if necessary, in levelling the water on either side. The 8-foot by 6-foot filling-culverts had, however, hitherto proved sufficient for this purpose. These additional culverts would probably be found useful in the future for scouring purposes. One sliding caisson of the smaller type and one of the larger type were erected complete in the contractor's yard, and thoroughly inspected in every detail before being taken to pieces and shipped to Keyham. The materials for the remaining caissons were marked off from the same templates

respectively. Each of the three floating caissons was erected complete Mr. Sadler. in the contractor's yard, then taken to pieces and shipped to Keyham. The final building was carried out in graving-dock No. 4. The top decks of all the caissons and the camber-decks were capable of supporting a rolling load, on the 4-foot $8\frac{1}{2}$ -inch gauge railway, of 72 tons, on four wheels at 6-foot 6-inch centres. Automatic switches were provided at each end to maintain the adjustment of the rails with those on the dock sides when the caisson floated transversely with any alteration of the water-pressure from one side to the other. Each sliding caisson was erected in its own stop. The erection was commanded by a fore-and-aft gantry carrying a traveller spanning the width of the caisson. The hoisting was performed by a 5-ton crab running transversely upon the traveller. The keel was laid upon a timber launching-cradle about 4 feet above the slope of the granite sliding-paths. The greater part of the structure was built with its centre-line about 2 feet out of the centre-line of the entrance, to enable the after stems to be completed and the greenheart meeting faces to be trimmed while clear of the granite quoins. The caisson was next launched by hydraulic jacks till its after end was about 2 feet into the camber, to enable the forward end to be similarly completed. The caisson was then moved back to its central position across the entrance, and four 250-ton hydraulic jacks were introduced under the bottom deck-beams, one jack being placed at each of the four corners. The launching-cradle was then removed and the caisson was lowered on to the granite sliding-path. The water-tightness between the greenheart heels and stems and the axed granite quoins was so good that leakage was scarcely perceptible. The weight of each of the three smaller sliding caissons, when lowered on to its sliding-path, was 533 tons before being ballasted, and the weight of each of the five larger caissons was 824 tons under the same conditions. The permanent ballast was deposited upon the bottom deck. About one-half of this weight was of "burr concrete" made from punchings out of steel-plates, rammed in 3-inch layers and grouted with Portland-cement mortar. The weight of the burr concrete was 350 lbs. per cubic foot. The remainder of the permanent ballast was of pig-iron packed as closely as possible adjacent to the burr concrete. To enable the sliding caissons to be floated for examination or other purposes, about 15 tons of pig-iron ballast, to give an excess of weight over buoyancy, was stowed in the air-chamber in such a position that it could be removed when necessary. When fully ballasted and with all water-tanks empty, the weight of each of the smaller sliding caissons was 710 tons; that of each of the larger sliding caissons was 1,080 tons, while the floating caissons under the same conditions weighed

Mr. Sadler. respectively 832 tons, 1,047 tons, and 1,043 tons. The capacities of the top tanks of each of the floating caissons were respectively 54, 57, and 57 tons of water, while the scuttle-tanks in the air-chambers were of the same capacity. These latter were filled from the outside water through 9-inch valves controlled from the top deck, and were emptied by blowing out into the top tank with compressed air or by pumps worked from a hand-capstan. The top tank was emptied by gravitation through a valve, into the middle chamber, which was in communication with the external water. The filling and emptying of the end chambers during the sinking or raising of the floating caissons was controlled by 18-inch valves, and by this means the trimming fore and aft could be controlled. The upper water-ballast tanks at each end of the sliding caissons were of sufficient capacity, not only to ensure an approved excess of weight over buoyancy under extreme tidal conditions, but also to enable the filling or emptying of either tank, according to the direction in which the caisson was travelling, combined with the rollers, described hereafter, to be arranged to prevent "kicking" or tilting of the caisson while it was being hauled, and at the same time involving the smallest practicable pull on the chains. The water-ballast tanks in the air-chambers were used for emergency only, and were emptied by pumps driven by compressed air. The sliding caissons were hauled by means of continuous steel pitch-chains working around sprocket-wheels, and were attached to the ends of a cross-head or yoke girder which was connected at its centre to a combined buffer and draw-bar at the after end of the caisson, thereby equalizing the pull on the chains. The after sprocket-wheels were driven, through gearing, by a double-cylinder compressed-air engine, the arrangement exerting a pressure of 70 tons and hauling or pushing the caisson at the rate of 25 feet per minute with air-pressure at the cylinders of 75 lbs. per square inch. The engines were also arranged, by gearing and lifting-screws, to lift the camber-deck, the main girders of which were hinged at their inner ends, to the extent required to enable the caisson to be hauled down the 1-in-40 incline into the camber. The clutches for changing the motions were automatically interlocked in order to render it impossible to start the hauling or pushing motions until the lifting motion had been completed, or vice versa. The motions were also automatically cut out at the ends of the travel of the caisson, and when the required lift of the camber-deck had been obtained. The hand-railing on the top deck of the sliding caissons was arranged to turn down automatically into troughs at the sides at the commencement of hauling into the camber, by the gradual release of a system of counterweights and rocking levers held up by a rod thrusting horizontally against the side wall at the entrance, and was lifted

by the same arrangement as soon as the caisson was drawn out across Mr. Sadler. the entrance. The point of application of the hauling force being situated at a distance of 3 feet 6 inches below the topdeck, the frictional resistance of the keels upon the granite sliding-paths would result in a tendency for the caisson to "kick" or tilt longitudinally during its travel. This tendency was, however, provided against by the cast-steel rollers provided, one near each end of the caisson, running upon a cast-steel roller-path situated upon the centre-line. Each roller separately could be forced down upon the path by a hydraulic ram worked from the top deck by a hydraulic hand-pump with distributing valves, enabling pressure to be put upon either roller or both at once. The forcing downwards of the front roller, according to the direction in which the caisson was travelling, converted sliding-friction into rolling-friction by lifting that end of the caisson to an extent sufficient to produce this result. The amount of the downward stroke of the ram could be limited by an adjustable lock-nut. The long upward stroke of the ram was to enable the roller-carriage to be drawn up to the level of the bottom deck where it could be examined by divers; and, if necessary, it could be hoisted up to the top deck for repairs. Each apparatus was capable of bearing with safety a vertical and rolling load of 50 tons. Mud-scrapers of vulcanized rubber were fixed at each end of the rollers and of the sliding keel. The following were the results of the contract-tests applied to one of the floating caissons.

1907. FLOATING CAISSON SUNK IN INTERMEDIATE STOP OF DOCK No. 6.
 27th May.
 9.55 A.M. Started pumping down south end of dock.
 11.15 A.M. South end of dock empty. Water-level in north end 49 feet 6 inches on intermediate sill or at H.W.O.S.T. Meeting faces water-tight.
 1.0 P.M. South end of dock flooded.
 2.0 P.M. Started pumping down north end of dock.
 4.45 P.M. North end of dock empty. Water-level in south end 50 feet 6 inches on intermediate sill or 1 foot above H.W.O.S.T. Meeting faces water-tight.

TEST OF RAISING CAISSON OUT OF STOP, TURNING END FOR END AND SINKING AGAIN IN THE STOP WITH THE WATER AT A LEVEL OF H.W. NEAPS OR
 1907. 46 FEET ON SILL.

- 28th May.
 2.35 P.M. Scuttle-tanks and top tank full. End-chamber valves open. Commenced blowing out scuttle-tanks.
 2.40 P.M. Scuttle-tanks empty. Valve opened to let water out of top tank.
 2.43 P.M. Caisson began to rise.
 3.3 P.M. Caisson raised 13 feet 6 inches and floating at the level of top deck of air-chamber.
 3.45 P.M. Caisson turned end for end and replaced in stop. End-chamber valves closed. Scuttle-tanks filled and then emptied by blowing out into top tank. Weight of water in tank caused caisson to sink about 3 feet below level of top deck of air-chamber.
 4.10 P.M. End-chamber valves opened. Caisson began to sink.
 4.20 P.M. Caisson completely sunk in stop.

Mr. Sadler. On the 29th May, the caisson was again tested for water-tightness by pumping out the dock, first on one side and then on the other, and the meeting faces were found to be as water-tight as on the previous occasion. The other two floating caissons were tested similarly with equally satisfactory results. The above-mentioned operations, which were carried out in a somewhat leisurely manner for test purposes and observation, would no doubt be considerably accelerated in practice. Inclining experiments were also carried out on each of these three floating caissons to prove that the conditions of stability had been fulfilled. In testing the hauling machinery of one sliding caisson of the larger and one of the smaller type, a dynamometer was inserted between a pair of links of each hauling chain, and the pull on the chain was noted under the following conditions:—

(a)	Hauling out of camber	Forward roller in action.
(b)	” ” ”	Both rollers in action.
(c)	” ” ”	Neither roller in action.

It was observed that, under low-water conditions, the action of the rollers had a marked effect in diminishing the resistance to hauling and consequently producing steadiness in the travel. Tests of the hauling-machinery of all the other sliding caissons were also carried out under low-water conditions, but omitting the dynamometer tests on the hauling-chains, as the weights of these caissons were known to be identical respectively with the weight of the caisson of each type selected for testing the pull on the chains. Sliding caissons C and E were caused to float by the removal of the pig-iron ballast in the air-chamber, and inclining experiments were carried out to prove that the conditions of stability had been fulfilled. After the above-mentioned tests had been completed Mr. Sadler had frequent opportunities of observing the working of some of the sliding caissons during the docking of ships, and he noted that their working and condition continued to be satisfactory.

Mr. Sandeman. Mr. J. WATT SANDEMAN, while giving full credit to the engineers and contractors for the successful accomplishment of these extensive dock-works on a site which presented unusual difficulty, had great reason to fear that the concrete used in the works was of such composition that it would be injuriously affected by the action of sea-water. The proportions of 1 of cement to 2 of sand and 6 of shingle, and 1 of cement to $1\frac{1}{2}$ of sand and 5 of shingle, mentioned for the concretes used in the principal parts of the walls, were such as to render them permeable by sea-water, and consequently incapable of resisting the destructive action of the acids contained in it. He had in mind several instances of concretes having pro-

portions which rendered them less permeable than the concretes Mr. Sandeman. at Keyham, but which, nevertheless, had been destroyed by sea-water. Referring to Appendix I, it was stated that in concrete of quality B, $3\frac{1}{2}$ cubic feet of cement, 7 of sand, and 21 of shingle, in all $31\frac{1}{2}$ cubic feet, when mixed, bulked as 26·25 cubic feet. The only way by which such a result could be obtained would appear to be by the concrete having been thrown loosely into the gauge-box without being worked with the shovel. This appeared from what was stated, namely, that the excess of mortar beyond that required to fill the interstices in 21 cubic feet of shingle was 1·3 cubic foot, which added to the shingle made 22·3 cubic feet to which the concrete should have been reduced, instead of 26·25 cubic feet as stated, or a reduction of 29·2 instead of 16·6 per cent. A reduction of 29·2 per cent. of dry materials when made into concrete agreed more nearly with numerous trials which he had made. The reduction stated in the Appendix (taking average weights of sand and shingle) would make the concrete weigh 123 lbs. per cubic foot. The corrected reduction would make it 145 lbs., which agreed better with recorded weights of that class of concrete. It was also stated that the excess of mortar beyond that required to fill the interstices of the shingle was 6·19 per cent., and that the shingle had 35·5 per cent. of interstices. The ratio of mortar to shingle would therefore be 41·69 per cent. Although theoretically it might appear that this quantity of mortar would be sufficient to render the concrete impermeable, yet from experience and repeated trials Mr. Sandeman had found it absolutely impossible with less than 50 per cent. of mortar to make impermeable concrete, and even with that quantity, the most careful manipulation and ramming were necessary. In concrete having 50 per cent. of 1-to-2 mortar, the proportion of shingle would be 4 parts, but on account of the difficulty which he had found in ensuring thorough ramming and manipulation (and also to admit of displacers being used), he always allowed 70 per cent. of mortar in concrete for sea-works, which gave a proportion of 1 of cement, 2 of sand and 3 of shingle, and with this proportion he had never failed to obtain absolutely impermeable and satisfactory concrete in piers and docks. Concrete of 1 of cement, 2 of sand and 3 of shingle, with displacers costing 7s. per ton, would not cost more than 1:2:6 concrete without displacers. He had no desire to be an alarmist, but since the destructive action of sea-water on permeable concrete became more generally known by the failure of the Aberdeen dry dock in 1887 he had made a special study of the subject, and judging from experience in both the failure and durability of concretes in sea-works, he was of

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Mr. Sandeman. opinion that the proportions of the concretes in the walls at Keyham must render them permeable, and therefore incapable of resisting the destructive action of sea-water.

Mr. Tait. Mr. W. A. TAIT observed that one feature of no little interest to a waterworks-engineer was that the sinking of the trench proper was not, after the first experiment, proceeded with until general excavation over a considerable area had been removed. This was precisely the course he recommended about 10 years ago in preparing for the sinking of a reservoir-trench to a depth of over 100 feet at the deepest part, through rather treacherous material. It was not the initial outlay which had to be looked to in such circumstances, but the ultimate cost, together with the reduction of risks during construction. The portion of the trench which collapsed was really very heavily timbered, but the movement happening as it did must have shown very clearly the desirability of modifying the method of procedure. It would be interesting to learn when the jointed piles were first adopted, and what was the difference in cost between such piles and single timbers of great length, which latter were usually very expensive when compared with piles in lengths of 30 to 40 feet. The arrangement of the dam described by Mr. Scott was very ingenious and, as Mr. Tait had seen on a visit to the works, very successful. It seemed to be an idea well worth adopting in other places where there was a considerable rise of tide. Having regard, however, to the rise and local peculiarities of the tide at Devonport he would be glad to hear the result of any experiments carried out with the sluices into the closed basin referred to on p. 8.

Mr. Voisin. Mr. VOISIN, of Boulogne-sur-Mer, remarked that the very interesting Papers upon the works carried out at Keyham brought again into prominence the following material differences from French practice. (1) The importance of temporary appliances. This, which had already been pointed out by him¹ in connection with the works at Folkestone, began to be appreciated more thoroughly, and the present tendency of the great French contractors was to provide themselves with such plant as to render them independent of most obstacles to the progress of the work. The increased cost must be discounted by the very appreciable saving in the time occupied in construction. In order, however, to get an idea of the economical value of the method it would have been useful to have the prime cost per unit of each element of the work under discussion. (2) The use in the rather deep foundations of the open caisson, more or less of the type used at Glasgow, that was, without compressed air. It might be

¹ Minutes of Proceedings Inst. C.E., vol. clxxi, p. 121.

questioned, however, whether this system was not just as far from Mr. Voisin, the mark in one direction as the continental practice, particularly that of France, was in the other. Thus, it might have been better to use compressed air in that part of the outside wall where a considerable thickness of gravel and stones was encountered before the rock was reached. Less trouble would doubtless have been encountered by reason of the dip, sometimes very sudden, of the rock, and, in short, success had been attained only because the mud was absolutely homogeneous and sufficiently water-tight. It was certain, however, on the other hand, that work in the open air, whenever possible without too great difficulty, was preferable to work in compressed air. (3) The general use, in sea-works, of concrete and also of artificial stone, instead of the almost exclusive use of masonry—notably in France. The regrettable decomposition of concrete which had been experienced in France a few years ago had naturally made French engineers less inclined to use it for sea-work elsewhere than in the foundations proper; but it must be recognized that in England the danger had in a certain measure been avoided by the following precautions: (a) The storage of the cement and its aeration for about a month—a regular practice with French engineers in former times, but one which had had to be given up to a large extent, owing to difficulties of storage; (b) the greater richness in cement as well as the higher proportion of large particles (gravel) as compared with the finer (sand), the gravel being besides finer than that used in France except for reinforced concrete. The concrete at Keyham of quality C, for instance, resembled, but only in this respect, what was used in France for reinforced concrete, which seemed to possess when in sea-water lasting properties which were not found in ordinary French concrete. The cement used at Keyham was on the average finer-ground, slightly more quick-setting, and of much greater strength, than that used for sea-works in France; and under these conditions it did not appear to offer such great guarantees as the latter. This was undoubtedly the reason why the richness of both mortar and concrete was greater in England. He presumed that the face was covered with a skin; this however did not appear from Sir Whately Eliot's Paper. From the point of view of design, it might be questioned: (1) Whether an entrance 120 feet in width, with a depth of 32 feet at low water of spring-tides, was not rather small (particularly the depth) for a naval tidal basin, having regard to future requirements and naturally ignoring any question of cost. (2) Whether it was altogether necessary to provide in the wet dock a depth of 32 feet 6 inches at low water of spring-tides. (3) Whether it would not be better, owing to the rapid deterioration

Mr. Voisin, of timber, due to the teredo, on the south coast of England,¹ to use in future reinforced concrete, which in this case would have obviated the loss of time involved in obtaining numerous Oregon piles 65 to 75 feet in length. The use on a large scale of sliding caissons, as a means of closing both locks and graving-docks, deserved to be noted; it would, however, be very interesting to have accurate information upon the working of these appliances. In short, the works carried out at Keyham presented the greatest interest equally in design and in execution, and they did credit to those who had been entrusted with them, notably the Authors.

Mr. Wells. Mr. L. FORTESCUE WELLS asked how the cost of Cornish and Norwegian granite delivered on the works compared, and whether it was all dressed at Keyham, or at the quarries. He understood that in the case of Norwegian granite, when dressed at the quarry, trouble was sometimes experienced owing to the dressing being inaccurately done, and the stone had to be re-dressed. The arrangements for dealing with and testing the cement had been very complete, and Mr. Wells wished that fuller information had been given in the Paper, because few engineers had opportunity or facilities for dealing with cement such as Sir Whately Eliot had had at Keyham. Perhaps he would state what tests had been used besides those referred to in his Paper, and give some information as to the chemical analysis required. It was now generally recognized that the result of a tensile test, after 7 days, of neat-cement briquettes might be in itself a dangerous one upon which to rely; 350 lbs. per square inch was not a high test to ask for. Had any tests been made with sand, and what expansion had been admissible? The poorest mortar used was 2-to-1. With the cement obtainable nowadays, a weaker mixture (except for special work or where great strength was required) might well be used, and on such extensive works he would have expected to see a weaker mortar adopted in many places, with equal efficiency and greater economy. The late Sir Benjamin Baker had used 4-to-1 cement mortar for part of the masonry of the Asyût Barrage,² and this mortar had also been used in the masonry abutments of the new bridge over the Nile at Cairo. Were there any special reasons for using broken stone instead of gravel for making the small concrete blocks referred to on p. 4? It seemed from the text as if there might be. It was interesting to see that the maximum quantity of concrete mixed in a day by six mixers worked out at 1 cubic yard in 3·13 minutes, and

¹ Minutes of Proceedings Inst. C.E., vol. clxxi, p. 122.

² *Ibid*, vol. clviii, p. 41.

that the maximum mixed by one mixer in the same time was at Mr. Wells. about the rate of 1 cubic yard in 2 minutes. No mention was made of "plums" or "displacers" in the concrete: they might have been used in the thick concrete walls with great advantage. What was the objection to their use? Why had the closed basin been made 6 inches deeper than the tidal basin? Over $35\frac{1}{2}$ acres of closed basin the difference in depth represented an appreciable quantity of excavation. There was 48 feet of water in the closed basin at high water of spring-tides and the extreme tidal range was about 15 feet 6 inches. It would be useful if the Author would state what draught of vessel the works were designed to accommodate, and what was the maximum draught of any ship of war at the present time. If the closed basin had not been made so deep, a considerable saving would have been effected, in both the general excavation and the walls, particularly the east wall. The water-level might have been maintained by using the sluices provided, and by pumping when necessary, as was done at London, Liverpool, and many other places. Vessels could still have passed in and out at high water without using the lock, under the same conditions as they could now during spring-tides. He would be glad if Sir Whately Eliot would give the weight per cubic foot of the mud and of the concrete walls, and state whether the retaining-wall near the Naval Barracks had been built in lengths, and whether any trouble had arisen from cracks due to expansion.

Mr. G. H. Scott, in reply, explained that the "segments" of the Mr. Scott. concrete columns were the separate parts of the rings or courses which, when fitted together, formed the complete course; they were clearly shown in Figs. 8, Plate 1. With regard to Mr. Barnett's remark as to the position of the south cross dam, when this dam was built it was designed to pass through the entrance of the tidal basin so that the north arm could be built clear of it, the original width of this entrance being 200 feet. The Naval authorities, however, considered this width too great, and it was reduced to 120 feet after the south cross dam was built. As to the turning of the cement, it was necessary to employ constantly a considerable number of men to unload and shoot the cement on arrival, and to bag it up after aeration for daily use on the works; it was found that these men were able to turn the cement as required, and therefore mechanical turning was not deemed necessary or desirable. The gravel bed met with in the foundations of the outer wall had been in every case removed, as explained by Sir Whately Eliot (p. 14). The columns themselves could not be sunk through it, but were afterwards, when the pockets were excavated, underpinned with concrete, so that the

Mr. Scott. whole area of the columns and pockets was eventually founded upon the bed-rock in every case. For obvious reasons he was not able to give the actual cost of the work done by Brown's scoops per cubic yard, but as 400 to 500 cubic yards were dealt with per shift with one 40-HP. and one 20-HP. engine and four or five labourers, it was clear that the work actually done by the scoops was distinctly economical. In reply to Mr. Sandeman as to the proportions of concrete-materials, exhaustive experiments were made with every cargo of ballast delivered, in order to arrive at the proper quantity of sand to be added to the shingle to ensure the concrete, when set, proving truly homogeneous; and where concrete had had to be cut away for various alterations in different parts of the works, notably at the square end wall of No. 4 dock, which was entirely cut away for the purpose of lengthening that dock, the concrete so removed had been found to be extraordinarily homogeneous—more like solid stone than concrete—without the slightest sign of honeycombing. No one connected with the work who had had the advantage of this ocular proof would share Mr. Sandeman's fears in the slightest degree.

* * * Owing to absence from England, Sir Whately Eliot's reply to the Correspondence (if any) is deferred to the next volume of the Proceedings.

14 January, 1908.

Sir WILLIAM MATTHEWS, K.C.M.G., President,
in the Chair.

The President. The PRESIDENT observed that since the last meeting the world of Science had sustained a great loss in the death of Lord Kelvin, and stated that the Council had adopted the following resolution: "That The Institution regrets deeply the loss which the engineering profession, as well as the scientific world in general, has sustained by the death of Lord Kelvin, who, prior to his election as an Honorary Member of The Institution in 1889, had served as a member of Council for 11 years, and who had, during many years, shown in various ways an active interest in the work of The Institution." The President was sure the members would concur in the action of the Council.