Mr. Stokes.

in—in fact, probably more sound, because the cement behind was harder. The lower surface was polished, but there was no sign of any damage having taken place, nor was there any sign of damage having occurred on the granite faces of the culverts. He attributed that to a very large extent to the skin-friction which took place when water passed a fixed surface; he believed it was a sort of rolling, eddying action and not a dashing past, which was generally assumed to be the case. Finally, some people were very anxious about the state of Philæ. The short answer to the question whether it was going to stand was that when the temple was built a wall was also built going down into the Nile, composed of the same stone as the temple itself, and that wall looked as fresh almost, he imagined, as the day it was built. If that wall would stand for thousands of years, sometimes wet and sometimes dry, surely Philæ would stand.

Correspondence.

Dr. Ball.

Dr. JOHN BALL congratulated the Author on the completion of an important and difficult piece of work, and especially on his victory in the long fight with the erosive forces of a mighty river. The detailed measurements of the effects of river-erosion made during the progress of the work furnished data which it would have been almost impossible to obtain in any other way, and which would be of great value both in the scientific study of river-action and in its application to engineering practice. As both the Author and Sir Maurice Fitzmaurice had pointed out, the granite on which most of the dam was built, though one of the hardest and most resistant of rocks, was traversed by joints and crush-planes and by bands of softer rock, which detracted considerably from its otherwise excellent nature as a foundation. He could bear witness to the anxious care with which the resident engineers had watched the excavation for the foundations, insisting on the excavations being carried down everywhere to good solid rock, though the depths were far greater than had been anticipated in the original design and estimates. At the time it had appeared to some that the insistence on a perfectly sound base was a little too rigorous in view of the expense entailed; but the policy had been completely vindicated by subsequent experience. Had less care been exercised in the original foundation, it was certain that the undermining of the

Dr. Ball. foot of the dam by the unexpectedly rapid erosive action of the stone-laden eddies would have exceeded the trifling amount chronicled by the Author. Besides justifying the caution of the Government engineers of the present day, the experiences recorded in the Paper afforded a striking proof of the honesty of their predecessors in the reign of Amenemhat III, about B.C. 2,300. These ancient engineers engraved the level of the Nile in their day on the rocks of the Semna Cataract, about 200 miles south of Assuan, and those levels were about 26 feet higher than the present high-Nile levels at the spot. The Semna Cataract was formed of a great natural gneiss barrier across the river, which acted as a weir with spill channels in high flood, and as a dam with a single great sluice at low Nile. When the ancient marks were discovered by Lepsius about 1845, the amount of lowering of the rocky barrier which they indicated was so great that the eminent English geologist Horner was reluctant to accept river-erosion as the explanation. But when Dr. Ball visited the Semna Cataract while the dam was being built in 1902, and examined the pot-holing which was still going on, he concluded[1] that the lowering of the barrier by $\frac{1}{12}$ inch per annum by erosion, indicated by the marks, was not only possible, but highly probable. Moreover, this lowering referred only to the vertical height of the barrier, and was doubtless accompanied by a gradual cutting-back of its down-stream face, diminishing its width; it could only be a matter of time for the complete demolition of the Semna barrier by this cutting-back action, but there had been no means of estimating the rapidity of erosion in that direction.

It had been obvious to him after his Semna studies that if his conclusions were correct a considerable amount of erosion of the river-bed was to be expected at the down-stream side of the Assuan dam. But the conditions of the natural dam at Semna and the artificial dam at Assuan were somewhat different, and it was not possible to estimate, even approximately, what the rate of such erosion would be. Moreover, the fact that so great an authority as Horner had differed in view had restrained him from being too positive as to the interpretation of his observations. The amount of erosion at Assuan recorded by the Author, however, proved in the clearest possible way that that interpretation had been correct; the measurements of erosive action made at Assuan could now safely be correlated with those at Semna, and the combined results could not fail to be of great use in the design of any further

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[1] "Quarterly Journal of the Geological Society of London," vol. lix (1903), p. 74.

Dr. Ball.

structures of similar character across the Nile cataracts, besides forming interesting data for geologists as to the rate at which the natural barriers of the Nile were disappearing. It was only by the comparison of high-Nile levels over several centuries, or by exact measurement of the rock displaced, such as had been rendered possible by the construction of the Assuan dam, that the rate at which the river was eroding its bed could be ascertained; for the natural fluctuations of the river in different years and at different seasons were so great as entirely to mask any steady change that might be occurring. There could be no doubt that the Author was perfectly right in ascribing the bulk of the erosion to the spaces between the sluices, whereby violent churning was set up in the backwaters formed. Even sand-laden waters would under these conditions cause the removal of a great deal of the hardest rock, and where loose stones were present, and the rock was fissured, the grinding effect would be immensely increased. Probably it was quite true, as the Author suggested, that if the waste stones during construction had not been thrown into the stream at the foot of the dam, the erosion would have been less rapid. But he was inclined to think this had been a blessing in disguise; for by accelerating the erosion it had drawn prompt attention to an action which would certainly have gone on by the ultimate loosening of blocks of the natural rock-bed separated by joint planes, and such action at low levels might have assumed serious proportions before being observed. As to the water-cushion, he was glad that this had been tried, though it had not been found satisfactory. The experience confirmed the natural evidence of the river-soundings that erosion could go on even at considerable depths, if the waters were thrown into eddies and laden with stones, or even sand. The soundings in the west channel of the Nile, less than half a mile below the dam, showed the river to have local depths of more than 130 feet, and these great hollows were doubtless due to pot-holing action proceeding at great depths. The protective apron, at its present high level, might, and almost surely would, need occasional repairs; but the circumstance that it was easy of access and inspection would render it a simple matter to ensure that no dangerous weakness could pass undetected. It might appear at first sight improbable that an apron artificially constructed of the same stone as formed the natural river-bed would be better able to resist erosion than the virgin rock. But apart from the greater suitability of form attainable in the artificial structure as compared with that procurable by dressing down the natural irregular rock-surface, the apron as constructed

Dr. Ball. possessed the advantages of more perfect homogeneity and greater freedom from cracks and fissures as compared with the natural rock. In the natural rock surface, even if dressed smooth, there were soft places which would soon give rise to slight depressions, and in these the sand and stones would be caught and would soon deepen the holes by rotatory grinding action, while the abundant joints and crush-planes would greatly facilitate the breaking-up of the mass. But in the artificial apron great uniformity in the stone could be attained by careful selection, and cracks and fissures could be almost entirely avoided. The Assuan granite was one of the finest building stones in the world, and it was fortunate that supplies of it existed so close to the dam. On the point of homogeneity of material, the Author's remark, that the mortar found best was a 2-to-1 mixture of coarse granitic sand and cement, was interesting. Dr. Ball had come to the same conclusion after testing various sands for use in the underpinning work at Philæ, and the explanation was that such a mortar, while possessing good adhesive properties, produced on setting a substance not so very different from the granite itself. The coarse granitic sand of the Assuan district, produced by the weathering of granite, was of a much greater mineralogical purity than ordinary granitic sands, because in that dry climate the process of weathering was almost entirely a mechanical one of disintegration by expansion and contraction, without the production of any sensible proportion of clay by chemical change of the felspars; the sand, in fact, was practically the same as could be produced by crushing up fresh sound granite. It was, of course, quite different from the finer wind-borne sand of the desert, which also occurred largely near Assuan. When the granitic sand was made into mortar with half its volume of cement, the latter formed a strong matrix, filling the voids and producing a material two-thirds of which was certainly actual granite, and which as a whole would probably expand and contract at nearly the same rate as the virgin rock. Apart from the difficulty of filling natural cracks and fissures with mortar, the surfaces of the roughly-dressed stones of the apron gave a far better key to the mortar than the faces of natural fissures, which were always smoothed and polished by the water-borne sand. The deduction from the measurements of the cracks, that the expansion and contraction of a mass of masonry comparable in size with the dam might be calculated by assuming the ordinarily accepted coefficient of expansion of granite (0·0000045) and a mean variation of temperature in the mass of one-third the annual variation of mean daily air-temperature, was interesting as having been made by direct measurement on so long a structure, and would be a

Dr. Ball.

useful datum. The fact that the range of temperature given in the Paper was that of the air in the shade, and not that of the face of the stone itself, should be emphasized, for the two ranges were very different. The stones probably had a superficial temperature in the sun of more than 140° F. in summer; in fact, he had found, when collecting specimens of the granite, that the stones were often so hot that they could not be held long in the hand for dressing purposes. This must mean a somewhat intense shearing force parallel to the faces of the stones, and readily explained the flaking-off of rock masses where there was schistose structure parallel to the exposed face. He thought it would be useful if the Author would record a few figures regarding the diurnal variations of the cracks, as well as the annual changes. It would be interesting to know, for example, the change in length observable between 2 p.m. on a hot sunny day and 2 a.m. on the following cool night; for such measurements were difficult to obtain, and diurnal changes were probably far more potent than the annual changes as disintegrating agencies. With regard to the Philæ temples, the Author had stated that these were underpinned down to solid rock. This had been the original intention, but, as a matter of fact, only a small portion of the underpinning as actually executed was on granite. When the excavations in connection with the preparation of the designs for the underpinning works were completed in 1901, it was found that in many places the granite core of the island was at such a depth below low-Nile level that very costly works would be necessitated if the temples were to be underpinned to solid rock. After the plans showing the foundations of the existing structures and the rock-levels had been carefully gone into by Sir Benjamin Baker and Sir Maurice Fitzmaurice, they concluded that stability would be amply secured by underpinning down to that depth where the old alluvium had been so saturated by the annual flooding during thousands of years that it had taken its final settlement, and that the new foundations should be inserted only in the stratum which, having been incompletely saturated, might be expected to subside further when the reservoir was filled. Thus in *Fig. 10* (p. 294), which represented an east-to-west section of the Temple of Trajan (Pharaoh's Bed), it would be seen that the rock was at great depth. But as all the silt below the level AA (the level reached every year by the Nile flood) had been annually saturated for unknown ages, had sustained the load of the temple for 2,000 years, and was confined by the quay-wall, it was extremely unlikely that further subsidence of this silt could occur. Between the levels AA and BB, on the other hand, the silt had not been

Dr. Ball. thoroughly saturated for a long period, as it lay above the natural flood-level of the river; this stratum might be expected

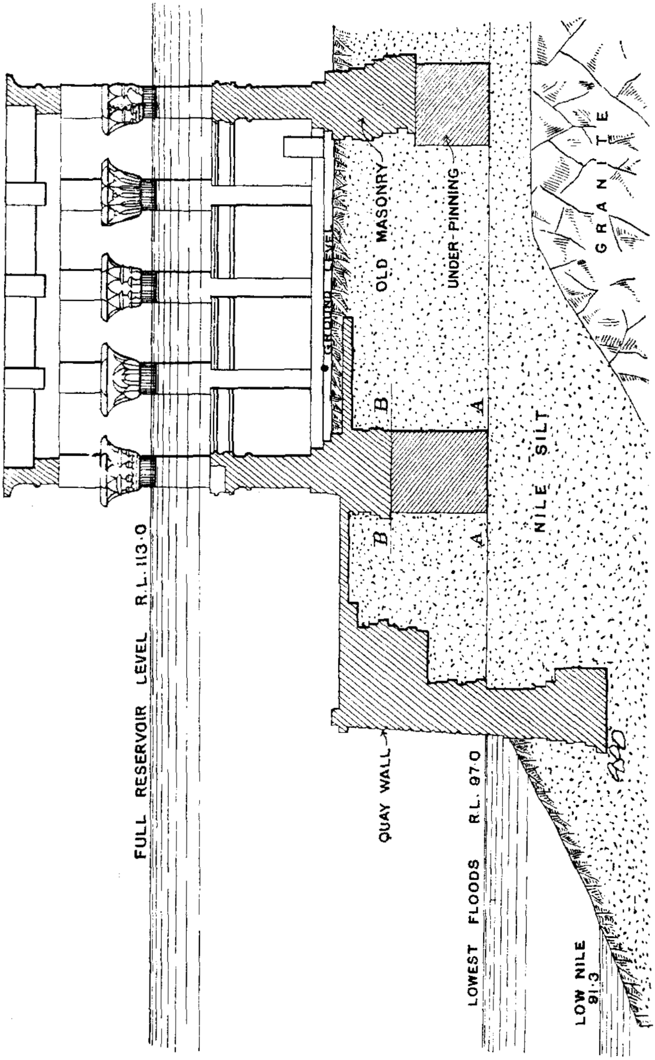

Fig. 10.

to subside on the artificial raising of the water-level, and the subsidence might be irregular owing to the lack of homogeneity in the material, which contained lumps of granite as well as silt. The

Dr. Ball. final plans therefore, as arranged by Sir Benjamin Baker, provided for underpinning down to solid rock wherever this was above saturation-level (R.L. 97·0), and in all other places down to saturation-level only. The fact that the island was nearly surrounded by heavy quay-walls with extensive counterforts, and the circumstance of its being situated above the dam in the lake-like reservoir, where it would never be subjected to erosive forces by which the silt might get away, was duly borne in mind in forming this judgment, which resulted in a great saving of cost over the original idea of underpinning everywhere to rock. The silt below the old foundations was a fine river sand, clean and very sharp; it showed surprisingly little tendency to run, probably owing to the interlocking of its variously-shaped grains, and formed a practically incompressible foundation. He was glad to read in the Paper that there was no sign whatever of any settlement having taken place during the 10 years in which the temples had been annually flooded since the work was completed, thus confirming the judgment of Sir Benjamin Baker that underpinning down to saturation-level was a sufficient measure to secure complete stability.

He had thought it worth while to make clear the reasons which guided Sir Benjamin Baker in deciding to underpin down to R.L. 97·0, because those reasons appeared to have been misapprehended by Captain Lyons in his "Report on the Temples of Philæ" (Cairo, 1908). In that report it was stated that the lowest water-level in the reservoir was about 97 metres above sea-level, so that the effect of the reservoir had been to raise the permanent saturation-level from 91 to 97 metres, and that it had been decided to carry the underpinning down to the permanent saturation-level. This, of course, presented an erroneous conception both of the actual regime of the reservoir and of the principle of the underpinning work; the low-Nile level sank far below 97·0 metres at Philæ every year, even now that the reservoir was completed, and Sir Benjamin Baker did not decide to underpin to permanent saturation-level in the sense that Captain Lyons had implied, but to that level (which for brevity was called saturation-level) below which the silt had been annually so thoroughly saturated *before* the construction of the dam that it could not be expected to subside further after the reservoir was filled.

He agreed with the Author that a further 7 metres depth of water could have no detrimental effect on the stability of the temples, as it would not produce any change in the condition of the ground below their foundations. With regard to the superstructure, though the temples were built practically without mortar, they

Dr. Ball. were constructed in such a manner that the stresses were almost all those of direct compression, and the stones were so large and well-fitted that a high degree of stability was secured by their weight alone. In a few cases of cracked and broken lintels the superstructure had been repaired and rendered safe by unobtrusive steel beams at the same time that the underpinning was carried out; but nothing in the way of cementing up the joints between the stones was done, as it was felt that this could not add to stability, nor exclude water from the porous stone, while it would detract from the appearance of the ruins. In fact, when the underpinning was completed, one could hardly detect that anything had been done to the temples; they now possessed as much masonry below ground as above it, but all the new work was out of sight. The popular idea that the cementing up of all joints and crevices, and the buttressing of the ancient walls, were necessary to make the temples secure, was extremely difficult to combat, but "repairs" of this nature would have been as useless as they would have been unsightly. It had been suggested at various times that a better way of preserving the temples would have been to build a water-tight wall around the island, leaving them in a sort of dry well; but such a method of preservation, besides ruining the external appearance of the island, would have involved works of something like the same order of magnitude as the dam itself, and would not have resulted in complete exclusion of the river. He thought that the most likely source of future damage to the temples was the possible bumping of boats against columns and lintels; for although the stone was not weakened by being wet, it had to be borne in mind that it lost two-fifths of its effective weight in water, and it was the weight of the stone on which the stability of the superstructure mainly depended. It would, however, be easy to regulate boat-traffic to avoid collisions with the temples, and even should such occur the boats would probably get the worst of the encounter. It would probably be advisable, as the Author had suggested, to replace a few of the more highly-damaged stones of the superstructure now that the temples were to be submerged to a further degree, but this would not be a difficult matter. No damage was to be feared from the action of water on the stone, for throughout the work of underpinning it had invariably been found that the parts of the temples which had been saturated by the annual flood were in the best condition, while the most highly damaged stones were those in high and dry positions, where they were exposed to the disintegrating influences of alternate heating in the sun's rays and cooling by radiation at night.

Mr. W. REID BELL referred to the shrinkage of the masonry of the dam in setting and hardening, producing the cracks which opened in winter when the water was being held up, and partially closed in the warm weather of summer. That they were shrinkage cracks, and not the result of cooling pure and simple, was evident from Plate 5, which showed that even in the solid dam the cracks never closed. The most remarkable statement about these cracks was that "these hourly and daily readings showed regular variations." The records of these variations would be of great interest if the Author would add some typical diagrams of them. It was not made clear what were the actual ranges of temperature to which the structure was exposed, nor what were the temperatures of the water and the relations between the height of water and the variation of the cracks. Further, the observations on the cracks seemed to have been confined to one point on the cross section, and that on the side most exposed to cooling influences. So far as could be seen, the temperatures appeared to be of the order of those to which masonry was usually exposed in subtropical regions, and if it were considered that at a very few feet below the surface of the earth the daily variations in temperature were effectually damped, it seemed impossible that daily and hourly variations could be transmitted through a solid mass of masonry 7 metres and upwards in thickness, so as to produce movement throughout the cross-sectional surface of the cracks. It must be noted that, although the observation points were on the side of the dam away from the sun, so that in winter they might be in shadow, the string course was the freest part of the masonry with regard to expansion and contraction. The natural shrinkage of the masonry in setting threw the whole mass into a state of tension, and it only required a change of section to determine, and some initial failure, or some shock, such as the impact of water, to produce, a crack whereby the tension was relieved. If the surface layers of masonry could respond so readily to variations of temperature, while the underlying layers were inert, it would point to the suppression of string courses and similar lines of excessive tension where fractures were likely to originate. With regard to effects due to temperature changes, the Assuan dam was a very complicated structure, and afforded a field for observations from which information of much value might be obtained. If the Author or his officers could present such information to The Institution at a future time, engineers engaged in masonry construction would be most grateful to them. Mr. Bell suggested that it might be possible to get definite results by fixing to the interior surfaces of a crack pairs of pointers extending

Mr. Bell.

Mr. Bell. outside the masonry, so as to indicate whether movements were parallel through the body of masonry, or whether there were angular movements due to the greater movement of the surface. It was known that in the vertical plane the movement was angular, and most probably such a measurement in the horizontal plane would show the same feature. It was impossible, or next to impossible, to avoid contraction cracks in cement concrete. Mr. Bell was at present building the parapet of a sea-wall in sections, with small spaces between them. After the concrete had hardened and contracted, he proposed to fill the spaces with concrete, and he considered it probable that the small amount of tension then developed in the hardening of the narrow filling would not be sufficient to cause rupture.

Mr. Lowe-Brown. Mr. W. Lowe-Brown thought it would greatly assist all who might have to deal with difficulties similar to those encountered by the Author if he would state in general terms the lessons derived from his unique experience with different types of aprons, especially with regard to the destructive effect of the water when it was allowed a free fall between the sluice and the apron, and to the maximum permissible inclination of the apron itself in avoiding such free fall. The Author had stated that he had made some measurements of the discharge of the sluices. If he would give some idea of the discharge actually obtained in practice, this would afford information of much value.

Mr. Bruce. Mr. A. Fairlie Bruce felt considerable diffidence in attempting to criticize the work of the eminent engineers concerned in this great undertaking, and only ventured to do so in the hope of learning the reasons which had led to the adoption of certain methods of construction. It appeared to him that as the object aimed at was the reduction of the destructive velocity of the water issuing from the culverts, that would have been better attained by using altar-steps in place of the ogee curves below Set 18, and constructing a subsidiary dam so as to form a water-cushion below the outlets instead of employing so much masonry in the aprons. There were possibly good reasons for not adopting such a course, and it would be interesting to know what they were. In thickening the dam the primary object was to add to its weight and consequent stability. Why then was it considered essential to bring about identical temperature-conditions in the old and new work, entailing great cost and loss of time due to the grouted joint between them? It did not appear at first sight that any slight temperature cracks which might have occurred at the junction would have impaired in any way the support given by the one to the other. Another part

Mr. Bruce.

of the work which apparently had proved troublesome was the extension of the culverts. Would not economy in time and money have been effected by the use of steel arches backed with concrete? Some of the unit costs of the work would be very interesting if the Author were in a position to give them.

Mr. Carew-Gibson.

Mr. H. F. Carew-Gibson observed that he left Assuan in the early summer of 1902, and as a consequence was not present at the opening ceremony; but as he had been in charge of the Eastern Section under Mr. (now Sir) Maurice Fitzmaurice and had been responsible for the excavation to foundation-level and the building of the first portion of the dam up to the road-level, he retained a mental picture of almost every foot of the foundation upon which it rested. With regard to the foundations, he would like to recall that in the original estimates the depth of trench estimated was, he believed, on the average only 2 metres, as the whole of the bed of the river at the first cataract appeared to be of solid granite; on reference to the section, however, it would be seen that in some cases the foundations were actually carried down a depth of more than 15 metres, the reason for this being that the granite varied very much in texture; and he considered it a pity that some geologist who was conversant with the district had not contributed a Paper on that subject, as, in view of what was said by the Author upon the question of scour, such a communication would be of considerable value. He had often remarked upon the great variety of granitic rocks on the site of the dam, ranging, as they did, from syenites through true granites of various closeness of grain and colour to those whose felspar contents were in the form of orthoclase instead of plagioclase—these in all cases being the cause of the deep channels met with in the bed of the river, such as were shown upon the section. He had always anticipated that masonry aprons and training-walls would be required below the dam, though not to the extent that had proved necessary, because he had seen the effect of water coming through, what were, he believed, the first Stoney gates ever erected, namely, those at Ballinasloe, in Ireland. In that case, although the head was not great with the gates lifted only a few inches, the cutting power of the water was very great, and pitching had to be resorted to for some distance down-stream. They were not submerged gates like those at Assuan, but he believed the design was practically the same, except that in the first instance the gates at Ballinasloe were hung by chains, which did not prove satisfactory owing to their tendency to stretch unevenly, so that steel ropes were substituted for them. Nothing was said in the Paper as to the condition of the cast-iron linings to the low-

Mr. Carew-Gibson. level sluices, but it was stated that where these were lengthened granite was to be used for the linings. Such information would be interesting, as they were accepted in lieu of granite in the first case, he believed purely because it expedited work on the building of the sluices during low Nile—a most important consideration, which could hardly apply with the same cogency to the widening and heightening of the dam when all particulars of the foundations were known. He remembered how difficult it was to ensure that solid work was done in building in these cast-iron linings, especially while the work had to be carried on at night by the light of arc-lamps. He was interested in the longitudinal section of the river from the dam up to Wadi Halfa, showing the water-line with reservoir full, as he had been responsible for determining these levels and the areas of the lands and villages that would be flooded out in the original scheme. Mr. Lowe-Brown and he had done this work in, he believed, one month during November and December 1901, while Mr. Lowe-Brown with Mr. W. Binnie had continued it for the heightened reservoir afterwards. He would like the Author to state what, if any, hydraulic gradient existed when the reservoir was full, and if this was affected to any appreciable extent by the prevailing north wind. With regard to the vertical cracks which had appeared in the dam, and which were ascribed to temperature-changes, nothing was said as to whether they wept or not under the full head of water, or as to the racking which must be caused at certain times by the cooling effect at full reservoir of the water on the south face combined with the heating effect of a fierce sun on the north or down-stream face, and if that caused any movement in the cracks. It was stated that, owing to the down-stream orifice of the original sluices being rounded off, the design for the extension of these sluices was altered, that was, they were made wider and deeper. Doubtless there were other reasons which had not been stated, as it seemed a pity to have altered the appearance of the dam from down-stream by substituting arches for lintels and sills, even if difficulty was experienced in handling the necessary large stones. In any case bonding irons had had to be sunk into the ashlar around the sluices, and therefore the key obtained by cutting out the rounding on the orifices would have served a useful purpose, besides keeping the stones required down to the dimensions of those used in the original work. The Author stated that it had been found impossible to grout up the whole of one bay, working continuously, without causing failure, and that the grout could not with safety be brought up more than 7 or 8 metres at a time. It would be interesting to hear his reasons for this, as Mr. Carew-Gibson

Mr. Carew-Gibson.

believed it was against common experience. He had always found it expedient to hurry on grouting work, as chemical set commenced, under average conditions, within an hour. Certainly he had never found any hydrostatic pressure that need be taken into account while grouting after a few hours; and, given the necessary appliances, quick grouting meant better work, as the dirt contained in the cement, which always formed a scum on top, was continually pushed upwards so long as the operation was continuous; whereas if it were done in stages this scum formed horizontal beds at every stage having no bond to it. The Author had not said whether any precautions were taken to wash this out at the different stages. If the Author would give in the Appendix a diagram of the filling and discharge from the old reservoir it would be of interest. During the 4 years Mr. Carew-Gibson had spent at Assuan he was responsible for the gauging of the Nile below Assuan during its low period, and he believed the figures then obtained were incorporated in Sir Maurice Fitzmaurice's Paper.[1] He was therefore particularly interested in knowing how they had proved in the light of the more exact measurements now possible. It would also be of interest to know the maximum velocity of discharge from any of the sluices under working conditions, as this was the main factor in determining the scour, and whether it would be increased by the raising of the dam.

Dr. Corthell.

Dr. E. L. **Corthell** observed that, by the courtesy of those in charge of the works, he had, in February, 1913, an opportunity of learning much about them from a personal visit to them. The Paper presented, with great clearness and much detailed illustration, a record of the construction and enlargement of one of the greatest works of modern times. An examination of the work, and a perusal of its story now fully told, would confirm the high esteem in which Dr. Corthell, with all others, had held the late Sir Benjamin Baker, whose sound judgment, engineering genius, and skill had done so much to make this great work successful. He had found it difficult, after the most careful reading, to find anything to criticize seriously in the Paper itself, or in the design and construction of the enlargement and protection of the dam. There were a few details, however, that the Author could probably elucidate.

There seemed to have been no examinations made by thorough borings into the rocky bed of the river before the construction of the foundation or of the down-stream apron. Had this been done and complete knowledge of the geological conditions been obtained,

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[1] Minutes of Proceedings Inst. C.E., vol. clii, p. 82.

Dr. Corthell. the apron which had recently been built might have been laid at the outset, for such knowledge, coupled with due appreciation of the effects of water falling on such a formation as the Paper described, would surely have led to the immediate construction of an adequate and permanent protection. The attempt to destroy the effect of the falling water by means of a pool below the dams was not a success, as the Author stated, and as Dr. Corthell's experience on many hydraulic works would have led him to predict. The momentum and impact of a mass of water falling over works, although under very small heads, into water of even considerable depth, would make itself felt upon the bottom, and the water into which it fell would not act as a cushion to any great extent. The effects of eddies behind the 5-metre (16·4 feet) thickness of the solid piers always occurred behind bridge-piers in a river of strong currents, and there was a tendency to undermining by these reverse currents. An eddy acted like an auger boring a hole, or a whirlwind picking up heavy articles by its rotary motion, and serious effects should always be provided against. It seemed almost providential that the foundation of the dam had not been undermined by this or other active forces before the general protection works were undertaken. For the information of members unfamiliar with conditions in Egypt or with terms used there and in England, it would be well to have the altitude expression "R.L." explained; also to be given the maximum and mean range of temperature, on both Fahrenheit and Centigrade scales, at the dam, both in the shade and in the sun; that was, in addition to the statement on p. 264. This would be helpful in appreciating the heat forces causing the expansion and contraction of the masonry so fully described in the Paper. Was no attempt made before commencing the original dam to avoid the annoying result of expansion and contraction by designing "slip joints" in the masonry at suitable intervals, as was often done in retaining-walls, dikes, and dams? This would have avoided the "eighty-two separate cracks . . . running right across the roadway of the dam . . . which in twelve well-defined cases could be traced from top to bottom on both sides of the structure, evidently dividing it into separate blocks." These separate blocks were made by irregular ugly cracks, the presence of which caused anxiety, disappointment, and blemish in a fine work, and they could possibly have been avoided and replaced by neat, workable, watertight slip joints. What was the meaning of the word "sudding"? Was it practically "coffer-damming"? Referring to the object and uses of the Assuan dam, which naturally overshadowed all other considerations, it was incumbent upon those

Dr. Corthell.

who proposed and built the dams, particularly at Assuan and Assiut, and the canals and secondary irrigation-canals, to prove that the work was a success in every way and that there were no unexpected deleterious results from it. Dr. Corthell had repeatedly been told recently that it was understood that the Assuan dam had failed to accomplish its purpose. As he understood it, the undertaking was not in any sense a failure, but it seemed to be evident that the demand was greater than the supply. Some water had led to a call for more water; some new land irrigated had led to a demand for more land to be irrigated. He had learned the following, which he would like to have confirmed or corrected. The original storage-capacity of the reservoir of the Assuan dam was about 34,610 million cubic feet of water, that of the heightened dam was 88,224 million cubic feet; but 140,000 million cubic feet, or nearly 60 per cent. more than the existing capacity, could profitably be employed in bringing new and accessible areas of Egypt into cultivation. A report was also current that the additional water furnished to Lower Egypt by the Nile reservoir had resulted in injuring the cotton, particularly that of the Delta. No doubt the well-studied plans for draining the Delta, so as to remove the water from the deep roots of the cotton, which went down 1·5 metre (5 feet), would not only rectify the deleterious results of too high subsoil water, but would, with the present systematic irrigation carried out in parallel, besides helping out the 2,000,000 acres now under cultivation in the Delta, also bring into cultivation the remaining 1,500,000 acres, now lying fallow and needing both deep drainage and irrigating water to make them cultivable. With regard to certain criticisms which had appeared in the press in Cairo in January and February, 1913, as to the subject just referred to, and as to the dam itself and some assumed errors in its design, construction, and enlargement, Dr. Corthell deplored that such a method had been taken in treating an engineering subject of great importance, in which all engineers interested should cordially assist to uphold the existing able management. How the additional quantity of water required was to be obtained was a problem the solution of which could not be long postponed. No doubt more reservoirs would be established at suitable points between Assuan and Khartum. With a sufficient quantity of water at command and much of it still wasting into the sea, doing no one any good, it would seem that the brains and the money should be found. The brains were there, he was sure, for no one could examine the splendid work already accomplished by the English engineers, without having entire confidence in their ability

Dr. Corthell. to cope with this new and possibly more difficult condition. With regard to the drainage of the Delta, accompanying that drainage there would be laid out a complete system of irrigation—main and secondary canals and ditches—all discharging into the drainage system. Therefore, instead of Egypt drifting into hopeless insolvency, whither it was rapidly tending a few years ago, and her people into the despair of abject poverty, Nile water utilized and distributed with impartiality was making and would still further make strong hopeful men of her fellaheen, and it was filling her exhausted treasury. The original Assuan dam had repaid its cost over and over again, and the new work would add enormously to the productiveness and wealth of Egypt and to the happiness and general welfare of her people.

Mr. Fergusson. Mr. JOHN C. FERGUSSON wished to comment upon the base-area of the dam, a factor which some engineers considered of less importance than its weight and impermeability. At a lecture in Birmingham on dams, which dealt particularly with the Assuan and some Indian dams, the distinguished lecturer drew his pointer across a diagram, as if he were cutting off the upper slope of the dam, and said that the dam would be just as good without the upper slope, provided the rest of the dam was watertight. During the discussion Mr. Fergusson expressed his dissent from this statement, and pointed out that it meant reducing the weight and the base-area of the dam, which were two most important factors of safety in any dam. Numerous examples might be given of dams in all parts of the world, especially old dams, where the safety of the dam depended on its weight and base-area long after it had ceased to be impermeable to water. The fact was that few dams were watertight, but still they stood, and even a sandbank permeated with water, forming a bar across a river, would stand, provided it had sufficient base-area. To prove the efficiency of a fore slope alone in a dam with a large base-area, hollow-framed dams might be met with in all parts of America employed in connection with water-power installations; they were little more than inclined planks spiked to blocks, forming an up-stream slope; yet many of these light structures were found to be very secure. While they served to raise the level of the water, they presented very little obstacle to the current passing over them; and the weight of the water itself, distributed over their large base-area, helped to keep them down. It was worth noting that in the Assuan dam the base-area, at the floor-level of the sluices, was reduced substantially in the deepest parts of the river-channel by the sluice-openings passing through it; yet the batter was the same throughout

Mr. Fergusson.

the entire face. He would like to have seen the 5-metre space between the sluice-orifices filled with curved buttresses, pointing down-stream, so as to form an extension of the sluice; these would have improved the outlet of the sluices, and would have reduced the serious disturbance and destruction wrought by the pressure-jet, caused by the form of the sluice outlet. The Author said in the Paper: "In one instance a block 80 tons weight was removed from a point close to the dam, lifted through rather more than its own height, 3 metres, and made to travel to a point about 20 metres down-stream." He also said: "These 5-metre zones formed backwaters in which loose stones were constantly carried towards the dam, to fall at the mouth of a sluice into the strong rush of outpouring water and be dashed away for some distance, only to return in a few moments in the same back-wash, and repeat their former cycle." While the form of the outlet of the sluices was allowed to remain unchanged, it was apparent that the engineers were working against all the forces of the river behind the sluices, when they strove to repair the holes by filling them with hand-packed rubble. It was strange that at the time it did not strike the engineers that the most important thing to do was to improve the shape of the orifices of these sluices, so as to reduce the action of the outrushing jet of water—the real cause of destruction. It was Mr. Fergusson's opinion that the bell-mouth formed at the entrance to the culverts would have been placed to more advantage at their outlet. Further, had the orifices of the sluices been widened or "flared" out, to properly curved lines, so as to draw their discharges nearer together, some little distance below the face of the dam, which might have been done by building pointed buttresses within the 5-metre spaces between the culverts, and extending them down-stream, then the out-rushing water would have been trained to discharge more easily over the apron of the dam. He believed that the outlets of the sluices might still be improved very much in this way, so as to diminish the force of the jet-action, and to do away with the "churning" in front of the sluice. At the same time these buttresses would increase the base-area at the sluice-floor level, where it was diminished by the line of sluice-openings.

With regard to the danger of the silting-up of the reservoir itself, his experience on such heavy silt-bearing rivers as the Yellow River, the Peiho, the Yangtze, the Woosung, and others, both in China and on the Pacific coast, had caused him to form the opinion that a wharf, pier, bridge, dam, or gateway in such rivers, even when large sluices or openings were provided, would ultimately

Mr. Fergusson. lead to the silting-up of the river-bed and of all flooded areas above such obstacles. It seemed to him that the same result must happen in the Nile, in spite of the claim that the sluices of the Assuan dam were capable of discharging the entire flow of the river in flood. For the fact remained that these sluices must be closed to conserve the water, and when they were closed the water behind them would deposit silt. Records showed that the Nile water carried more or less silt during every month in the year. In rivers carrying much silt in suspension the water became clearer at flood-times, when the current had ceased to flow, frequently owing to the congestion of the river-channel;[1] it was at these times that sandbanks were formed in the channel of the river and in the flooded districts forming the reservoirs of the river. This would occur every time the gates of the dam were closed and some of the deposit would adhere to the bottom of the river-channel, whence it could not be removed merely by the scour caused on the reopening of the gates. This would apply particularly to the whole area of the reservoir outside the immediate channel of the river. Had the engineering staff yet found any noticeable rise in the river-channel or in the bed of the reservoir? In spite of any difference of his views with regard to some of the details of the sluices in the dam, upon which an exchange of opinion had been invited, Mr. Fergusson joined with everyone in expressing approval and admiration of the Nile dam, as a very noble work.

With regard to the cracks found in the Assuan dam, he was inclined to attribute the cause of their formation to vibration throughout the structure, rather than to any expansion and contraction of the mass of the material. His reason for this opinion was the known fact that many dams had been found to tremble. Trautwine had alluded to certain dams in America "trembling," and he had stated that "they occasionally cause a rattling of windows within a distance of half a mile or more," and that "building a wide-crib apron a few feet high against the front of the dam, at a slope of 1½ to 1 covered with plank, has been perfectly effective in stopping it." In British Columbia, the Cariboo Hydraulic Mining Company had laid two long siphons across a valley which carried water under a high head. The siphons were supposed to have been

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[1] It frequently happens, that when the water in the Peiho river tops its banks, the water becomes quite clear, yet steamers cannot get up the river on account of the sandbanks formed in its channel, by settlement, deposited during the floods, when the river-channel is surcharged and the current ceases to flow.—J. C. F.

Mr. Fergusson.

built alike, but one of them trembled. Mr. Fergusson was asked his opinion of the cause, and he attributed it to air-pressure within the siphon. As the Assuan dam was intersected laterally by so many culverts, and vertically by wells, instead of a spill-way, for discharging the high-level water on to the floors of these culverts, it was quite probable that at times there might be vibration of the dam, as the Author stated, which had caused these slight cracks; for it must be remembered that sometimes 500 tons of water per second were discharged through the sluices at the toe of the dam. It was of the utmost importance that this enormous discharge should be caused to run away, as smoothly as possible, over the greatest width of the apron. He would not have given a falling gradient to the apron, as had been done by the engineers in this case, but would prefer a long apron laid to a slightly rising gradient; this form of apron would tend to spread the water in its outlet across the whole width of the apron, and would cause the discharge to flow away more smoothly.

Professor P. Forchheimer.

Professor P. Forchheimer, of Graz, referred to the difficult task of counteracting the erosive power of great masses of water pouring from sluices under a considerable head. The mean velocity of a moving liquid mass could only be diminished by a counteracting external force, and whirls did not influence the medium velocity of rushing water except by increasing the friction of the water on the subsoil. To this friction could be added the resistance of a downstream weir, by which a water-cushion was formed. The efficiency of water-cushions must not, however, be overrated. If a single drop fell on an extensive surface of water, it split into small particles, but if a continuous jet were projected into a surface of quiet water the process was entirely changed. As each particle of a continuous jet passing through water was preceded by another particle moving with nearly the same speed, the particle had its way cleared as it were, and its velocity was hardly influenced by the resistance of the surrounding water. The fact that the water of the water-cushion through which the jet passed was set rotating, was another reason why the jet was not hindered effectually in its passage through the water-cushion. It appeared that the rotating water remained the same for some length of time, and therefore when once put in motion it absorbed but little of the working-power of the jet. He agreed with the doubts expressed by the Author as to the efficiency of water-cushions for the Assuan dam. However, there was another method, namely, to carry the harmful rush of water as far down-stream as possible, so that it could not seriously endanger the foundations of the dam. This could be achieved by

Professor P. Forchheimer.

constructing the aprons as smooth as possible. He had deduced, from experiments made for the purpose with soil consisting of a mixture of clay and sand, that every protuberance of the surface of the soil caused the washing out of grooves and channels. If a pebble, too big to be carried away by the force of the water, was left on the surface of the subsoil, it caused an excavation by its rotation. At the corner of the sluices, where the gushing stream touched the quiet water, rotation of water was induced and whirlpools were formed. These harmful rotations might be prevented by buttresses of appropriate outlines erected between the sluices. In his experiment also, whenever the surface of the soil (representing the apron) was not level with the sill of the sluices, a narrow and deep groove was excavated at the toe of the dam. He had taken much interest in the fact that the old dam was showing many cracks. He believed he was the first to draw attention to the disadvantage of building dams in the hot season. In the Proceedings[1] for the year 1894 he had observed that dams were usually built during the warm periods of the year, and the masonry had a tendency to contract in the cold weather, and he pointed to the fact that several dams had failed in winter. To further reduce the dangers of contraction, he had advised the construction of dams in curved lines, as straight dams were more liable to crack than curved ones. As no horizontal ties were used in the additional masonry of the Assuan dam, he agreed with the opinion expressed in the Paper, that the new masonry would also crack. If the cracks widened and if they caused serious anxiety as to the stability of the structure, a heavy superstructure along the waterside of the roadway would improve the stability of the wall.

Professor Gaudard.

Professor J. GAUDARD, of Lausanne, noticed that in the Assuan dam the wisdom of very eminent engineers had been directed to guide the flow of the river, to protect the down-stream bed against erosion by the aid of protective masonry groynes, and to shield the dam itself from the dangers arising from the percolation of water. A dam could resist in two ways, if it were suitably built. Either it might act as a mass against overturning, being supported by the pressure of the water combined with the weight derived from the resultant of the forces in the interior of the supporting base; or it might act as an arch, thrusting across the voussoirs by the pressure of the water, while the weight acted normally in a general sense, and did not affect this mutual pressure. The first type was a dam rectilinear in plan, although a slight curvature might not be useless,

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[1] Vol. cxv, p. 146.

Professor Gaudard.

since it would diminish the risk of overturning of the dam, supposing this to move as one mass. If such a dam were well founded, well built, and protected against down-stream erosion, there still remained the possible danger arising from fissures due to cooling. These fissures were not harmful if they occurred regularly, normally, and not by unequal tearing tending to produce disintegration. According to the figures given in the Paper, it seemed that 15 to 20 metres could be fixed upon as the interval between the open cracks caused across the dam, and subdividing it into independent sections. In the cold weather small streams of water escaped harmlessly through these fissures, which could, moreover, be covered on the up-stream side with movable plates. The second type of dam, a circular wall sustaining a volume of water on its convex side, was similar to an arched cellar, and would have a pressure-curve equally circular and concentric, if the circle were complete. If a single arch were considered, the dam must be buttressed at its extremities, either against the rocky sides of the ravine, or against intermediate piers constituting a kind of vertical abutment, being supported also by the neighbouring arch. The system might become a mixed one; the piers would then concentrate upon themselves the pressure of the water of a complete arch: however, by giving these piers a wide base, it would be possible to effect some economy in the actual cubic contents. The arch would maintain itself locked and closed, but there might be, as in bridges, certain joints tending to open slightly at the intrados or at the extrados. However that might be, the engineers at Assuan had favoured the first type, which probably had appeared to them to be simpler. Of all cracks, the most dangerous, particularly in a rectilinear dam, were those which occurred parallel to the length. The water once inside, exerted its full static pressure, and, supported on the one side by the up-stream part—which was maintained momentarily in place—overturned the down-stream part by its forward pressure; after which the escaped water, no longer exerting its auxiliary counterpressure, let the up-stream part fall in its turn. It was therefore an instructive part of the Paper which described the precautions for maintaining a space of fixed width between the old masonry and that added for the thickening, by a series of rods embedded into both works, which afforded strong resistance to the separation of the parts; then, after settlement and equalization of the temperature, arrangements were made by means of pipes for grouting, to fill the space completely and to expel infiltered water. Thus it was sought to secure an absolutely compact monolithic block; and everything led to the belief that the success of these precautions had been complete.

Mr. Harper. Mr. WALTER A. HARPER observed that he had had several opportunities of examining personally the work of the dam and the method of construction; and during the past and present year he had visited the dam on two occasions. On his last visit he had had an opportunity of inspecting the apron, which had been exposed from one end to the other, and in his opinion this structure was of an absolutely permanent character, and would be subjected to no disturbance beyond the ordinary wear and tear incident to the passage over it of such large bodies of water under considerable pressure. With regard to the grouting, he was confident that there was no occasion for any modification in the scheme that had been adopted, since, as in all other work in connection with the construction, no rule-of-thumb methods had been resorted to; and before the grouting was proceeded with, a complete test had been made which on examination had shown that the result of the grouting done in a sample hole formed a solid mass, which after proper ageing would be equivalent in strength to the masonry itself. With regard to the work as completed, there were no two opinions on the point that it was probably the driest dam in the world; for from end to end, the actual masonry construction showed no leak or passage of water beyond the ordinary "weeping" found on all concrete or masonry structures with water behind them, and this "weeping" was a negligible quantity. With regard to developing the power stored by the dam, the Government were investigating the whole matter, and subject to arrangements being made for the erection of plant which would not interfere with the ordinary uses of the dam as a storage-reservoir, or form any impediment to the free uses of the sluices during the time of flood, there was every reason to believe that the power would gradually be utilized—both for supply purposes and for the production of fertilizers. For the latter purpose it was necessary to take into consideration that large quantities of power were only available for a little over half the year, and that any chemical process selected for the utilization of this power must therefore be such that the power portion of the industry could be carried out during the time of low Nile, and the chemical portion of the industry during the period of flood, when the power would be shut off. Such a process had been laid before the Government and was under consideration by the Author, and there was every reason for hope that this great asset (100,000 to 150,000 HP. available for conversion into electrical energy) would at some date—not far distant—contribute largely, if not wholly, towards the payment of interest and sinking-fund on the cost of the works.

Mr. Hill. Mr. ARTHUR HILL remarked that during 33 years' service in the Irrigation Branch of the Bombay Public Works Department he had had many opportunities of observing the effect of falling water upon rock and masonry. When constructing weirs across the rivers of the Western Ghauts, special care was always taken that, wherever possible, thoroughly sound rock should be obtained for a foundation subject to falling water. The following test was used to ascertain whether the rock was sound :—A blow from a 28-lb. sledgehammer swung with a man's full power was delivered on the rock, and if the latter were sound the hammer rebounded with a clear ringing sound. The difference between the sound of the blow on good sound rock and on rock cracked or jointed was very marked, and the test was a reliable one. As a rule, in the Deccan good sound rock foundations could generally be obtained at a moderate depth. In cases where rock of the quality desired was not available, and protection from falling water was necessary, a concrete rich in mortar was found to be the best material to use for the protection. In the construction of masonry subject to falling water, or water flowing at high velocity, as in sluices through masonry dams, the joints were invariably made large. Mr. Hill used to specify that the joints should not be less than ½ inch wide and should be filled thoroughly. Unless the joints of the work were filled completely stones would certainly be torn out by the action of water. It was an axiom in all irrigation-works that the strength of the construction depended on the mortar, and unless masonry subject to falling water were perfectly bedded in good mortar it would certainly fail. It was more difficult to fill thoroughly the bed or side joints of large than of small stones, and large stones were liable to be moved, or shaken, after they had been placed in position and before the mortar round them had set, hence a concrete rich in mortar, where there was no doubt that every stone was properly surrounded with mortar, would better resist falling water than would masonry. The use of ashlar and big stone was a mistake ; the Author had described how a stone of 80 tons was moved by the water, and Mr. Hill had seen many similar instances of large rocks being cleared and moved away by water below the weirs of newly-constructed storage-works. His experience accorded with the action of the engineers in building the face of the new work at Assuan of small stone which could be conveniently handled and securely bedded, in preference to using heavy ashlar blocks, and he invariably specified that the facework should be of uncoursed rubble of the same quality as the mass of the dam. Some engineers preferred the appearance of coursed to uncoursed work, but it added greatly to the cost and was not

Mr. Hill. necessary, while to many the uncoursed rubble had the more pleasing appearance. Although falling water exercised a most destructive effect on jointed rock, or on any masonry work with imperfectly filled joints, it caused very little wear to the surface of sound unjointed rock or concrete unless it carried sand or gravel with it; or unless there were loose stones lying on the surface to be whirled about by the water. Where the foundations to be protected were uneven and great expense would have to be incurred to build them up to a uniform level, it was often cheaper and equally effective to clear the surface of all loose stones, to then surround it by a wall which would prevent currents from bringing back the stones removed or carrying others to the area, and then to protect the surface by a moderate thickness of concrete; 3 feet would be sufficient. This method agreed with the description given in the Paper of the plan followed below the sluices of Sets 7B and 8A. With regard to the junction of the old work with the new, Mr. Hill did not think any advantage was gained by the method of arranging for a clear space between the new and the old work until the whole of the new work had been completed, and then filling the space with liquid cement; on the contrary, he considered it would have been better to build the new work close up against the old with a thick mortar joint against the face of the old work. In the construction of a masonry dam the quantities of work to be executed were so large that it was easy to avoid the building rapidly of any considerable vertical height of the dam, and in the normal course the mortar of any horizontal set of joints would have set sufficiently to bear the weight of the work constructed above the joints, and there need be no fear of the crushing of the mortar or of any settlement greater than could be met by the elasticity of the mortar. At the joint between the new and the old work any action in the way of settlement would have the effect of bringing the new work more closely against the old; and this was what was desired to resist the overturning thrust of the water-pressure. He would therefore have built the new work close up against the old, and would have provided drainage openings through the new work spaced at the corners of 20-feet squares. These drainage-openings should not be pipes, but should be formed in the new masonry, so that they might drain the new masonry as a whole, and not merely the joint between the new and the old work. They should be large enough to avoid being blocked by deposits of lime; about 6 inches in diameter would be ample. The explanation was given in the Paper that the peculiar joint between the old work and the new was adopted because very fine cracks were noticed in the old dam; but

Mr. Hill. it was not clear what advantage was gained by the introduction of 2 to 6 inches of cement grout between the new and the old work. The cement grout was a different material from the cement mortar of 1 part of cement to 4 parts of sand, and would expand and contract in a different manner; and in any case the cement grout could not add materially to the strength of the dam. Further, the cracks mentioned did not seem to have caused any inconvenience. In the Deccan irrigation-work no trouble had been experienced from cracks in long masonry dams or weirs, and he was well acquainted with structures, having lengths ranging from 8,000 feet downwards, wherein no inconvenience from cracks had been experienced.

Mr. Johnson. Mr. F. R. Johnson had some fears as to whether sufficient consideration had been given to the minority report of Mr. Boulé, and the great volume and weight of the water which had to be dealt with, apart from its velocity. He might be in error, but taking into account the pounding and the stress which must be set up in the aprons, it seemed to him that the rubble masonry used in their construction was hardly suitable, and that a weak spot anywhere in a joint was liable to result at any time in very serious damage before steps could be taken to remedy it. He ventured to suggest that the use of strongly reinforced concrete, which would have possessed greater homogeneity and power to resist varying stress developed either from above or below, would have been economical, and would have diminished the risk which attached to work of this description, under any circumstances. In view of the large quantity of rock which either had to be excavated or had disappeared opposite some of the sluices, and which was afterwards, in most cases, filled again with masonry, it might have been preferable to excavate a little farther to a semi-circular basin form, and line it with a comparatively thin layer of reinforced concrete, so that the water might the better exhaust its velocity amongst its own molecules by reacting and falling back on itself, instead of having to expend its force either on the flat rubble aprons or on the natural rock bed. This principle appeared to have been practically ignored in favour of high sloping aprons which would have the advantage of being exposed at low water, varied in only one or two instances with comparatively shallow flat basins formed by side walls and a subsidiary weir, the general idea being to save the trouble and expense of having to drain for inspection and repair. It seemed to him that sounding, and the use of native divers at small expense for inspection purposes, would have obviated the necessity of draining submerged basins, except when actual

Mr. Johnson. damage had resulted. The advantages obtained by the semicircular form, had it been adopted, would have far outweighed the cost of draining for repair-work, and would, in addition, have made the probability of much repair-work extremely remote, especially if the form in question had been associated with reinforced lining. In his opinion, if the floor as constructed ever showed signs of erosion, there would be something more to do than pointing joints, as it must have been an exceedingly difficult matter in such a climate to construct perfect rubble masonry, which could be absolutely relied on as free from any weak spots. In any case the system adopted was not, he thought, an economical one, so far as the portion of the work under review was concerned.

Professor Luiggi. Professor LUIGI LUIGGI had had the good fortune to visit the dam in April, 1911, when the top was being raised and the reservoir was completely full—in other words, when conditions were at their worst, because with the completed dam conditions were greatly improved. And yet he only saw very slight cracks across the dam and but little water coming through; in fact, so little that it evaporated before reaching to the bottom of the down-stream face of the dam. It must have been indeed an insignificant amount, and certainly this percolation did not interfere at all with the perfect service of the dam, the working of the sluices, and the durability of the masonry. Perhaps by building the dam in several sections, and curved in plan —as Sir William Willcocks had originally proposed—these slight defects might have been avoided, but certainly the work would not have looked so majestic as it now appeared. In a country like Egypt, where all was colossal and grand, it was imperative that the dam should be built on lines not only of absolute safety but also of architectural beauty. He still remembered the outcry about the submersion of the temples of Philæ; and proper respect to appearance was necessary in such important work as the Assuan dam in a centre of artistic and historical remains. When an engineer prepared plans of a great work like this dam, and had the advantage of being able to inspect the construction frequently, he had a chance of adopting during construction any subsequent improvements that suggested themselves after the plans had been approved; and no doubt Sir Benjamin Baker—who was so impressed by the importance of the effects of temperature in the very hot climate of Upper Egypt—would have adopted proper means to avoid "temperature cracks," just as he adopted the artifice of the "space" filled with ballast, to be grouted after the new masonry had attained the temperature of the old masonry. Before the first part of the dam was built no one had thought of expansion joints in dams. These had been adopted

Professor Luiggi.

only lately, first by American engineers, then by others; and even now many engineers objected to their use and preferred to make the dam solid and curved in plan, in order to allow, by the variation of curvature at the crest, a certain movement due to variations of temperature. These movements were most noticeable in the Barossa dam in Australia; in the Urftahal dam in Germany and the La Mouche dam in France. Professor Luiggi had had occasion to build some batteries in the military port of Bahia Blanca, Argentina, with a parapet of concrete about 400 feet long. They were built during the summer, with all possible precautions. During the winter they developed four cracks, each about $\frac{1}{8}$ inch wide and nearly all equidistant, which in the following summer almost closed again, to reappear in the winter. They comported themselves more or less like the cracks in the La Mouche dam and the Assuan dam; and the Author had done good service in bringing this phenomenon plainly to the notice of the profession. Save this and other equally small defects, relating especially to the apron down-stream of the sluices, the Assuan dam was a monument of beauty and utility, that would give satisfactory results for centuries to come, without fear for its safety and working. Only an earthquake could damage the structure. The dam, by regulating the winter flow of the Nile—storing in the reservoir nearly 2,500 million cubic metres of water, to be drawn upon during the low-water flow of the river—had realized the dream of all the rulers of Egypt, from the first Pharaohs to Napoleon and Mehemet Ali, whose aim was to transform the basin system of irrigation during the flood period of the Nile into perennial irrigation. Thus in the hot climate of Egypt there was the possibility of growing yearly as many as three crops of cereals, or one of cereals and one of cotton or sugar-cane. This had more than doubled the produce of the soil, and had redeemed the fellaheen from misery and the Egyptian treasury from bankruptcy. The impounding dam at Assuan, and the regulating weirs at Zifta, Calioub, Assiut, and Esnè had changed these former conditions, and Egypt was now a land of plenty with a bright future. He had visited Egypt before and after the Assuan dam and subsidiary works were built, and the improvements in agriculture were absolutely marvellous.[1] The value of the irrigated land had increased under the perennial system from £25 a feddan (nearly an acre) to £130; and the annual rent of a feddan from £4 to £9. The

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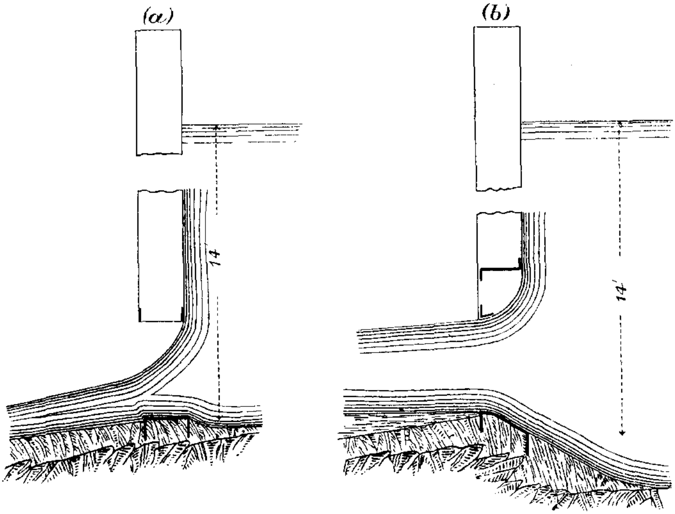
[1] L. Luiggi, "Irrigation in Egypt," Annali della Società degli Ingegneri e degli Architetti Italiani, 1913, p. 263.

Professor Luiggi. Government revenue from the irrigated land had increased more than ½ million pounds sterling, or, more than 5 per cent. on the capital invested in the works, which amounted to about 10 million pounds sterling.

Mr. Price. Mr. JAMES PRICE, who had been Resident Engineer on the construction of the Belleek sluices for Lough Erne drainage in 1883, suggested that it might be of interest to compare some particulars of those sluices, which were the first roller sluices constructed in the United Kingdom on the Stoney system, with the sluices mentioned in the Paper. The Belleek sluices were 29 feet 2 inches span by 14 feet 6 inches high, and as it was often necessary to have one sluice raised only 6 inches when the head of water was 14 feet, the scouring action was severe. The sluice-piers were 10 feet 4 inches wide, and extended 38 feet down-stream from the sluice-gates. They were of boat form in plan, so as to give a fair run to the water, with no backwater or eddy at the ends of the piers. These and the side wall were on limestone rock, which was excavated to 3 feet under the cast-iron sills for the inverts. Two of the inverts were formed of rough mosaic limestone masonry on concrete, and the other two were formed of concrete, laid on the rock, in situ. Within a few years of the opening of the sluices all these inverts were carried away by the scour to within 4 feet of the sills, and were never replaced. The sluices were in use at present with the scour acting

Figs. 11.



on the rock bottom. No settlement had taken place in the sluice-piers. The form of the piers seemed to make the cushion of 3 feet of water sufficient to protect the rock bottom from injury. The trouble with the Assuan sluice-inverts appeared to have been caused by the eddy produced by the 45-foot space between the sluices, and might have been obviated by extending the piers down-stream in boat form. It was observed that the water discharged from sluices with the usual rectangular form of sluice-bottom and sills nearly level with the bottom of the approach-channel, took a downward direction very destructive to the inverts. The water above the opening running down the face of the gate to the point of discharge directed the water running horizontally over the sill in this direction: that could be clearly seen at Belleek sluices (*a*, *Figs. 11.*) Mr. Price suggested that such action could be obviated by making the channel deeper above the sills, with a slope upward to the sills, and making the bottom of the sluice curved as shown in *b*, so as to cause the water to take a horizontal direction at the point of discharge. Mr. Price.

Mr. Sandeman Mr. EDWARD SANDEMAN considered that the idea of thickening the Assuan dam by carrying the added portion on iron bars embedded in the old and new work, and filling in a space left between the two masses of masonry after a lapse of 2 years, would be regarded as a clever design by those who had had experience of the effects produced on masses of masonry by variations of temperature. The success which had followed the carrying-out of this idea on so large a scale only added to the respect felt for the work of Sir Benjamin Baker, and at the same time reflected credit on all those engaged in the execution of the work. Since the problem presented was one connected with temperatures of masonry, it would have been of interest to have more particulars of the temperatures of the original dam and of the added portion. Regarding the original dam, the only information given was that "the lower central mass of the old dam had evidently cooled down to its present small range of temperature of 13° F., thus indicating that external conditions now affect it only partially. On the other hand, the outer layers, as they recede in distance from this central mass, probably responded rhythmically to air temperatures as they do now." That statement gave the impression that the lower central portion did not respond to difference of air temperatures, as it formerly did. After masonry had cooled from its initial heat, engendered by the setting of the cement mortar, it still continued to respond to temperature-changes, which affected it to a slight degree even to upwards of 30 feet from the outer face. It was not stated at what distance from the face of the masonry the tempera-

Mr. Sandeman. ture-range of 13° F. was observed, but he had calculated that the distance must have been 20 to 25 feet. The temperature-range at the face of the dam (say, 1 inch below the surface) would probably be five or six times the amount mentioned. In England the maximum internal temperature in masonry at a distance of 20 feet inwards was reached in October, and the minimum temperature at the same point was reached in April. There was thus a lag of about 3 months in the penetration of the heat and cold to this distance within the masonry. The formula given by Mr. Thaddeus Merriman in a discussion before the American Society of Civil Engineers on "The Effect of Temperature Changes in Masonry,"[1] agreed very closely with results observed in England, so far as regarded distances between the limits of 1 foot and 15 feet from the face of the masonry, but beyond 15 feet the variation in England was less than that given by the formula, which was :—

$$\text{Temperature-range} = \frac{F}{3\sqrt[3]{D}}$$

where F denoted the atmospheric variation in degrees Fahrenheit,
and D ,, ,, distance from the face of the masonry in feet.

It was presumed that the objection to building the added portion as a part of the old dam was that the heat engendered in the setting of the cement mortar would raise the temperature of the new work 20° or 30° above that of the old work; and the gradual cooling of the added portion might tend to a separation of the new work from the old work longitudinally. It was an interesting question to consider whether there would have been any disadvantage if there had been no division between the old and the new work, assuming that the work had been tied together with iron bars in the same manner. The construction of the added portion occupied 5 years (1907–12), and if the same time had been taken to build the added portion joined to the dam, provided the foundation was practically unyielding, it seemed improbable that beyond a hair-crack between the two portions any detriment would have occurred. The allowance of a 2-year interval between the building of the new masonry and the grouting was certainly on the safe side, as it had usually been found that the heat developed in setting was eliminated within 1 year. Possibly the Author could say whether measurements were taken of the 6-inch space from time to time, and also whether these showed any variation in the period before

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[1] Trans. Am. Soc. C.E., vol. 61, p. 413.

grouting, for if any definite movement were observed it would unquestionably point to the fact that the right method of dealing with the problem had been adopted. It had been pointed out that the large number of cracks was one of the difficulties which the design had to meet. By joining the new work to the old, the cracks would almost inevitably have extended through the new work also, but the method adopted of dividing the masonry must have allowed of a separate system of cracks in the new work, with—after the grouting—a possibility of the original cracks also extending to the new work. The well-known Sweetwater dam[1] had, within the last 3 years, been strengthened by adding considerably to its thickness, and, in this instance, since water oozed through the old work, galvanized corrugated iron was placed with the corrugations vertical against the old work to keep the water from affecting the new concrete, and also with the object of keeping the new work apart from the old. In this case also it was considered that, owing to the weight of the new portion and the shortness of the time in which it was to be built, there might be settlement during or after construction. No attempt was made to join the new work to the old; but the internal face of the new work was reinforced by the introduction of 30-lb. and 40-lb. rails placed vertically. Below the corrugated iron a channel was formed to allow of the escape of any water collecting in the corrugations on the up-stream side. If the Author would give the following information it would add further to the interest of the Paper:— Mr. Sandeman.

(1) The atmospheric range of temperature.
(2) The temperature of the face of the old dam and the adjoining face of the new work before grouting was commenced.
(3) The range of temperature of the outer face of the dam close to the surface.

Mr. Charles W. Smith had been privileged to visit the Assuan dam work as it was nearing completion in 1908; and, reading the Paper in the light of the experience thus gained, he anticipated that the Author's condensed yet lucid exposition of a subject containing material for many Papers would meet with sincere appreciation. Doubtless for members specially experienced in dam-construction much of the interest of the Paper would centre in the phase of the work concerning the protection of the rock surface of the Nile bed immediately down-stream of the dam. Mr. Smith's Mr. Smith.

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[1] Minutes of Proceedings Inst. C.E., vol. xcvii, p. 449.

Mr. Smith. experience in regard to protective work of the kind bore out the wisdom of the course followed by the Author, namely, that of adopting solid apron work rather than a water-cushion. In the case of a concrete weir in Victoria designed by Mr. Smith, and surmounted by a series of Chaubart tilting gates, he had provided a water-cushion deemed at the time sufficient to neutralize the destructive effect of a cascade of a calculated maximum flood upon the river bed of Silurian rock. But inspection about 15 years later had shown that the cushion's protective effect had been inadequate, and concreting of the bed had been resorted to in making good the damage done by the undercutting force of the cascade. In examining the designs of the apron work shown in Plate 3, it would appear that in some of the sections shown, e.g., that down-stream of Set No. 1, where discharge from the upper sluices came into action with cascading effect, the excavated natural rock bed of the river was continued for some distance in a very desirably gentle rising gradient from the toe of the apron proper, and so, at low stages of the river-level there, tended to deflect the rush of water somewhat upwards, and thus to dissipate some of its destructive energy. It would, however, be interesting to learn whether the continuation of the apron in that form had been adopted advisedly for that purpose and generally throughout the work, as the "Typical Cross Section of Pierced Dam" did not afford an answer. In view of the high velocities of influx to the lower series of sluices he was led to inquire whether special observations had been made with a view to ascertain whether the river-bed in the vicinity of the intakes to those sluices was showing any significant erosion under the influence of eddies and the grinding effects of debris?

Mr. Strange. Mr. W. L. Strange observed that, although the erosion of the bed of the Nile below the undersluices of the Assuan dam was facilitated by the jointed nature of the rock and by the churning action of detached blocks of stone, that bed had been protected by a jointed masonry apron, laid at a comparatively high level, which was thus exposed to the full force of the large jets of water issuing at very high velocity from the undersluices. It seemed evident that this protection would be successful only so long as the skin of the apron remained intact, and that the detachment of any portion of it, by producing irregular motion of the water, would subject the neighbouring parts to excessive erosion which might lead to their destruction and to a consequent extension of damage. Such damage might, moreover, occur at a time when it would not be possible to limit or repair it. Nature gave protection to the bases of large waterfalls by the excavation of deep pools which deadened the force of the water and prevented the further erosion of the bed immediately down-stream. Man had elsewhere imitated this kind of protection by constructing weirs below overfalls or across rapids, so as to form water-cushions. It was originally proposed to build a water-cushion weir below the Assuan dam, but the idea was rightly abandoned, as the weir contemplated was a low one and would therefore not have had any protective effect. A short length of water-cushion was subsequently constructed below undersluice Sets 7B and 8A, but this basin seemed to be too narrow and too shallow to give full protection. Seeing that the rock down-stream of the dam had been eroded to a considerable depth, it would appear that a comparatively low weir constructed some distance below the dam would have secured a deep water-cushion and would have been the cheapest and most permanent form of protection. Such a weir would have the further advantages of enabling the bed below the dam to be examined at a minimum expense for pumping (especially if the water-cushion were divided into two basins by a cross wall) and of allowing the discharge from the sluices to be measured with the greatest degree of accuracy. Mr. Strange.

The temperature cracks in the masonry appeared to have resulted from the construction of the dam with rigid cement. Similar cracks had not occurred in dams in the Bombay Presidency, as these had been built with hydraulic lime, which was amply strong, and was at the same time sufficiently elastic to prevent cracking. This effect of the temperature in the Assuan dam seemed to have been the principal reason for adopting the ingenious and novel method of thickening the structure which had been carried out. The interval allowed—2 years—for enabling the new masonry to acquire the same temperature as that of the old masonry appeared ample; indeed, taking into account the length of time necessary for constructing the thickening, it might be considered excessive for the purpose. In this respect the thickening of the dam was beneficial by reducing the ratio of the external surface to the quantity of the interior hearting. More important considerations appeared to be connected with the settlement of the new work, the effect of the new work on the stability of the old work when the reservoir became empty, and the prevention of infiltration between the two masses of masonry. With regard to settlement, it would seem desirable to construct the new work at a vertical rate not greater than 30 feet in a year, and to allow each additional part of the height not less than a full year in which to set, before further heightening took place. At Assuan, however, each portion of the new work was raised in a single year to the whole height of the old dam, which

Mr. Strange. rapid construction would tend to cause difference of settlement between the two. The effect of the new work built in courses normal to the steep face-batter of the old work, and not bonded to it, would be to give the former a tendency to overturn the latter when the reservoir was empty. Owing to the heavy section of the original dam, and the comparatively small extent of the raising, this tendency at Assuan would not be of great magnitude. Where, however, an original dam was of slight section, and its proposed heightening was considerable, the tendency to overturn might be increased considerably and to a dangerous extent were a similar form of construction adopted.

Percolation of water between the new and the old work might lead to prejudicial hydrostatic pressure. Although every precaution practicable appeared to have been taken at Assuan to make the joint between the two quite watertight, it was possible that in the large area of joint concerned there might be defective places, and water getting into them might not be drained by the grouting-pipes, which were cleaned out to effect drainage. Inspection-shafts were sunk at the dividing chases of the grouting-bays, but these would not permit of the examination of the joint. When a considerable increase to the height of a masonry dam might subsequently have to be carried out, it would appear desirable, in order to secure the proper bonding of the new work with the old, to build the original down-stream face with a stepped and not a curved profile, and, at intervals, with vertical, dove-tailed recesses and projections. The new work should be raised as slowly as possible in level courses and level stages continuous throughout the dam, starting from the lowest part of its base, and should be made to abut tightly against the old work in order to prevent infiltration. At vertical intervals inspection-culverts should be constructed longitudinally throughout the dam at the junction of the new and old work, with cross culverts at horizontal intervals to drain them. The former would tap all infiltration water met with at their level, and intermediate water would probably disclose its existence by dripping into these culverts. The longitudinal culverts would enable any subsequent repair found necessary to be carried out at a minimum expense and to be localized to really defective parts of the junction between the new and old work.

Prof. Warren. Professor W. H. Warren observed that the thickening and heightening of the dam by building the masonry with its bed-joints at right-angles to the batter on the down-stream side appeared to be a good feature. The method of providing a space between the old and the new work, the filling of this space with granite chips, supporting the new work for a time with steel rods, and subse-

Prof. Warren. quently pouring in thick Portland-cement grout when the whole mass had attained the same temperature, was a well-thought-out scheme, unique in engineering construction. Again, in carrying out this scheme, the method of separating the space between the old and the new work into sections, and grouting each section after ascertaining the necessary quantity of grout to fill completely the interstitial spaces of the granite chips, and the arrangement of the grouting-pipes so that it could be seen when each section had received the correct quantity of grout, all taken together formed an instructive example of the use of cement grout on a large scale. The method of application of cement grout was an important feature in the foundations of the reconstructed Delta barrages and the subsidiary weirs below, and appeared to be thoroughly understood by the engineers in Egypt. He had inspected a sample of the concrete formed in this way at the Assuan dam, representing a length of the filling between the old and the new work, and he considered it to be of excellent quality, suggesting that the junction between the two portions had made the dam in every respect as perfect as if the structure had been built originally to its present dimensions. He also considered the alterations in the locks and lock-gates, rendered necessary by the increased height of the dam, had been carried out in an economical and efficient manner. With regard to some statements which had been made as to the safety of the dam, he had computed the intensities of pressure by considering a portion of the dam between two vertical planes passing through the centres of the lowest sluices 7 metres apart horizontally. The results he had obtained at R.L. 87·50 were:—Maximum normal pressure, from the trapezoidal equation, 6·1 tons per square foot being denoted by σ, $\sigma \sec^2 \theta = 8{\cdot}2$ tons per square foot. At R.L. 82·00, σ being 7·4 tons per square foot, $\sigma \sec^2 \theta = 10{\cdot}8$ tons per square foot, where θ denoted the angle which the resultant of all the forces, above the horizontal section under consideration, made with the normal to that section. Comparing these pressures with those obtained in a similar manner from similar investigations of some notable dams built in other parts of the world, and comparing also the foundations of these dams with that at Assuan, he considered the pressures to be very moderate. Again, since the aprons had been strengthened on the down-stream side, all anxiety as to undermining of the foundations had been removed.

Sir Arthur Webb. Sir **Arthur Webb** took the opportunity of heartily congratulating the Author on his very able and interesting Paper, as well as on the successful completion of the works therein described. Having been

Sir Arthur Webb. responsible to the Public Works Ministry of the Egyptian Government for the construction of many of the very important irrigation-works executed during the last 18 years, he could safely say that Mr. Macdonald had so fully described all the technical points in connection with the Assuan dam that it would be quite unnecessary to enlarge on them. He would, however, like to bring to notice a few other matters which might be of interest apart from the purely technical subjects. During the discussion at the Institution in 1903 on Sir Maurice Fitzmaurice's Paper, "The Nile Reservoir, Assuan," the late Sir Benjamin Baker said[1]:—"The Home engineers had left . . . but those of the Public Works Department were still responsible, and had not seen the end of their anxieties, because the working of the dam had to be looked after. It remained to be seen what would happen in the way of silting; what difficulties might occur in consequence of loose rocks being washed down against the sluices and lock-gates . . .; and what the effects of the water rushing out of the sluices would be on the bed of the river below the dam. All those responsibilities and anxieties were upon the shoulders of the engineers of the Public Works Department." On the completion of the original dam at the end of 1902, Sir Arthur Webb had been most fortunate in securing the services of Mr. Macdonald, one of the home engineers who had been employed throughout the period of its construction and was acquainted with all its details, as permanent Resident Engineer. The "working of the dam," that was, the regulation of the levels in the reservoir and the river down-stream of the dam, as well as the manipulation of the sluices, has been perfected by him, and was now reduced to a matter of diagrams and tables. The amount of "silting" had been very small and in no way affected the main volume of the reservoir. No difficulties had arisen in connection with the sluice-gates of the dam or the lock-gates: the former could be examined and, if necessary, dismantled by using the ingeniously designed curtain constructed by Messrs. Ransomes and Rapier. The effect of "the water rushing from the sluices on the bed of the river below the dam" had, however, been very serious. The measures taken to meet this were fully described in the Paper and Mr. Macdonald deserved every credit for their success. By the simple operation of manipulating the sluice-gates it was now possible to examine the aprons at any time during the working-season—a result which gives great confidence to the engineers in charge of the dam. The Author stated the reasons which led the Egyptian Government to consider the

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[1] Minutes of Proceedings Inst. C.E., vol. clii, p. 137.

Sir Arthur Webb.

necessity of increasing the summer supply. At the same time, Sir Wm. Garstin, Adviser to the Public Works Ministry, had instructed Capt. Lyons, R.E., Director-General of the Survey Department, to prepare surveys of all the cataracts south of Wadi Halfa, in order to ascertain if there was any possible site for a new reservoir instead of raising the level of that at Assuan. The late Sir Benjamin Baker and he had examined these surveys, and in the spring of 1907 they proceeded to the Sudan. They encamped at the Shabluka Cataract, which was on paper the only promising site for a reservoir dam, and found that there were many objections to its adoption, but one was sufficiently strong, namely, that it would probably ruin Khartoum. The next step, therefore, was to come to a decision regarding the Assuan dam. Proposals had been made for raising the water-level in the reservoir from R.L. 106 to R.L. 112 by merely building masonry on the top of the existing dam. For some time, however, the whole question of the theory of the stability of dams had been raised, and numerous experiments had been carried out without any conclusive results. Sir Benjamin Baker had, in the meantime, been considering what might possibly be done to the Assuan dam, and, being quite satisfied regarding the success of the aprons, had decided that whatever was done should result in having a work possessing the same factor of safety as laid down for the original construction. The design, conceived by Sir Benjamin Baker and accepted on behalf of the Egyptian Government by Sir William Garstin, was that which the Author had fully described in his Paper. He had had the privilege of discussing with Sir Benjamin Baker, on many occasions, the details of the design and the methods of constructing the work, and could confidently state that it had been carried out strictly in accordance with Sir Benjamin's views. Statements had recently appeared in the correspondence columns of a leading engineering publication disparaging not only to the work itself, but to the engineers responsible for its design and execution. He would take this opportunity of flatly contradicting those statements. He had on several occasions seen the works, both during and after construction; the whole of the work was founded on hard rock throughout, and no settlement or movement whatever had taken place in either the masonry or ironwork. Owing to the very low state of the river in 1912, the reservoir was raised to its full level of R.L. 113 early in December and maintained at that level for some months. In 1913 the river was still lower and the reservoir was actually raised to R.L. 113·50, or $\frac{1}{2}$ metre higher than the designed full level. The results had been eminently satisfactory and showed that the dam, with its

Sir Arthur Webb. protective aprons down-stream, was probably as safe and stanch a structure of its kind as existed in the whole world. In 1913 the dam was the means of saving a large area of the cotton crop, and the gain to the country was many times the cost of the works described in the Paper. In 1914, with a much lower supply, the results would be still more remarkable.

The Author. The AUTHOR, in reply to questions put during the Discussion which took place when the Paper was read and in the subsequent Correspondence, observed, with reference to Sir Hanbury Brown's remarks, that the stresses in the dam, after grouting, with the reservoir full to 114·00, were taken to be 4·75 kilograms per square centimetre as the maximum on the foundation of the dam. With regard to comparison of the methods of lining the culverts with cast-iron and with dressed granite, both had now been tested for some time at Assuan, and the Author had found them equally sound. They had shown only the slightest trace of being affected by water-action. The granite was fine-point dressed. Naturally, all kinds of stone dressing, other than polishing, produced minute fractures and dislocations of the surface crystals. In the case of Assuan granite, these fractured crystals showed signs of removal, leaving a new and, if anything, somewhat rougher surface than the stone had when dressed and before being submitted to the water-action. This new surface was that which would be subject to genuine wear through the lapse of time. He had intended to put measuring-rods between the sides of the sluices, in order to discover the rate at which erosion would take place, but as the stones had not yet reached the stage in which all the minute fractured crystals might be said to have been removed, he did not consider the time ripe for such an experiment. Possibly in the older part of the dam this might be carried out in some of the sluices during the next few years, though it was already evident that the rate would be an extremely slow one. In answer to the question what type of lining would be used if the dam were to be built again, the Author had a preference for granite, feeling that if erosion, corrosion, or any other sign of failure took place in the cast-iron lining, repair would be more difficult. Since, except a slight appearance of oxidation at a few points where a drip of water came through a joint, there was not a single mark to indicate that the cast-iron linings had been affected in any way, and as they remained as sound as on the day they were built, that particular objection which the Author had in his mind had not turned out to be a cogent one. The question, therefore, could only be answered on the score of convenience, cost, and possibly sentiment.

The inspection-shafts were about 1¼ metre square, and were sunk wholly by hewing, no blasting of any kind being permitted inside them. The granite chips used for filling up the space were similar to large-sized road-metal and had no flat beds on them—the red Assuan granite being a material which did not give a flat fracture. A number of experiments were made to test the flowing property of grout before the work was commenced, and a sample was built against the dam at its solid end for the purpose of showing the nature of the space when grouted. This, and the samples made before the work was begun, showed that the material used and the method adopted for filling the space with grout resulted in a homogeneous mass containing no vacant points visible to the naked eye when the samples were broken up and carefully examined. It was amusing to notice that the sample against the dam, about 5 yards long, 6 feet high, and about 8 inches thick, had been mistaken for a buttress by an engineer who had nothing to do with the building of the dam, but who, it might be thought, ought to have made inquiries on the subject. It was not necessary to introduce water into the "space." This was proved by the manner in which, when filled to the level of one of the horizontal pipes, the cement flowed freely in a liquid stream on to the down-stream face of the dam. The grout was kept to its specified thinness by carefully measuring each batch of grout, as regards both water and cement. **The Author.**

The measurements of water passing through the sluices were still in operation, and coefficients were being obtained for the discharge under the new head produced by the heightening. The Author thought it a little premature to publish them, though he was prepared to do so if they should be considered worthy of it when the experiments were completed.

He was in full agreement with Mr. Stokes's opinion that it would have been better had the higher sluices been placed at a considerably lower level. That was an error of the original design, which has been corrected to some extent by the construction of ogee aprons underneath them.

With reference to Dr. John Ball's remarks, particulars of the original diurnal expansion and contraction, information taken by the Author 8 years ago, could not be found, but he recollected that the variations formed separate curves superimposed upon the main annual curve for each crack, and varied very much in the same ratio per degree of temperature. In this connection the Author remembered placing a thermometer on the sand and covering it with about ½ inch of that material, when he found, on a particularly hot day, that a temperature of 170° F. was recorded.

The Author. He agreed with Mr. Reid Bell that it was unlikely that hourly or even daily variations of temperature would affect the whole mass, but thought it evident that the seasonal variation had such an effect. It was inadvisable to allow water to fall on a flat surface practically normal to its course if the height was greater than 4 metres, even when using hard-grained granite or whinstone with strong cement joints. At Assuan, above that height, the use of ogee curves caused incidence at a much easier angle and consequently reduced to a minimum the destructive effect on the aprons. The aprons were designed not so much for reducing the velocity of the issuing volume of water from the culverts as for altering its direction and allowing it to waste its force while flowing parallel to the rocky river-bed far away from the dam.

The following were the main unit costs of the work:—

			£	s.	d.
Excavation	per cubic	metre	0	6	0
Masonry	,,	,,	1	10	9
Ashlar	,,	,,	9	4	6
Facework	per square	,,	0	19	0

For the greater length of the reservoir there was practically no gradient on the water, the cross-sectional area now being very great when the reservoir was full, the discharge at the same time dropping to about the minimum. The greatest difference observed to date as produced by the prevailing north wind, when suddenly blowing strongly, was 25 centimetres reduction of level at the dam within an hour. As those figures were intimately connected with the regulation and discharge of the dam, which might form the subject of another Paper, they need not be referred to further here. The cracks in the old dam all "wept" to some extent. It was interesting to observe how the volume issuing from the cracks decreased as the summer advanced. There had been no reason for widening the culverts other than that stated in the Paper. In any case it would have been impossible at a reasonable cost to quarry and handle the blocks necessary to span the culverts. There were no bonding-irons sunk into the ashlar round the sluices; the Author was unable to understand how Mr. Carew-Gibson arrived at the conclusion that there were. The meaning of the paragraph regarding grouting was that in the Author's opinion it would have been very inadvisable to grout up a whole bay at one time. This opinion he adhered to. Any scum there was on the grout would have been washed off with the additional filling always allowed for, in order to make it flow out of the horizontal pipes and show that the space was really full. In the sample models no difference of

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quality was observable in the set material, though several layers were put down and the scum was not washed off. In reference to the gauging of the Nile below Assuan, the figures were believed to have been 15 to 20 *per cent.* in error. Undoubtedly scouring was bound to be increased if the dam were heightened and no aprons were constructed.

In answer to Dr. Corthell, the term "R.L." meant "Reduced Level," that was, the height above mean sea-level at Alexandria. The following Table (p. 330) was a list of temperatures in the sun. The Author would draw attention to the figures on Plate 5, below Key No. 5, where there was a note showing the maximum and minimum shade temperatures observed during 1907. The term "sudding" meant coffer-damming by earthen embankments, and was a local expression. The Author agreed that Dr. Corthell's figures for the capacities of the old and new dams were approximately correct; they were 980,000,000 cubic metres and 2,420,000,000 cubic metres respectively. The exact quantity still required to satisfy all possible future requirements of Egyptian summer irrigation was not definitely known, but it must at least be in the region of the figures indicated by Dr. Corthell.

The Author was of opinion that splaying of the down-stream mouths of the culverts would not alone have stopped erosion; after the construction of the aprons the splaying would have been unnecessary. The backwash now existing carried no debris in it to do damage. No appreciable deposit had been observed anywhere in the reservoir, nor was there indication of the bed of the river rising. The Author wished Mr. Fergusson could see the water spreading itself out fan-shape on the steepest apron—Set No. 1—to realize how evenly one sluice could spread over the apron in a short distance. Pumping each year for the whole length of the dam would have been prohibitive; besides that, economy might suggest the omission of such work for a year or two, with possible great loss resulting if any undermining took place. He was interested in reading Mr. Harper's opinion that the Assuan dam was probably the driest in the world, more particularly with reference to some criticism which had appeared in the press. He had seen it stated that serious leakage caused by settlement took place on two lengths, one being in the solid dam and the other in the pierced dam. He would like to say that the seepage was on the whole not nearly so great as that in the original dam. It only occurred above the level of the old dam in the new heightened masonry, as the grouting of the 6-inch space effectually stopped it below that level. Provision was made to carry away any water which might accumulate up-stream of the

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SEVEN-DAY MEANS OF SUN AND SHADE TEMPERATURES TAKEN AT ASSUAN RESERVOIR, WEST BANK, DURING THE YEAR 1911.

Degrees Fahrenheit.

Date.	Sun Temperature. Maximum.		Shade Temperature.		Date.	Sun Temperature. Maximum.		Shade Temperature.	
	Black Bulb.	Bright Bulb.	Min.	Max.		Black Bulb.	Bright Bulb.	Min.	Max.
Jan. 1– 7	124·4	96·3	62	84	July 2– 8	164·7	126·1	78	104
„ 8–14	129·7	96·3	56	78	„ 9–15	169·6	131·4	82	111
„ 15–21	122·3	88·1	51	52	„ 16–22	164·1	125·3	79	105
„ 22–28	114·9	83·2	49	70	„ 23–29	166·7	128·4	78	108
„ 29– 4	129·4	90·4	46	68	„ 30– 5	164·4	126·7	79	104
Feb. 5–11	131·1	90·9	45	72	Aug. 6–12	162·0	123·0	77	101
„ 12–18	132·8	93·2	46	72	„ 13–19	162·4	123·8	76	103
„ 19–25	136·3	98·6	49	73	„ 20–26	162·6	124·3	76	106
„ 26– 4	136·3	97·8	56	79	„ 27– 2	165·2	127·3	80	107
Mar. 5–11	142·7	103·7	56	86	Sept. 3– 9	159·7	121·1	76	99
„ 12–18	147·5	107·7	60	87	„ 10–16	157·2	118·3	73	97
„ 19–25	148·7	107·7	59	84	„ 17–23	157·5	119·9	73	98
„ 26– 1	148·7	107·7	59	85	„ 24–30	159·0	121·7	73	101
Apr. 2– 8	155·9	115·2	62	93	Oct. 1– 7	158·3	127·0	73	94
„ 9–15	162·7	123·1	69	102	„ 8–14	159·9	126·4	75	103
„ 16–22	150·7	110·2	63	87	„ 15–21	151·3	115·1	71	95
„ 23–29	157·0	117·7	74	82	„ 22–28	146·1	110·0	64	91
May 30– 6	160·0	119·8	68	96	„ 29– 4	146·7	110·0	66	91
„ 7–13	167·4	129·0	75	106	Nov. 5–11	137·7	101·3	61	82
„ 14–20	168·0	130·5	81	108	„ 12–18	141·8	105·0	61	86
„ 21–27	163·4	124·9	77	103	„ 19–25	139·1	104·5	60	85
„ 28– 3	161·1	121·7	71	100	„ 26– 2	138·8	102·9	58	83
June 4–10	163·6	124·7	80	102	Dec. 3– 9	132·0	95·9	53	77
„ 11–17	167·0	128·0	82	106	„ 10–16	130·3	93·4	55	74
„ 18–24	164·0	125·5	81	103	„ 17–23	127·0	90·6	49	75
„ 25– 1	166·9	128·0	79	108	„ 24–30	109·9	87·4	47	74

grouting by the horizontal pipes left in the work for the purpose as shown in Plate 4. On the solid dam this seepage water was gathered together in small channels about the dimension of a lead pencil in diameter, laid in the pointing and leading to the foot of the dam, where the volume could be measured. The volumes passing were given below, and constituted the entire

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seepage through the 200 metres of solid dam where settlement was erroneously said to have taken place. The measurements were made when the reservoir was full at R.L. 113·00, and the quantity was repeatedly checked to find if there was any variation. The section began on the top of the exposed solid granite rock appearing above the ground line in the centre of the solid dam, and extended to the junction with the pierced dam at Set No. 18 sluices, measuring roughly 200 metres in length:—

	Distance from beginning of Section.	Distance Apart.
	Metres.	Metres.
Beginning of section	0	1
No. 1 = 0·23 gallon per hour	10	10
No. 2 = 0·58 ,, ,, ...	20	10
No. 3 = 4·33 gallons ,, ...	55	35
No. 4 = 7·37 ,, ,, ...	80	25
No. 5 = 1·17 gallon ,, ...	118	38
No. 6 = 0·82 ,, ,, ...	138	20
End of section	200	62

The result was 14·5 gallons per hour of seepage from an area of 1,000 square metres. On the pierced dam where it occurred no attempt was made to gather or measure the seepage, but from appearance it must be less per square metre than the volume in the solid dam. Very little of the oozing water reached the foot of the dam at any time, as evaporation was usually sufficient to remove all that came out before it could reach the bottom. The Author thought the quantity extraordinarily small and quite negligible, and believed that even this small quantity could be reduced by careful examination of the up-stream face of the dam when the reservoir was empty and repointing it where necessary.

In regard to settlement, repeated careful examination by himself and by the staff did not reveal the slightest sign of anything of the kind. What might have misled an ill-informed critic, who came to the conclusion that because there was a little seepage therefore the dam must have settled at the points where the seepage showed, was that seepage only occurred in the solid dam, and in that portion of the pierced dam where the sluices were stanched against the masonry down-stream of them, thus causing the wells to be full of water to the same level as in the reservoir, that was, where the non-roller sluices were placed in the culverts. The reason

The Author. for the seepage was that the reservoir water in these cases was pressing right on to the main masonry, and as much water could percolate as could find its way in, past the pointing and through the rubber interior. In the case of the remaining—and by far the greater—portion of the dam, the gates were stanched on the up-stream side, thus leaving the wells in which they moved clear of water. These wells had only a few feet of masonry between them and the reservoir, and as they formed about 50 per cent. of the length of the 7-metre space from centre to centre of a sluice, they acted as traps for any seepage coming through, thus preventing it from reaching the down-stream face of the dam at all and allowing the latter to be perfectly dry.

On re-reading the statement regarding the central mass of masonry and its response to variation of temperature, the Author would say that he was of opinion that less effect was made on the central mass now, as probably the variation of temperature was less. He regretted no attempt had been made to measure variation in the size of the space: he came to the conclusion that none would be visible. Neither were there any records kept of its temperature. The record of temperatures for 1907 was marked on Plate 5. Wherever considered necessary, the Author purposely altered the gradient at the outer end of the aprons in order to give a slight upward throw to the water; very little was required, and what was done had proved effective. No change of any kind had been observed in the bed of the river on the up-stream side of the culverts. The Author very cordially thanked the President and Members of the Institution for the manner in which they had received his Paper.