is not fully understood, it is not possible to indicate the probable range of action in other types of soil.

It seems likely, however, that a closer spacing of electrodes would be desirable, and advantage may be gained by using cathode wells of larger diameter.

Any future application of the process should still be regarded largely as an experimental procedure, but measurements of the kind outlined in the Paper should add materially to existing knowledge by yielding results on different types of soil.

Acknowledgements

The Author desires to express his thanks to Mr W. Y. Sandeman, M.C., B.Sc., M.I.C.E., Civil Engineer, Scottish Region of British Railways, for his assistance in the preparation of the Paper and for permission to present it. He also wishes to thank the Building Research Station of the Department of Scientific and Industrial Research for their co-operation in relation to the application of electro-osmosis and to acknowledge abstracts from their report, summarizing the results of their laboratory and field soil tests.

The Paper is accompanied by twelve photographs and nine sheets of drawings, from which the half-tone page plates, the folding Plates and the Figures in the text have been prepared.

Discussion

The Author, introduced his Paper by giving a review of the situation at Ayton after the heavy rains of August 1948, and a brief account of the preliminary work involved before the embankment was dried out by electro-osmosis and a new culvert constructed.

Mr L. E. Hawkins asked if some idea could be given of the cost of electro-osmosis, either the total or some unit costs per foot of tunnel or per cubic yard of bank dried. A good deal more work would have to be done on electro-osmosis before it became an established practice and such figures would be helpful to others considering the method. Had any comparison been made between the overall cost of tunnelling with the aid of electro-osmosis and the better known methods for tunelling through difficult ground?

Those who had seen the devastating effects of water overflowing an earthen embankment would regard it as a very daring action to lower that water by cutting a trench through the bank; could more information be given about the safeguards which had been adopted? The stream had already scoured away the culvert, which was a permanent structure; yet the proposal had been to let the water through the bank in a temporary structure. Mr Hawkins felt sure that that structure must have been very carefully safeguarded to prevent the water from taking charge, washing the whole thing away and making its own cut much too fast. Reference had been made in the Paper to a sluice, but it was not clear how it was proposed to lower the sluice as the trench was lowered. It had been stated that after a short time, owing to the difficulties of excavation, that method had been abandoned.

He suggested that a possible procedure would have been to cut a slightly wider trench almost down to the top level of the water and then to put siphon pipes across the embankment on one side of the trench, fixed on to the timber, and to lower the trench at the side of the siphons as the water-level went down. By the time the water-level had dropped so that the siphons were not so efficient and had not such a big discharge, the siphons could be lowered into the trench again, and so the work could proceed in stages. It seemed to Mr Hawkins that four 9-inch siphon pipes there would have given at least as great a discharge as the pumps and might have been quicker and less troublesome.

Had that method been considered? If so, what were the reasons for its rejection?

Mr L. F. Cooling explained that normally the question to be answered was not whether electro-osmosis would work, but how effective was it likely to be in practice, and how much it would cost. It should be emphasized that, prior to that trial, there had been virtually no background of practical experience in the use of electro-osmosis for drying out a mass of clay. Earlier applications of electro-osmosis, mainly due to Dr Leo Casagrande, were described in B.R.S. Technical Paper No. 30, which had been prepared by Dr Casagrande when he was a member of the staff of the Building Research Station. In most of the cases mentioned in that report, the main purpose of the use of the method had been to overcome difficulties encountered when making excavations into waterlogged silt, and electro-osmosis had been used to increase the stability by diverting the flow of water away from the face of the excavation.

The case described in the Paper represented the first time that electro-osmosis had been used, not only in Great Britain but anywhere, for drying out a mass of clay. It was true that a few odd attempts had been made in relation to industrial sludges, but they had been very tentative and the expenditure of energy had been so high as to be discouraging. It had therefore been with some diffidence that the Building Research Station had approached the problem when consulted. They had carried out preliminary tests to see how the soil would react. In the first place they had tried electrical tests, and had also made a study of the relationship between strength and moisture content of the material, the result of which was shown in *Fig. 20*. That diagram showed that, at the moisture content existing in the bank, a small reduction would cause a fairly substantial increase in the shear strength of the soil, so that any reduction in moisture content which could be effected by electro-osmosis would yield a fairly high dividend in giving increased strength.

The use of the method having been decided upon, he had been extremely pleased by the co-operation afforded him and his colleagues ; the facilities given them had led to field observations which had yielded very useful data.

He would now consider very briefly the results of some of those observations, particularly those summarized in *Figs 15, 16*, and *21*, and would indicate how they had added to existing knowledge of the process.

Considering a small element of soil (length d, cross-sectional area A) under a potential difference of V volts, studies of electro-osmosis had shown that the rate of flow,

$$Q_e = K_e A \frac{V}{d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where K_e denoted a quantity called the electro-osmotic permeability. In the case of the soil in question, $K_e = 7 \times 10^{-6}$, the units being cubic centimetres per square centimetre per second per volt per centimetre. That was the value of the moisture content which had existed in the bank.

Considering the electrical relationships of the element, the current

$$I = \mu A \frac{V}{d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where μ denoted the "overall" specific conductivity. For the soil as it existed in the bank, $\mu = 2{\cdot}4 \times 10^{-4}$ ohms^{-1} centimetres^{-1}. The combination of equations (1) and (2) gave,

$$Q_e = \left(\frac{K_e}{\mu}\right) I$$

and the multiplication of each side by time gave,

$$Q_e \times t = \left(\frac{K_e}{\mu}\right) I \times t.$$

That meant that the quantity of water transported was proportional to the quantity of electricity used. In the practical case of a very fine-grained material there was almost no hydraulic flow, and a correspondence between the small-scale test and the large-scale test was to be expected. For the soil in question, the factor $\frac{K_e}{\mu} = \frac{7 \times 10^{-6}}{2{\cdot}4 \times 10^{-4}} = 0{\cdot}029$ cubic centimetre per ampere-second, which upon adjusting the units became 0·023 gallon per ampere-hour.

Looking at the results given in the Paper, it would be seen at the top of

p. 19, that, for well-points Nos 2 and 3, the yield was 0·02 gallon per ampere-hour, and that for Nos 4 and 5, 0·014 gallon per ampere-hour ; well-point No. 1, which leaked, gave a low value. A closer examination of the actual figures showed that for each well the initial value was about 0·02 gallon per ampere-hour. Under the conditions of the full-scale test, where the potential drop was 100 volts, each ampere-hour, of course, took 100 watt-hours giving a theoretical output of 0·23 gallon per kilowatt-hour. From *Fig. 15* it would be seen that the actual output had started off at about that amount, or a little more than 2,000 gallons for 10,000 kilowatt-hours. The subsequent decrease was not unexpected, because the value of $\frac{K_e}{\mu}$ decreased as the water content decreased. It was possible, therefore, from the small-scale tests to give an indication of how much water would be associated with the number of ampere-hours.

The rate of yield of water and the rate of expenditure of electricity depended, of course, on the geometry of the system, which was rather complicated to analyse in the present case. Mr Cooling felt sure, however, that it could be done if necessary by model tests. From that point of view the observations given in *Fig. 16* would also prove useful, if they could be compared with the results of model tests.

Fig. 21 summarized the results of a lot of careful work by his colleague, Mr Loudon, and it indicated the very local nature of the drying. The actual drying out of the bank as a result of electro-osmosis was a very complicated process, which was not completely understood. As the water was forced away from any region, say towards the cathode, the decreasing water content produced a capillary suction and water was drawn in from the surrounding soil. The mechanism of that process was complex and it was not easy to get a clear idea of it from small-scale tests. It was for that reason that the observations made in *Fig. 21* were so valuable.

The Author had asked why the pores clogged up. Mr Cooling could not give a full answer. It had been observed during the tests that the soil round the cathode became hardened. He had had a section made of that material round the cathode, and it had been inspected under the microscope and found to contain secondary silica in the pores ; the silica had been dissolved out of the soil and precipitated round the cathode, clogging up the pores.

Mr E. J. C. Reed observed that the decision to carry out the work by tunnelling had been amply justified by all subsequent events and, although there had been some difficulties in carrying out the work, there had also been a fair measure of good fortune. As the Author had said, it had been impossible to determine the centre-line of the old culvert exactly, and, as it happened, during tunnelling operations part of the old culvert had been found on the Berwick side of the new one. Most of it had been intact, except for a portion where it had been penetrated by some of the box piles. It was probable that if the steel-sheet piles had been driven and continued down to the bottom of the trench as in the original scheme, they would have penetrated the old culvert and would doubtless have caused a collapse of the stone lining. It had been intended, as part of the repair work, to find and fill any voids which might well have existed down in the bottom, in order to save trouble later. If the piles had been driven, some of those voids would have been outside the piling and it would have been troublesome to find them and fill them.

As the new culvert had been aligned on the old inlet walls, which had remained in view, it was fortunate that instead of the old culvert crossing the line of the new one it ran, he believed, roughly parallel to it, possibly owing to a movement of that inlet towards Edinburgh at the time of the flooding, whilst the part of the old culvert remaining in the bank had not moved ; so that when the filling and grouting of the old culvert had been carried out and the tunnelling for the new culvert continued, there had been no need for any cutting out. Furthermore, on probing the invert of the old culvert it had been found to be very soft, but in the new tunnel alongside it the ground had been very much better. It was possible that, owing to that soft ground, if the tunnelling had been carried out on exactly the same line as the old one it might have been necessary to put a concrete cradle in the bottom, and that would have delayed progress considerably.

There could be no doubt that the application of electro-osmosis had improved the condition of the ground sufficiently to simplify tunnelling operations. To Mr Reed the ground had appeared to have been dried out partly by heat as well as by electrical means. Whether that was right or not Mr Cooling would probably be able to say, but it had looked as though it had been partly baked. Since, by that time, the ground had been in such a satisfactory condition for tunnelling, the use of an advance heading had been possible, and with an advance heading there was a more rapid rate of progress. Some years ago, when some Greathead-shield-driven tunnels were being built, an advance heading had been used in the bottom and 50 per cent. extra progress had been made by that means. It was just a box heading of 9-inch by 3-inch, the side timbers standing on foot-blocks or on a sill right across, according to the condition of the ground.

If electro-osmosis had been unsuccessful, or if it had not been applied, then since the ground had been very soft and puggy before the process was used, he felt sure that progress in the tunnelling operations would have been not more than half that actually achieved, and perhaps less : whilst the timbering would have been much more complicated.

With regard to the sheet piling which had twisted, especially at its ends, Mr Reed suggested that in future, where sheet piling was to be driven on a considerable skew, both lines of sheeting should be tied back near the edges of the bank top, where the twisting was liable to be greatest. He believed that in the case concerned the piles had been fairly plumb under the 6-foot way, but had twisted from there outwards.

Mr A. M. Muir Wood said that from the Author's introduction it appeared that the original failure had probably been caused by scour. Mr Muir Wood suggested that it was possible, and even likely, that the events had taken place in the following way. First of all scouring had caused collapse of the culvert on the down-stream side of the line and then the water, rising to form a lake on the upstream side, had by its buoyancy set off the slip on that side and brought the culvert down with it.

With regard to the piling which had skewed after being driven, that was presumably due to the fact that the piling, at any rate in the cess, had pierced the surface of failure of the slip, and therefore the piles had been affected by a continual movement of the slip. Had any records been taken of subsequent slips or of the slip-cum-settlement which might have been brought about by the gradual dewatering, which he believed would have been approximately 6 inches?

It was stated in the Paper that when the culvert had originally been built the line of the stream had been moved slightly from its original bed; and he suggested that it might have been possible to deal with the old culvert in such a way, for instance by probing down to it with borings to find exactly where it lay and then grouting it out, that all the excavation might have been done elsewhere, perhaps on the line of the original stream bed, so as to find stronger and better ground for any tunnelling or excavating.

Was it considered that the laboratory tests of the remoulded clay, which had been made homogeneous for those tests, had reproduced the conditions in the bank, where, owing to slips, the clay would have been fissured and would have had some fairly hard zones and some fairly soft zones in it? Was it considered that the conditions in the laboratory test had sufficiently reproduced the actual conditions in the bank to yield reliable results? The figures which Mr Cooling had presented apparently showed that that had been the case.

Had it been considered possible to use electro-osmosis in the form in which it had been used in Germany and in Holland? He realized that at Ayton the work had been in clay rather than silt: but would it have been possible to use the seepage forces as a help rather than the drying out; and to use the sheet piling as the anode, as had been done, but to put some of the cathodes behind the sheet piling and therefore increase its stability during excavation?

Had it been necessary to put in a new culvert of double the original capacity, since there had been no suggestion that the culvert had failed whilst running full bore? Would not it have been possible to have kept to the original size, in which case the objection of the piling converging on the line of the old culvert would not have arisen?

It had been pointed out that the cathodes had dried out around the periphery of the bore. That, presumably, had been primarily because the flow-lines of electric current had converged there. The Paper also had shown that the electro-osmotic permeability would have decreased more quickly by drying out than the conductance, and therefore one would imagine that, once any drying out had tended to take place near the cathode, it would have been accentuated.

When an electric current was passed through water or soil between two electrodes, mineral salts, previously in solution, were frequently precipitated at the cathode. That phenomenon, first remarked by Sir Humphrey Davy in 1824, had had many subsequent confirmations. It was attributed to the formation of molecular hydrogen at the cathode causing local alkalinity which promoted a chemical reaction that changed the compounds from soluble to insoluble forms in water. It might well be expected, in consequence, that when electro-osmosis was applied, the permeability of the ground immediately adjacent to cathode well points might be reduced. It seemed, therefore, to be expedient to examine the water and soil to be dealt with by electro-osmosis to determine the likelihood of such deposition; if necessary, counter-measures could then be taken. Had any such chemical analyses been made, or could they be made at Ayton so that the deposit of silicates around the cathode, mentioned by Mr Cooling, could be accounted for?

Mr J. D. West said that the decision to cut a relieving trench had been, in his view, a sound one. It had been an essential part of the scheme, which could have been omitted only with some risk of the flood-water getting out of hand at some stage of the temporary or permanent work. He said that for the following reason. The impounded water had gathered into a lake in 19 hours, as mentioned in the Paper; and, although a second and similar concentration of rainfall could hardly have been expected, the lake had been observed on more than one occasion to rise, 12 inches from a night's rainfall. That, expressed in terms of pumping meant the output of a 2,000-gallon-per-minute pump for about 6 days; so that not only had the accumulated flood water to be drained off but also a constant intake of water from the Horn Burn itself. The trench had done yeoman service in the early days of the drainage of the impounded water, which it would have been difficult to surpass by pumping alone; and in the early days the large pumping machinery required for the work could not have been brought on to the site, owing to the flooding of the adjacent valley and the bad condition of the ground in the fields around.

One point which might have been mentioned in the Paper was that while the trench had been under construction a good deal of attention had been given to the stability of the damaged embankment, and some thousands of sandbags had been deposited on the upstream face of the embankment with a view to preventing the embankment giving way and causing disaster to the village of Ayton below.

Throughout the flood-damaged area the policy had been to restore the traffic quickly, and to fashion the temporary works so that they would be a useful contribution to the construction of the permanent works which were to follow at a later date. In that respect the Ayton culvert had been no exception, and the opening of the line had been in keeping with what was being done at the other sites. Another day in completing the temporary works at the Ayton site would have delayed the opening of the line by that amount, whereas a day less would have served no useful purpose. That was significant, because it was a moot point whether the 30-foot sheet piling should not have been driven to a depth of 60 feet and toed in virgin soil. The latter course would have been preferred at the time, but it had become increasingly apparent that that could not be accomplished. As events had shown, the clay in the embankment had remained in a very soft condition, and it was hardly likely that the original scheme would have been fully successful in so far as the stability of the embankment was concerned.

The Author should be thanked for having placed on record the details of the use of electro-osmosis for that work. In order to make the record as informative as possible, Mr West suggested the addition of some longitudinal and transverse sections through the embankment to illustrate the disposition of the anodes and cathodes with their sphere of influence, though he appreciated that that information was obtainable by a detailed examination of the Paper.

Mr W. Y. Sandeman said that he did not know the exact cost of the work described. It had been substantial, but with the embankment in such a condition and with the sheet piling twisted, it had been necessary to come to some decision. On advice from headquarters electro-osmosis had been tried, and had been successful in that it not only had made the tunnelling easier but also had made a permanent reduction in the quantity of water in the embankment and therefore improved the stability.

The advisability of digging the trench had been raised, and he had been glad to hear Mr West defend it. That decision had been reached the first time that Mr Sandeman had seen the embankment. It had been necessary to get rid of the water and to have some means whereby the water could flow during reconstruction, so that a trench had seemed the best solution. As a safeguard the trench had been timbered and, in addition, before any water had been let out it had been floored and the wooden sluice put in position. No risk had been taken there, but the method had been carefully considered at each stage. He had come to the conclusion that pumps were essential in the final stage and accordingly should be brought on as soon as possible. The Metropolitan Water Board had been so kind as to do that job. He was certain that if he had a similar job to do again he would have the pumps at the start, so that the trench could be dug in the dry throughout.

He thought that they had been very fortunate in finding the portion of the old culvert remaining, so that they had been able to fill it in.

It had been suggested that the damage to the embankment had probably occurred first on the downstream side. He did not know, but he could not imagine that, if the damage had occurred on the downstream side first, the lake would have been formed in the way it had been. He felt that the damage must have occurred on the upstream side, so that the core of the embankment, where the 30-foot length of culvert had remained undamaged, had held the water.

It had been asked whether the culvert had ever run full bore. He did not think that it had. A few hours before its collapse the ganger had informed them that it was running $\frac{2}{3}$ or $\frac{3}{4}$ full. The suggestion had been made that the size of the new culvert might have been reduced. He had not done that because it was a statutory work. If it had been made smaller and there had ever been any flooding, the railway would have had to take the whole responsibility, whereas if they kept to the statutory size they were covered by the Act to a certain extent.

Mr A. H. Toms thought that he and Mr Cooling had been jointly responsible for influencing the final decision to have well-points, in order at least to see whether there was water coming in and, if so, where it was going, instead of simple anodes around which it might be imagined that water was collecting although it could not be seen. He would like to see the inclusion in the Paper of a drawing of the well-points.

Another point which he wished to make had already been covered by Mr Cooling, namely that with material which had a very low liquid limit and plastic limit, a very small percentage decrease in moisture content could effect a large increase in the factor of safety. That seemed to be very significant, because a different type of material might not have given comparable results. He wished to know whether Mr Cooling's laboratory tests under conditions of parallel flow in the rectangular tank used, had shown the hardening round the cathodes found on the actual job, where there had been an acute concentration of flow lines, both water and electrical, towards the cathodes.

Further to the question of the formation of an impervious barrier to the water passing to the cathodes, would it not be better on a subsequent occasion to use large-diameter boreholes with a small tube well down the centre and surrounded with a filter of sand-gravel, or some other medium ?

Mr Cooling had mentioned that there was secondary silica deposition. Mr Toms had intended asking whether the mud grouting had therefore been unnecessary, and whether it would have been sufficient merely to have flooded the borehole with water before turning on the electricity.

There was mention at the bottom of p. 19 of seepage of water away from the well points when the current had been turned off. Would that seepage away from them in fact have occurred while the current was turned on ?

A point which was worth some emphasis was the statement on p. 20 that the wetter parts of the soil had been affected more than the drier parts. That had tended to produce uniformity in the final result; the parts which had most needed to be affected had been so affected.

Mr J. M. Liddell asked whether the railway authorities had received any compensation for the extensive damage to bridges and culverts and track from any outside Government department, and, if so, whether it had included the expensive new works which had been provided, and which appeared to exceed the previous structures.

In the Paper, the size of the original culvert was given as 8 feet wide and 8 feet high, of masonry, with a semi-circular top, having an area of about 56 square feet; but on p. 8 reference was made to an approved design "for a reinforced-concrete box-culvert having internal dimensions 10 feet wide and 12 feet high and a concrete-thickness of 2 feet." That meant an area of 120 square feet, which seemed to be more than double the original size. Reference was later made to the fact that that method of construction in a trench had been abandoned, owing to difficulties with the piling, and tunnelling resorted to. Had there been any special circumstance to suggest the design procedure for the box-culvert in deep trench, because normally Mr Liddell thought it would be felt that tunnelling would in any case have been both cheaper and quicker, where the depth was of the order of 50 feet.

Could the Author confirm that the new culvert had been constructed of reinforced-concrete segments about 12 feet in diameter, lined with 1 foot of reinforced concrete, with an internal diameter of 10 feet?

Reference had been made to the cause of the damage. Mr Liddell's recollection was that the damage had been caused by trees being uprooted. Had a screen been provided on the upstream side to trap such obstructions?

Mr Oliver Kipps said that everything had been done with the safety of the traffic as the first consideration, because whatever happened the line had to be kept running throughout the reconstruction work. When first suggested, the osmosis had been entirely experimental both for the particular application intended and for Great Britain. The first suggestion had been that a voltage of 220 would be reasonable. That suggestion had not been adopted, and a voltage of 110 had been used. It was quite true to say that there had been no accidents, serious or otherwise, due to electrical faults or contact with the conductors throughout the duration of the osmosis work.

The experiments carried out at the Building Research Station had led to the belief that the osmosis process could be completed in about 10 weeks, drying out the embankment to the degree required, but, as would be seen from the Paper, it had actually taken 23 weeks. That was the sort of happening which experimental work necessarily entailed.

It would have been noticed that seven generators had been provided for that work, and some people might wonder why so many small generators had been used. One reason was portability. All the machinery had had to be brought over nearly half a mile of boggy ground up to the site of the job. Of the generators available, those had been considered the most suitable for the work. A certain amount of difficulty had ensued in attempting to gang up a number of generators all to feed into the same circuit, but that had been overcome without much trouble and the whole system had worked very well indeed throughout the duration of the osmosis.

Another point of interest was the fuelling of the generators. Being so far from the road, it had been necessary to lay on a fuel supply by gravity from tanks on the highway to the temporary power station.

Mr Muir Wood had raised the question of shrinkage of the embankment as the water had been extracted. The Author would probably confirm the fact that the track had been constantly in course of adjustment on each side of the temporary bridge, and the total amount of adjustment had been of the order of several inches. Would the Author confirm that figure ?

The actual size selected for the tunnel had been determined, among other reasons, with a view to attempting to encircle the old structure, so that it could be completely dug out leaving no voids or collapsed masonry. The fact that the centre-line had been 10 feet away from its intended position had been unfortunate.

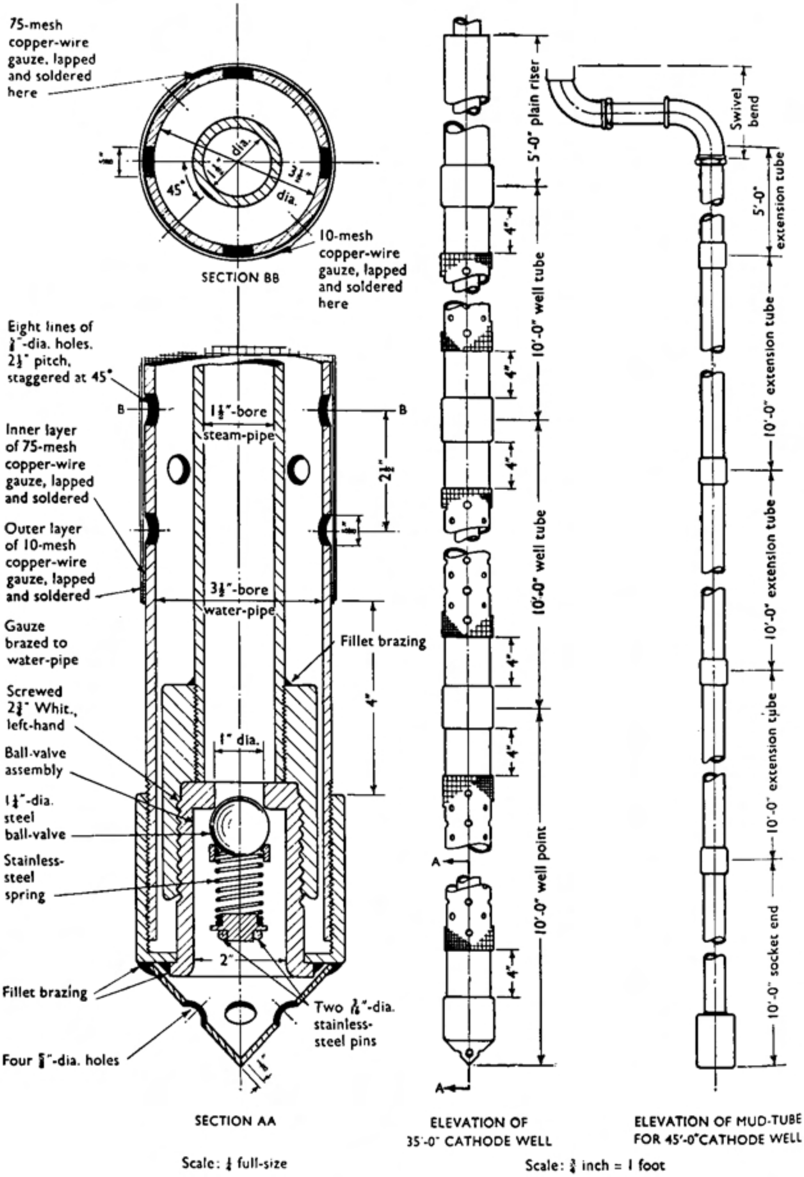
The cofferdam arrangements up and down stream might seem a little elaborate, with their inner and outer cells, but there again the whole design of those works had been largely guided by the necessity for ensuring the safety of the bank. Being on the skew to the embankment, it had not been easy to ensure that the excavation in the open there could be carried out without distortion and a tendency to slipping, so that it had been tackled in two stages ; the outer cell had been done first, and then the inner cell. The work in the outer cell had given an abutment for the strutting of the inner cell. That had been necessary to get sufficiently far in to give headcover from the tunnelling. The remainder of the work was best described as a quite straightforward tunnelling job, and the difficulties and breakdown of plans which characterized the earlier part of the work had not recurred.

The Author, in reply, said that most of the questions had been answered for him.

Mr Hawkins had asked for the cost of the electro-osmosis. That information could be better obtained from the facts and figures given in the report. If the cost of a unit of electricity in any given locality were known and if the soil analysis were the same as at Ayton, then the costs could be calculated from the figures given in the Paper.

The safeguards taken in allowing the water to pass through the trench were quite adequate. A solid earth dam had been left at the inlet end, and covered with tarpaulins which stretched down the bank. The level of the trench had been reduced to about 4 feet below water-level, but the last 8 to

Figs 22



DETAILS OF CATHODE WELLS

10-feet length under the tarpaulins had not been excavated until the last moment. The water had discharged at a depth of 1 or 2 feet at a time, and as soon as the flow had eased off, excavation had been continued under the tarpaulins again and so the water-level was reduced to the excavated level.

Mr Sandeman had answered most of Mr Muir Wood's questions, but electro-osmosis problems should be referred to Mr Cooling.

Figs 22 gave details of the cathode wells.

Mr Cooling would probably agree that in his tests no deposit had been found on the well-points. It was interesting to note in Dr Casagrande's booklet that the deposit which he had obtained had been actually on the anode, not the cathode; that was one of the drawbacks of the electro-osmotic process which had been discovered at Ayton, and an answer to it would have to be found eventually. The process had continued to work, although the water had been prevented from getting into the well-point and a mass of water had been left round the outside core. In *Fig. 18* it would be seen that there was a line which went straight up at each well-point (in the case of No. 4, going up to almost 24 per cent.). That was a region just outside, so that electro-osmosis was clearly still working even with the hard core formed. It might be a question of moving the well-points nearer to the anodes to dry the bank sufficiently.

Mr Liddell had asked about compensation, but the Author was not in a position to reply. Mr Liddell had also asked why tunnelling had not been adopted in the first place. It had been the opinion of the Executives' Engineers that, in view of the obstructions which they had expected to meet, it would be less troublesome if such obstructions were encountered out in the open rather than in a tunnel.

A screen had been provided on the upstream side of the new culvert.

Mr Kipps had asked for confirmation of the subsidence on either side of the bridge caused by the osmosis. Unfortunately the Author could not give a definite answer to that question, because half-way through the experiment the tell-tales which he had put in, in the form of concrete blocks with wooden pegs on top, had been uprooted by the permanent way gang in one of their packing operations. He thought that the area affected would be about 20 feet on either side of the temporary bridge, and possibly the rails had been uplifted about 10 inches in all.

In conclusion the Author drew attention to the section entitled "Conclusions" on p. 24.

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