

### Discussion.

Mr. W. J. E. BINNIE, referring to the Paper on the Silent Valley Mr. Binnie. reservoir, remarked that one sentence therein required a little further elucidation, namely, the statement that "From the results of the borings, it became increasingly apparent that the building of a reservoir in the Silent Valley was far beyond the scope of the original contract." The silt contained very large boulders indeed, and the original bore-holes, on reaching them, had been assumed to have found the surface of the rock. As one of the boulders subsequently found was as big as a cottage, it was not surprising that wrong conclusions had been drawn. The late Sir Ernest W. Moir, Bart., M. Inst. C.E., asked him if he could arbitrate between the Belfast Water Commissioners and the contractors, because they were not finding the rock where they expected to find it as they approached the centre of the valley. There was, however, insufficient evidence available, and he suggested that Sir Ernest would do better to obtain the Belfast Water Commissioners' consent to sinking further bore-holes, which should be carried on for 20 feet after they struck what was assumed to be rock. That was done, and the new bore-holes showed the true state of affairs. The parties then came to the arrangement which was set out briefly in the Paper. He did not think there could be any reflection on the late Mr. McCullough, because anyone might have been deceived by the exceptionally large boulders. The Board referred to in the Paper was then set up, and was given a year of exploratory work with the contractors, who were to carry out anything which the Board thought desirable. Farther up the Valley there was another possible site where there would have been no difficulties with glacial material overlying the rock, but, if that site had been adopted, the expenditure of about £500,000 already incurred would have been thrown away. It was therefore essential that, notwithstanding the known difficulties, the dam should be constructed at the original site if possible. It was interesting to find that if a move had been made to the other site the total expenditure would have been about the same as that actually incurred. He would like to endorse all that the Author said with regard to the excellent work of the contractors, Messrs. S. Pearson and Son; there were few firms in the world who had such a knowledge of compressed-air work. He would also like to pay a tribute to Mr. Lovatt, the contractors' agent, who had exercised the greatest vigilance in order to get the work done as cheaply as possible.

Mr. Binnie.

With reference to the sinking of Shaft D, the geological history of the site was of interest. The formation of the silt and deposit was due to ice coming from Scandinavia and passing along the Irish coast, which blocked up the valley, and then deposited the silts as it retreated. An examination of the boulders contained in the glacial material clearly proved that they were not of local origin; most of them came from Scandinavia. The ice, as was well known, ground the debris to the very finest silt. It had been desirable to get a shaft down in the deepest part of the valley, as if it had not penetrated to the bottom of the old pre-glacial valley, it would probably have been necessary to sink into the rock, drive underneath to the old valley and work upwards from that; but by a great piece of good fortune Shaft D and Shaft 13 had been sunk right down. (The results of the bore-holes had indicated more or less where the deep part would be.) The Author stated that Shaft D reached a depth of 212 feet from the surface, and the lowest water-level, as given in Appendix I, was 341 O.D., so that the water was about 89 feet below the surface; and sinking had still to go on for a further 123 feet. When the granite was reached it was not possible to seal off sufficiently to prevent the pressure tending to increase as sinking progressed, and as the pressure reached was only 34 pounds per square inch he wondered what the explanation was. It seemed to him that, as a result of the pumping which was taking place through a number of tubes let into the material, and also generally in the manner described in the Paper, a local cone of depression was probably formed in the water-surface around the shaft, so that the pressure in the working-chamber was reduced.

As mentioned on p. 498, it was found that the silt exerted a pressure equivalent to that of a liquid having a density of 100 lbs. per cubic foot. It was obvious that no ordinary timbering would resist such pressure, unless the trench were so closely strutted that there would not be room for a skip to go down between the struts. The segmental cast-iron lining described on p. 499 was therefore devised. The Author stated that the segments were 18 inches deep, but it was sometimes necessary to use 9-inch segments in very bad places. Altogether about 3,000 cubic yards of material entered either the shafts or the trench simply through blows, which would give some idea of the nature of the material. When that material left the outside of the trench or the shaft cavities were formed, and as it was intended to put the embankment over the top of the ground, no risks could be taken, so the cavities had to be packed with stone and sand or grouted. The grouting would have been difficult with timbering, but with the cast-iron lining it was comparatively simple; further, the corrugated surface at the back of the lining

tended to prevent the descent of the silt. The worst part of the Mr. Binnie. job was when boulders were encountered, as explosives could not be used, and when a boulder was met with the tendency to crack it and cause a rush of silt into the trench was very great.

On p. 486 the Author referred to the flood experienced during the construction of the works and appeared to be a little doubtful of the accuracy of the figure of 3,600 cusecs, but at all events that estimate agreed very closely with one made by the contractors. In the Report of the Floods Committee it came on the curve of maximum floods,<sup>1</sup> but in the Silent Valley very severe floods would be expected owing to the bare mountain-sides and very steep slopes up to the top of the drainage-area. Cloudbursts sometimes occurred, and had formed valleys in the mountains. In designing the flood-discharge works, therefore, it was thought desirable to take into consideration not the ordinary rules but the very exceptional circumstances, and those works were designed to deal with a much larger volume of flood-water than would ordinarily be the case.

With regard to the quality of the water from the reservoir, the Author made a statement on p. 508 which he did not altogether like. A deep peat-bog inside the reservoir was covered with 3 feet of sand, as the cost of removing the peat would have been very great. Although the stream generally ran beautifully clear, the water would have become a filthy black colour if it had been allowed to stand over the top of that peat in a reservoir. It did not cost a great deal to shift the available mound of glacial sand and spread it all over the peat bog to a depth of 3 feet. The Author stated that the water was not acid, nor was it unduly coloured for the type of catchment from which it was obtained. He did not know what the Author meant by "not unduly coloured," because the water was uncommonly clear. It was not filtered, and it was supplied to the consumers in Belfast without any complaint.

Sir MURDOCH MACDONALD congratulated Mr. Binnie on the Sir Murdoch MacDonald. wonderful work which he had accomplished in putting the Silent Valley reservoir on a sound footing. Sir Murdoch had had a little to do with the reservoir, in that Mr. Edward Sandeman, the Engineer for the Commissioners, had consulted him with regard to it. The Commissioners had found themselves in very great difficulties with their contractors, and the Author's words "From the results of the borings, it became increasingly apparent that the building of a reservoir in the Silent Valley was far beyond the scope of the original contract" came very forcibly to his mind. He was not sure that

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<sup>1</sup> "Interim Report of the Committee on Floods in relation to Reservoir Practice," Fig. 3, Plate 1. Inst. C.E., London, 1933.

Sir Murdoch  
MacDonald.

he agreed with them. He had seen the original contract, which, together with the circumstances of the work, constituted a very grave warning to engineers. The contract documents provided that the contractors should sink down to 120 feet or more. A price was asked for each stage down: 50 to 60 feet, 60 to 70 feet, and so on, and then the last price was for "120 feet and over." The contract-drawings did not agree with that; they showed a probable rock-level very much higher than 120 feet—something like 50 or 60 feet down. To his mind, the contract-drawings were not necessarily the vital factor; the contract itself was of primary importance, and that was why he felt that in the case in question the Author's statement that the work was "far beyond the scope of the original contract" might not be correct. It was true that for a certain part of its length the trench went down to 196 feet, that Mr. McCullough, who designed the work and drew up the specification, referred only to "120 feet or more," and that, therefore, in so far as a much greater depth was attained, an extra price would naturally be applied for by the contractor and might well be paid by the engineer. It was clear that engineers should take a warning from what had happened, and should see that their contract-drawings and contract-specifications for future works were as nearly as possible in agreement with each other.

The Author stated that the contract had been signed in 1923, and pointed out that the work carried on from that date until 1926 had indicated that difficulties might arise in the excavation of the trench owing to the running nature of the sand encountered. In 1926 the contractors had thought it desirable to verify whether the engineer's drawings were correct or not, and put down borings in the centre to see where the foundation was really going to be. It seemed to him that it might well have been possible for the engineers and the contractors to confer and arrange an extra price for the extra depth. The engineer had not specified whether the material to be excavated was to be lively (running sand) or otherwise, and that was a matter for the contractors; but with regard to the actual depth it would have been right for a full price to be paid to the contractors. He made those remarks because of the untoward death of Mr. McCullough, who had been told by the contractors, "You have spent a lot of money, but you cannot build a dam on this site; you must move elsewhere." Mr. McCullough had been very gravely perturbed, and his anxiety might well be considered to have hastened his death. It was, therefore, right to pay a tribute to his memory by saying that he had done everything that he reasonably could to meet the contractors, and, as far as Sir Murdoch knew, had been willing to agree to an extra price for the extra depth in

so far as his contract would allow him ; outside the contract there was always the possibility of appealing to arbitration.

Sir Murdoch  
MacDonald.

In conclusion, he was delighted that the Board of Engineers which dealt with the matter had been able to make arrangements so that the money spent by the Commissioners under Mr. McCullough was not wasted, and that a very successful dam indeed had been completed under their auspices on the original site.

Mr. H. PRESCOT HILL observed that in all his experience of reservoir-building, extending over more than 40 years, he had not met with any other instance of dealing with such difficult material or such critical work as that at the Silent Valley. The bed of the valley, through which the trench had had to be sunk, consisted of granite sand and gravel, containing boulders, some of enormous size, the whole being permeated with the very finest silt. As indicating the fineness of that silt he well remembered an experiment made by the late Sir Ernest Moir for the purpose of ascertaining its character, in the course of which a large glass tube, 5 or 6 feet in length, was first filled with a desiccated sample of the material and then stood in a pan of water ; the moisture travelled upwards through the silt by capillary attraction to a height of about 5 feet. The silt being of such an extraordinarily fine quality as to be practically liquid when wet, it was essential to extract much of the moisture before there could be any hope of sinking a trench through it down to a foundation of such a depth as that which the circumstances foreshadowed. Under those conditions it was consequently necessary for the Board of Engineers to find out first of all whether, in view of all the prospective difficulties, the construction of a reservoir on the site selected was practicable. A sum of about £500,000 had already been spent on the site, and the position of the Belfast Water Commissioners was therefore somewhat desperate in that respect. In fact, he thought that if the Board of Engineers had not been disposed to advise the prosecution of the work the Commissioners would probably have tried to find someone else with the courage to attempt it by some means of other.

Mr. Hill.

The use of cast-iron segmental tubbing with struts for supporting the sides of the reservoir trench during sinking operations in the centre of the valley was unique, but essential, seeing that it would not have been possible to achieve the same object by the use of timber. In fact, as Mr. Binnie had said, when the excavations reached a considerable depth, the silt threatened to become uncontrollable owing to its pressure and consequent tendency to flow even after so much moisture had been previously removed by draining operations, and the depth of segments forming the tubbing had to be reduced accordingly, because the space needed to accommodate an 18-inch

Mr. Hill.

segment was large enough to cause inrushes of silt before the segment could be fixed. However, notwithstanding all the difficulties and the necessity of using compressed air and drainage-shafts, the sinking of the trench itself only occupied about 18 months and its refilling with concrete about 6 months, after which the work became comparatively straightforward. It would be noticed from the cross section of the embankment (Fig. 6, Plate 9) that unusually flat slopes had been adopted, because most of the underlying ground was of such fine and water-logged material that it might not satisfactorily sustain the weight of the embankment upon it unless the base was sufficiently extensive to distribute the load adequately. The clay used in the puddle-wall was extraordinarily good, but as in its natural state it contained a considerable amount of pebbles, special treatment was necessary for dealing with them. The largest of the pebbles were removed by hand on the stage above the pug-mills, and the remainder were crushed as the clay passed through rolling-mills before being dealt with by the pug-mills in the ordinary way, the result being puddle of excellent quality. The Author mentioned that the silt of the overflow consisted of stone from Norway, the blocks being each about 4 tons in weight ; it might be explained that the corresponding local material was not so adaptable for the purpose, whilst it would have cost twice as much. Throughout the execution of the extraordinarily difficult work, the Board of Engineers, the Contractors, and all concerned with the undertaking, co-operated in the greatest harmony.

Mr. Walters.

Mr. R. C. S. WALTERS remarked that the late Dr. Herbert Lapworth, M. Inst. C.E., had been associated with the Silent Valley reservoir scheme in its early stages and had, he believed, been inclined to the opinion that the trench was almost too hazardous to be undertaken ; but Dr. Lapworth would have been the first to congratulate those responsible on the successful completion of the work. Regarding the filling for the trench, in an old reservoir built on granite the trench had been puddled and carried down on to the granite, but in excavating for repairs it was recently discovered that the puddle rested on 6 inches of mush, and he could not imagine anyone deliberately putting down puddle on to such material. He thought it probable that the granite had in some way disintegrated since the placing of the puddle. In the Silent Valley he thought the engineers had been very wise in adopting concrete for the trench, and also in making the concrete with stone brought from elsewhere, not using a granitic aggregate. The Author stated that £60,000 had been saved by adopting the circular overflow-weir 80 feet in diameter, decreasing to 16 feet in diameter, in lieu of a weir 250 feet long. That was interesting, as the weir in question was one of the largest in the

British Isles, but there was one at Davis Bridge in America which Mr. Walters. was about 166 feet in diameter. In England there were six other circular overflow-weirs in existence, ranging from 10 feet to 93 feet in diameter at the crest, as given in the following list :—

Blackton (Tees Valley) . . .	Crest 93 feet and shaft 20 feet in diameter.
Pont-sticill (Taf Fechan) . . .	„ 66 „ „ 16 „ „
Font (Tynemouth) . . .	„ 34½ „ „ 15 „ „
Powdermill (Hastings) . . .	„ 22 „ „ 8 „ „
Royd Moor (Barnsley) . . .	„ 13 „ „ 4½ „ „
Trentabank (Macclesfield) . . .	„ 10 „ „ 6 „ „

Those at Hastings and Macclesfield had, he knew, been put in by Dr. Lapworth for reasons of economy.

Mr. G. W. M. BOYCOTT observed that on p. 476 the Author described Mr. Boycott. a method of decompression used at the Silent Valley worked out in accordance with the principles laid down by Dr. Haldane. Mr. Boycott wished to compare that method with a revised method described in a lecture<sup>1</sup> delivered by Mr. Leonard Hill dealing with Admiralty trials. The following figures, taken from a Table in that lecture, gave the time in minutes required to decompress a diver after a dive to a depth of 180 feet (the figures were not yet officially adopted). After 20 minutes had elapsed from the time of entering the water until the time of commencing the ascent the decompression time was 36·4 minutes, as compared with 38 minutes according to Dr. Haldane's method given in Siebe, Gorman and Company's Diving Manual. It would be noticed that those figures were almost the same. After 60 minutes the Admiralty Committee proposed 66 minutes for decompression, as compared with 108 minutes according to Dr. Haldane's method; and after 106 minutes the Admiralty Committee suggested 73 minutes and Dr. Haldane 189 minutes. A maximum of 75 minutes was suggested by the Admiralty Committee and 215 minutes by Dr. Haldane. The Admiralty Committee thus appeared to consider that saturation was complete in about 2 hours, so that the practice at the Silent Valley reservoir of increasing the period between the shifts from 45 minutes to 3 hours on reaching a gauge pressure of 30 lbs. might appear to have been unnecessary; but in his opinion, according to his experience, saturation was not complete in 3 hours or even in 6 hours, and, therefore, he thought that in that respect the Admiralty Committee were wrong in their proposals. On p. 477 the Author referred to the well-recognized fact that below 18 lbs. gauge pressure there was no danger of "bends." Based on that fact, it was assumed in

<sup>1</sup> Leonard Hill, "Diving." With mathematical and tabular section by H. E. Soper. Proceedings of the Royal Institution of Great Britain, vol. xxiv (1929-30), pp. 184-196.

**Mr. Boycott.** Dr. Haldane's method that the absolute pressure might always be dropped to one-half, even after complete saturation. In the Paper dealing with the Admiralty experiments it was proposed that divers should make a rapid ascent to 66 feet below surface from a depth of 300 feet. As, however, it was proposed that the diver when at the bottom should breathe air in which the oxygen had been reduced to 5 per cent.—because oxygen was dangerous to breathe at higher tension—the result was that the tension of nitrogen was increased, so that the effective ascent was from about 360 feet to 66 feet, the absolute pressure dropping to about one-quarter. That might be compared with the greatest depth and shortest exposure given in Messrs. Siebe, Gorman and Company's Diving Manual, based on Dr. Haldane's system, where the diver ascended from 204 feet to 50 feet after 7 minutes from leaving the surface to beginning the ascent, and the ratio of the drop in absolute pressure was 2·9 to 1, instead of 4 to 1. From one aspect, the Admiralty ratio was really 8 to 1, because the diver breathed oxygen on arriving in the submersible decompression chamber, which meant that the pressure surrounding the diver's body must be twice as great as when ordinary air was breathed. According to the U.S.A. Diving Manual, a diver from a depth of 250 feet, 10 minutes after leaving the surface, ascended to 90 feet, the ratio in that case being 2·2 to 1. After a very short time at the bottom, the proposed decompression ratio of 4 to 1 might be consistent with Dr. Haldane's method, since a considerable amount of desaturation took place during the time taken in the ascent, but with a more prolonged stay at the bottom he would expect a very much larger number of cases of "bends" to occur than when Tables were used calculated in accordance with the rules laid down by Dr. Haldane. He might qualify that to some extent by saying that from a later Paper<sup>1</sup> he saw that Messrs. Siebe, Gorman and Company had joined forces with the Admiralty and had placed their experiments at the disposal of the Admiralty, and he gathered that their experiments and their deep dives had been based on Dr. Haldane's work. However that might be, his own conclusion was that, using ordinary air, no better method was at present known than that based on the principles laid down by Dr. Haldane and adopted at the Silent Valley reservoir construction works.

**Mr. Harding.** Mr. H. J. B. HARDING remarked that the method of unwatering employed at the Silent Valley reservoir was extremely interesting. It would be noticed that the greatest rate of pumping from all the shafts and the trench was 1,686,000 gallons per day, which was

<sup>1</sup> Surgeon Lieutenant-Commander A. E. Philips, "Recent Research in Deep Sea Diving." Journal of the Royal Army Medical Corps, Vol. LIX, July-December 1932, p. 35.

only slightly over 1,100 gallons per minute. That was surprisingly **Mr. Harding** small, and showed that the reluctance of the fine ground to yield up its water prevented the water from being pumped out as quickly as might have been expected. The effect of the pumping was to lower the level of the water by 74 feet to 341·0 O.D. A much greater lowering might have been expected, but possibly the explanation was that the water was unable to enter the shafts at a sufficient rate. There was only one hole per segment for the inflow, and the little 9-inch long 1-inch diameter filter-pipes were obviously much too small to affect the issue. Possibly a much better effect would be obtained in such a case if the segments were made with a great number of perforations and an inner solid sheeting provided, the space between being filled with granular material, with a valve-controlled inlet leading to the shaft. In that way the whole surface of the ground passed through would be drained; that would be most advantageous, because such fine ground yielded up its water only very slowly, and the amount of water which could be withdrawn depended chiefly on the depth of draw-down in the well and on the porosity of the ground. Mr. Binnie's suggestion that the draw-down round the shaft explained the possibility of sinking the shafts under less than the theoretical air-pressure would seem to be correct.

It was interesting to consider for similar cases the possibilities of the water-lowering method which Mr. F. E. Wentworth-Shields, M. Inst. C.E., had used at Southampton, employing bored filter-wells and deep-well pumps at the bottom, which had also been used by Sir John Wolfe Barry and Partners at the Grimsby fish-dock. When the work at Belfast was done that system was only in its infancy. It was not always appreciated that in the same ground and with equal draw-down two 6-inch diameter wells would yield theoretically as much water as one 10-foot well; the amount of water which would percolate into a well increased very little with increase of diameter above about 1 foot. At Southampton the wells were 200 feet deep, 28 inches in diameter at the top, and reduced to 24 inches in diameter after 100 feet. Inner mesh-covered filter-tubes were placed in the bore-holes; two different grades of filter-gravel were filled in between the inner tubes and the boring tubes as these were withdrawn, so that the graded gravel filter would prevent any sand being drawn into the wells. At the Silent Valley a great deal of ground had been lost through the openings, which caused considerable trouble and expense. If wells had been sunk at the Silent Valley to tap the fine ground in a sufficient number of places and draw a little water in each well, the wells being bored deeply to enable the pumps to be submerged below water-level, it

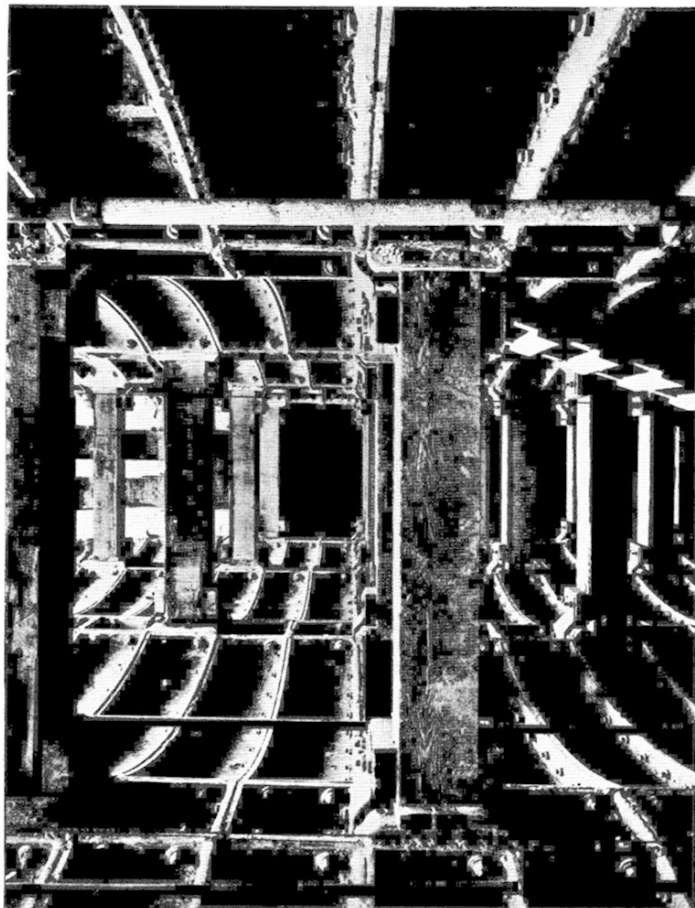
**Mr. Harding.** might have been possible to get considerable draw-down and much better unwatering than was in fact obtained. In that case it might have been possible to cut out the compressed-air work in the shafts completely, the bore-holes being made of bigger diameter in case of difficulties with boulders. The pumps which had been put in at Southampton took 7 kilowatts; they were only 9 inches in diameter and were capable of pumping 165 gallons per minute at 122 feet head, but they actually pumped 65 gallons per minute each, a total of only 600 gallons per minute, to drain the whole water-pressure under the graving-dock, reducing the head by over 100 feet. In the case of the Silent Valley the maximum quantity was 1,172 gallons per minute, which decreased to about 800 gallons per minute by April, 1929, so that possibly only fourteen wells would have been needed to draw down the water sufficiently low to eliminate compressed-air work; the trench could then have been dug much more simply. It would be of interest if the Author could explain why the method actually used only lowered the water-level to + 341 O.D.

With regard to preliminary bore-holes, there had been many cases where the ground when opened up had proved to be different from that suggested by the bore-holes; possibly in some cases, though not necessarily in that under discussion, the expenditure on bore-holes might usefully be increased, especially in the case of small works where there might be a tendency to stint the money. Several small bridges had been heard of where one bore-hole had been sunk on each bank and a line supposed to show the level of the strata had been drawn between them; but when a shaft had been put down in the middle of the river the state of affairs had been found to be very different. With a system of deep-well pumping it was usual first to make exploratory borings of small diameter and to fit them with 2-inch and 3-inch diameter filter-tubes through which the water-levels at all times could be recorded; the deep wells could then be located in the best positions. Where a trench had to be dug through a very watery, silty, or sandy valley, as in the case under discussion, there might be considerable advantages in putting a fairly concentrated system of bore-holes along the line or just off the line of the trench, equipping them with filter-tubes through which the water-level could be observed for the duration of the job. Possibly the extra expense at the beginning might lead to very much more economical construction as the work was carried on.

**Mr. McIlldowie.** Mr. McILLOWIE, in reply, expressed his gratitude for the vote of thanks which had been accorded to him and for the way in which his Paper had been received.

*Fig. 1* showed the segments and strutting in the trench. It was

*Fig. 1.*



CAST-IRON SEGMENTS AND TIMBER STRUTTING OF SILENT VALLEY TRENCH

true, as Mr. Binnie had said, that there were some 9-inch segments Mr. McIlldowie. in the shafts. Personally, he had not thought the point worth mentioning as they were so little used. In general, 18-inch segments were used, but a certain number of 9-inch, 12-inch, and 15-inch segments were provided and utilized in a few places where the ground was particularly lively.

Sir Murdoch MacDonald had referred to the cost. He had taken out the cost on the basis of the original contract, carrying the trench down to the depths to which it became necessary to take it, and there was very little difference between the cost of the work as carried out and the cost if the work had been carried on according to the schedule. Mr. Hill had mentioned that £500,000 had been spent before the exploratory period, and it was desirable to emphasize that point by repeating what had been stated in the Paper, namely, that £824,500 had been spent on the Mourne aqueduct in addition to the £500,000 on the reservoir. That was to say, a total of £1,324,500 had been spent at the time when the necessity arose to take the measures described in the Paper. Had the dam been built at a different site, not only would the £500,000 have been wasted, but the City of Belfast would not have obtained the full benefit of the £824,500.

Mr. Harding had referred to the difficulty which had been experienced in getting the ground to give up the water it contained. Reference had been made to that matter in the Paper. When the shafts were being pumped out every possible effort was made to encourage the water to enter. At first the filters remained in position, but, as the flows from them decreased, first of all the filters were removed and finally the hand-hole plates on which they were fixed were removed, and rods and bars were put in to stir up the ground in every possible way. It was necessary to see that an undue amount of material was not brought in as a result, and if the agitation caused the ground to come in the stirring was stopped and the plates were put back until the ground settled again. Mr. Harding had asked why the water only went down to 341 O.D. He was afraid that he could not answer that question; it certainly did not go below that level during the construction of the dam, and it had been found that it was possible to carry on without it going below that level. No worries had, therefore, been caused because the water did not go down lower. Mr. Harding had also suggested that compressed air might not have been necessary if certain things had been done, but the real necessities of the case were only disclosed by the exploratory measures taken in 1927—measures embodying the use of compressed air. The operations carried out from 1927 till 1930 to complete the trench excavation and concrete were the outcome

Mr. McIldowie, and continuation of the methods adopted for the exploratory measures.

\*\* The reply by Messrs. Bromage and Sethi will be found on p. 542; that by Mr. Kelso will be printed in the next volume of Proceedings.—SEC. INST. C.E.

### Correspondence.

Mr. Climie.

Mr. H. R. CLIMIE, of Napier, N.Z., observed that it would be interesting to know on what evidence a steel reservoir had been chosen for the Murree water-supply as being better able to withstand earthquakes than a reinforced-concrete structure. When reconstructing the municipal services at Napier, following the disastrous earthquake of February, 1931, he had come to the contrary conclusion. In 1922 he had designed for the neighbouring municipality of Wairoa three reinforced-concrete reservoirs, which withstood the 1931 and subsequent earthquakes without suffering any damage whatever. That was the more remarkable as the reservoirs were founded on alluvial ground about 2 feet below the surface. They consisted of cylindrical tanks 38 feet in diameter and 22 feet deep, the walls, floor and roof being all 6 inches thick and suitably reinforced. The behaviour of those reservoirs was convincing proof of the suitability of reinforced concrete for the purpose, and he had chosen it in preference to steel plates for the new reservoirs in Napier.

The new reservoirs consisted of cylindrical tanks, 75 feet in diameter and 29 feet deep. The walls tapered from 9 to 6 inches in thickness, with a fillet on each side at the base 3 inches wide and 1 foot high. The circumferential reinforcing-rods had a mechanical bond and were simply overlapped 40 diameters. There were two spiral rows suitably spaced to give a hoop-stress of 12,000 lbs. per square inch. The walls had a footing 3 feet wide and 15 inches thick, which was tapered off to give a floor-thickness of 6 inches. The floor was reinforced with radial and circumferential rods,  $\frac{5}{8}$  inch in diameter, to give a mesh about 12 inches by 12 inches. The wall was restrained at the floor, and was tied to it with  $\frac{3}{4}$ -inch vertical rods, of hairpin shape, placed at 8-inch centres close to the face of each fillet to resist a bending moment of 50 per cent. of that given by Hool's formula (which was based on the assumption of an unyielding foundation). To resist the reverse bending moment on the outside of the wall  $\frac{5}{8}$ -inch vertical rods at 8-inch centres were provided, and the hoop-steel was supported in position by  $\frac{5}{8}$ -inch