Costs

The underpinning of the cylinders, including the reinforced-concrete raft, was carried out on a cost-plus-profit basis. The total cost of the foundations, including the partial sinking of the cylinders, was approximately $2,600,000 (Straits). The cost of the underpinning, exclusive of Consulting Engineer's and Architect's fees, was approximately $2,140,000 (Straits).

Acknowledgements

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The Author wishes to thank, in particular, Mr Steen Sehested for providing most of the data relating to the design and history of the foundations.

Mr J. B. Murray, B.Sc., M.I.C.E., was the Contractors' Managing Director responsible for the planning and organization. Mr E. D. H. Johnstone and the Author were respectively the Contractors' Agent (part-time) and Engineer in charge of the underpinning of the foundations.

The Paper is accompanied by twenty-one photographs and fifteen sheets of drawings, from some of which the half-tone page plates, folding Plates 1 and 2, and the Figures in the text have been prepared.

Discussion

Mr Rudolph Glossop remarked that the Paper showed how important it was, when dealing with foundation problems in difficult ground, to choose the right method; that choice could only be based on careful site investigation. If the right method were chosen all would go well and to programme; if the wrong method were chosen, there would be nothing but trouble throughout the job. The simple fact in the case in question was that caissons had not been the right answer because there were big boulders in the ground, so that the operation had been doomed from the start.

Another point of interest to engineers who had spent their lives in England was that even in a big city like Singapore troubles arose from lack of suitable plant and key men. There was no doubt that all the troubles experienced in connexion with the Asia Insurance Company Building resulted from the fact that no diamond drilling equipment was available in Singapore. If there had been, the consulting engineer would have used it, and would doubtless have adopted a different design.

The Paper interested him also because it dealt with one of the few cases within Mr Glossop's knowledge where segmental shafts had been used for foundations. To the tunnel engineer they were very familiar structures. By a curious chance, however, in 1951, his colleague Mr Harding and he had been preparing a Paper for the Building Congress held in London, and had been going through various types of structure used in foundation work. They came to the question of segmental shafts, and had had considerable discussion whether those could be regarded as normal expedients for foundation work ; they had been inclined to decide that they could not be regarded in that way. One instance of their use which they had known at that time had been for the National Provincial Bank building in the 1920's, when Sir Harley Dalrymple-Hay made use of shafts because the site, like that described by the Author, had been very congested ; it had been essential not to lose ground, and Sir Harley wanted to support every inch of ground as he went down.

Within a month, however, they had had a letter from the Municipal Engineer of Hong Kong referring to the very building which the Author had described, and after reading that letter and looking at the drawings, they had come to the conclusion that, by an extraordinary chance, that was an example where the segmental shaft used, of course, with compressed air unquestionably was the right answer. Afterwards, his colleague, Mr Wild, had gone out to Singapore, carried out a site investigation, and discussed the problem with the architect and consulting engineer ; eventually the scheme which the Author had described had been produced.

Generally speaking, then, the segmental shaft was the answer where there were very difficult conditions of running sand with high water-pressure and large boulders, which made it impossible to use bored piles, caissons, steel sheet-piling, or anything else. With compressed air, there was complete control of the face. If there was a boulder it could be got out without losing too much ground, and the ring could be built and grouted up tight, so that the situation never got out of hand.

The Author had mentioned that very large quantities of grout got away and that there had been great losses of air. Mr Glossop thought in that kind of ground such losses must be expected, and individual judgement should be used in dealing with it. It was astonishing how much air did escape from a shaft, and how far it travelled without disturbance to the ground. It might be of interest to mention two cases he had known where air in the Thames Valley had travelled very considerable distances ; it had passed through peat beds, lost its oxygen because the peat began to oxidize, then had got into a neighbouring excavation and, being deficient in oxygen, had formed a death trap. At Dagenham five men had been killed when they went down a shaft; all died before they could be pulled out. There had been another narrow escape in 1939 for the same reason. It was something worth remembering, and could hardly be foreseen by those who had no actual experience of it.

Mr J. A. K. Hamilton, congratulating the Author, said that he had evidently taken a considerable time in choosing the method of doing the job, because it would be noticed that the contract had been let two years before work was started on the site itself and, presumably, most of that time had been spent in investigating actual site conditions and the ground.

The excavation necessary to place the precast segments had obviously been very difficult. The Author's photographs had shown some very large vertical faces, and candidly Mr Hamilton did not like them, though probably they could not have been avoided. The large vertical faces in running ground with boulders, adjacent to a large building such as the K.P.M. building and a main roadway, must have caused the Author some sleepless nights, with the ground moving and water pouring in. The Author made only one reference to poling; that was at the special base of cylinder E15, but presumably in many cases to stem the flow of the ground and water he used poling and other precautions not mentioned in the Paper.

The decision to underpin the old cylinders was interesting, and had apparently been justified by the results; but, generally speaking, it was a good deal more difficult to underpin than to sink cylinders in that type of ground; it would be interesting to know whether, in the case of the nine old cylinders which had been left at distances ranging from 2 to 16 feet in the old beach formation, and the three new ones, consideration had been given to sinking instead of underpinning them. Probably the Author would say that the presence of boulders in the ground, together with old piles, had been the deciding factor; or it might have been the results achieved by the previous contractor. The Author did not say much about how that contractor had sunk those cylinders into their position and condition; some information about that might be illuminating. Cylinder B3, at any rate, had started on its own initiative and had to be stopped; so that it would appear that there could have been some possibility of sinking those cylinders, and not underpinning them.

It would also be interesting to know whether any bores were made in the bottom of the cylinders immediately prior to concreting, whether the Author test-loaded any of the cylinders prior to concreting the raft at the top, and whether he had obtained any settlement figures on individual cylinders from test-loading.

The work on cylinders E12 and E15 had been done under compressed air, and two air-locks had been used. Had there been any particular reason for using two air-locks at once, or was it a matter of delivery of plant? Mr Hamilton did not know why two cylinders fairly close together should be sunk at the same time under air. As Mr Glossop had said, it was always a difficult matter to restrain air, and with underpinning it was twice as difficult as with sinking cylinders. If there were two adjacent cylinders to be sunk under air, it was not the general practice, in Mr Hamilton's experience, to sink them both at once. He had sunk a number of bridge cylinders side by side, but had never sunk two adjacent at the same time.

He noticed that the low-pressure air had been obtained from a compressor rated at 1,800 cubic feet, driven by a 185-brake-horse-power electric motor. The ground had certainly been very bad, but, even so, that would appear to be a very big consumption of air. The Author, however, had almost answered the question already; apparently it had been necessary, because he had lost the air pressure altogether on occasion. Mr Hamilton had been going to ask him whether he really did use the whole capacity of the motor when dealing with the cylinders in compressed air, because even in bad ground he thought that if a small vertical face was taken out at a time and the leaks were stopped by plugging of some sort, it should have been possible to reduce materially the horse-power consumption. He did not know whether rolling-drum rotary compressors were invariably oily, but that was the case so far as Mr Hamilton had had any experience of them, and the air was very much worse than that obtained from a piston compressor.

There was one small question which he wished to ask in conclusion. It had probably something to do with conditions in the East, about which he knew nothing, but why did the Author consider it necessary to take the low-pressure air pipe nearly down to the bottom of the cylinder?

Mr G. E. Wild said the Paper was very interesting about a job with certain very special characteristics in Singapore, although perhaps it would not have occasioned quite so much trouble in Great Britain. The ground conditions at the site had been most unfortunate; beneath the fill and the geologically recent beach deposits there had been tropically weathered, triassic sandstone-shale formation, which was now known to extend to at least 95 feet below ground level, and which might go down for another 50, or even 100 feet. The results of tropical weathering were, of course, most impressive. That formation had become nothing but a series of large sandstone boulders, more or less decomposed, set in a matrix of multi-coloured stiff clay, which softened very readily in contact with water. Above that, the beach deposits consisted of very soft black organic silt with many shell fragments and a mass of sponge-like corals. In some places he had been told that hard coral had been found, but he had seen none, and he wondered whether in fact in the subsequent work the Author had found any hard coral.

The job had been another very striking testimony to the paramount necessity of carrying out a thorough and adequate site investigation before the job rather than afterwards. Mr Hamilton had remarked on the two years which had elapsed between the signing of the contract and starting work on the site, and had wondered whether that had been devoted to site investigation. It had not; if it had been, the designers might well have embarked on an entirely different sort of foundation. Mr Wild thought that perhaps a deep basement-raft could have been constructed at considerably less cost than the cylinders which had, in fact, been used. After all, £300,000 (which was what he made the cost to be) for the foundation of a building 100-foot square in plan was a great deal of money.

A site investigation had been carried out beforehand, and those responsible had found out accurately all about the soft ground, but, having got to rock, there had been no diamond drill available, and it had not been thought necessary to bring one out specially. Mr Wild knew that the consulting engineer had wished to proceed very cautiously and sink a trial cylinder, but he believed that the building owners had forced the pace, and the contract had in fact been let on the basis of a cylinder foundation before it had been proved suitable for the site.

Mr Wild had been associated with the work in June 1951, when about 16 cylinders had been sunk to various levels by the contractor who had preceded the Author's firm on the site. At that stage, of course, the project had been committed to cylinder foundations if they were in any way practicable, but there was very considerable concern at the subsidences which had been taking place round the site, as well as at the failure to find the promised sandstone foundation. He thought that that answered a point which Mr Hamilton had raised. At that time the cylinders were being sunk as monoliths by hand excavation under the cutting edge, and the water was being pumped from under the bottom of the cylinders. The Author had illustrated the type of ground below the beach deposit, the big boulders in a matrix of clay, and *Fig. 6* in the Paper showed a crumpled cutting edge and large boulders jutting out. The Chinese contractor had only hand tools, and the big boulders were just being pulled out. If the cylinder went with a rush it took the boulder down itself, with the result that behind the cylinder walls there were very large voids, and the soft ground from above ran down to the bottom. It was not surprising that the Author should later have found very big voids in the ground above, which he had had to attempt to fill up with grout. It had definitely not been a place for sinking cylinders as monoliths.

In the Paper the Author repeated an opinion which Mr Wild had heard expressed at the time, that if only the water had been got down and kept down, the runs from the beach deposit would have stopped. Whilst that would certainly have reduced them, he was sure that it could not possibly have stopped them altogether. In that sort of ground it was not possible to get the water uniformly low, and to provide adequate filters against loss of ground with the run of the water. The situation was helped, of course, by the effect of the corals, and, where they existed, they were certainly of assistance, but it was not possible to guarantee that they would occur in all the places where they would be needed. The use of compressed air had therefore been adopted initially after restarting work for sinking through the beach deposits to avoid that loss of ground. He noticed that cylinders E12 and E15 had been sunk in that manner, but between E12 and E15 there were two cylinders, E13 and E14; which had been sunk in free air, and he thought that the Author and the Author's firm might congratulate themselves on being a little fortunate in doing that without any obvious subsidence.

It would be of interest if the Author could give the approximate total quantity of water which they had been pumping at that stage, and whether in fact they did get any considerable runs of material.

The concrete segments, which had been designed and made on the spot, appeared to have been very well suited to their job, but Mr Wild thought that it would have been very much better had they been provided from the start with proper packing and grummets, and possibly with more grout holes, so that they could have been grouted more effectively. The Author had stated that a good deal of grout had been lost initially through the joints, and they had in consequence been unable to stop the water. Mr Wild felt that the whole essence of the scheme was to grout very well to ensure that the water was stopped, because water in a clayey foundation of that kind was an abomination.

The Author also referred to grouting under a cylinder base in order to prestress the clay. Mr Wild gathered that under the cylinder base the Author put first of all a certain thickness of large stones, topped with broken aggregate and a little sand, and when the cylinder had been completed, that had been grouted up. Mr Wild was not quite sure what the Author had had in mind in using the word "prestressing," but leaving water in contact with the clay under the base would allow the clay to soften, and although the subsequent grouting might fill all the remaining voids in the stones and prevent any more movement of the clay into them, there would still be the normal consolidation of the softened clay under the load. No amount of grouting would stop that.

With regard to the reassessment and redesign of the foundations to suit the actual ground conditions, it had been a relatively simple matter to arrive at the safe bearing pressure for the cylinders, but it had been most difficult to obtain samples which could be tested, because there had been so many little fragments of sandstone in the clay. It had been basically a matter, however, of determining shear strength, and obviously it had had to be treated as clay. A much more difficult problem had been that of settlement, and everything depended on whether the 100 feet below the cylinder bottoms was going to act mainly as clay or mainly as sandstone. It had been for that purpose that the four diamond-drill holes had been put down by a local firm to about 60 feet penetration. It had been hoped that it would have been possible to recover a large percentage of core so that an accurate assessment could have been made of the proportions of clay and sandstone, but, of course, those conditions of alternating sandstone and clay were very difficult to bore in. It was necessary to have a very experienced operator and large-size drilling equipment, with special core barrels to recover cores of the soft ground. In fact they obtained about 50 per cent recovery, of which about 50 per cent was clay and 50 per cent sandstone, and it had been reasonable to assume that that proportion could be taken for the general 100-foot depth.

On that assumption, and assuming that the clay was evenly distributed throughout the whole of the 100 feet, the settlements had been calculated under each cylinder, assuming that they were all independent, and it had been found that the maximum settlement was about $3\frac{1}{4}$ inches, and that the differential settlement between the maximum and minimum would be about 1 inch. The settlements had also been calculated by the alternative method of assuming that the cylinders had, at about 15 feet below their bases, the same effect as a flexible raft; that had been where the larger figure quoted by the Author, of about 1·9 inch, came from; that would have been the differential settlement between the centre and corners of a flexible raft. The raft which topped the cylinders was in fact of very considerable stiffness, so that the differential settlement likely to arise would be very much less.

Finally, he would like to ask the Author whether, in his experience on the site, he had discovered anything which would have prevented a deep raft foundation being built, had it been desired to do so. Would it in fact have been possible to drive steel sheet-piles down through the beach deposit and into the 10 feet or so of clay which occurred before reaching any serious sandstone, and to excavate a large hole in that protection?

Mr D. H. Little observed that what surprised him was that the soil conditions in a large city such as Singapore should not have been better known by now than they appeared to be from the Paper. The penetrometer described sounded very much like the vane instrument which had first been used with great success, he believed, in Holland, where there was a fairly consistent soft clay at very considerable depth. When he had first seen that at the Second International Soil Mechanics Conference at Rotterdam about five years previously, the general opinion of British soil engineers had been that it would only be suitable in a material in which it had been used a number of times; that was, it was necessary to have plenty of practical experience of the instrument in order to interpret the results. He believed that that instrument, or similar instruments, were being used in Great Britain at the present time on alluvial deposits at estuaries, where again the soil was fairly consistent in its quality. For the site under discussion, however, it would seem to have been quite unsuitable.

Reference had been made to the shear-strength and consolidation characteristics of the clay. It would be interesting to know whether it was a natural clay, and whether it was really a true clay and not a laterite.

If it was a laterite, had it been considered that normal clay techniques were applicable to it?

The calculated differential settlement had been given as between 1 inch and 1·9 inch. Did that mean that the minimum was 0 and the maximum 1 or 1·9 inch? Mr Wild had suggested that the maximum was likely to be 3½ inches, and the minimum, presumably, would be 2½ inches. Had any special precautions been taken in the superstructure to deal with that overall movement and with the differential movement?

Fig. 2 in the Paper seemed to show that the site was at least 300 feet from the sea, and Mr Little would not have thought that the water level would be much affected by the tide. The Author stated that a variation of only 3 feet in the water-table resulted from rain or tide. Had any definite measurements been taken to establish the relationship between tide and water level? The deepest cylinder appeared to have been 40 feet below high water. It would be interesting to know whether any of the water at any time was salt, or whether it had always been fresh.

Reference had already been made to the cost. It would appear that the first contract amounted to $460,000 (Straits), which was about £50,000, whilst the second contract, which had presumably been carried out to put the first one right, cost more than $2,000,000 (Straits), which was about £250,000. The building was of 10,000 square feet, so that it worked out at £30 per square foot for the foundations. Mr Little did not know whether £1 per square foot for foundations would be a proper figure to take, or whether it should perhaps be £2, but he would have thought that £20,000 would have been quite enough for the foundations. A cylinder basically was simply a large-diameter column, and a pile was a small-diameter column. Because there were big loads on a cylinder, cylinders had to be spaced at wide centres, and the raft and superstructure became correspondingly heavy to bridge those big spans. In jetty work, therefore, it was almost always better to use piles at close centres rather than cylinders, and he felt that the Asia building was no exception. The Author said that it was not possible to drive concrete piles, and perhaps they could not be driven far into a clay or material like clay with a shear strength of 3,000 lb. per square foot; but Mr Little would suggest that there was no need to penetrate very far into such a strong soil. If concrete piles could not be driven, had consideration ever been given to the use of steel piles? Steel joists might have been driven down at 5-foot centres, and if a pile hit a boulder, it could be moved slightly aside. Such piles could be capped with a slab about 2 feet thick, and even if the centres proved to be closer than 5 feet, the total foundation cost must have been far less than £250,000.

*** **Mr H. J. B. Harding** observed that Mr Glossop, in his contribution, mentioned the rarity of the use of segmental shafts for founda-

*** This contribution was submitted in writing upon the closure of the oral discussion.—SEC. I.C.E.

tions. In practice that expedient had been chiefly employed by the few consulting engineers who pioneered and specialized in soft ground tunnelling for tube railways and other purposes where cast-iron lining was common-place and readily available; they had made many ingenious uses of that material, not only for tunnels and shafts, but for cellular cofferdams. Its uses in London were not widely known outside that group of engineers.

For instance, the machine chamber for the Bank escalators had been constructed of a series of small diameter cast-iron shafts at intervals, with cast-iron segments spanning as horizontal arches between them; that construction acted both as retaining wall and foundation. The method had been employed in places on Bazalgette's Victoria Embankment, as well as recently at Mile End and Stratford stations on the Central Line extension of London Transport Railways, where that form of construction was used both horizontally and vertically.

Mr Harding quoted other examples. The foundations of Brittanic House in 1922 had to be carried below the tube railway tunnels at Moorgate Station. In that case the foundations had been placed in tunnels constructed at station level in semi-circular form, and lined with cast-iron segments. Afterwards 6-foot diameter cast-iron segmental cylinders were sunk from the basement of the existing building on to those foundations previously installed, and steel columns were erected inside them. That method had been also used for the same purpose on extensions to Peter Robinson's shop building, to carry foundations below the tube tunnels at Oxford Circus tube station; a third case was its adoption as a temporary expedient in erection of the columns supporting the roof of Piccadilly Circus station prior to the excavation of the machine chamber, which was carried out after the roof had been fully completed.

The Author, in reply, said that, as Mr Wild had explained, the 2 years preceding the underpinning operations had been devoted not to investigating the site conditions but to the partial sinking of the cylinders by the previous contractor. The following summarized the approximate dates of the various operations :—

(*a*) First soil investigation (Penetrometer tests and soil sampling by Messrs Ewart & Co. Ltd.)	March 1949.
(*b*) Sinking of three trial cylinders (By Messrs Ewart & Co. Ltd.)	September 1949.
(*c*) Sinking of all cylinders (By Chinese contractor)	January 1950.
(*d*) Site examination (By Messrs Soil Mechanics Ltd.)	June 1951.
(*e*) Second soil investigation (Diamond drilling by Messrs Ewart & Co. Ltd.)	September 1951.

(*f*) Underpinning of cylinders Started: February 1952.
(By Messrs Gammon (Malaya) Ltd.)
Completed: February 1953.

In fairness to the Consulting Engineer and in order to explain a number of anomalies, it was necessary that certain facts be made known. It was not the Author's intention that the following remarks be interpreted as being derogatory in any sense whatsoever.

Mr Steen Sehested, who did not feel that the work as a whole should go to execution without first proving the design, had recommended the owners to sink one trial cylinder. The owners, in their anxiety to hasten the completion of the building, had suggested sinking three cylinders. That work had still been in progress when the owners reversed their policy and awarded the contract to a Chinese firm. The choice of contractor had been unfortunate, for he had had little experience in that type of work. The situation had been aggravated by the disregard, on the part of the contractor, of the clauses of specification relating to the safe conduct of the work. A peculiar situation had arisen wherein the power of the Consulting Engineer to control the contractor was in name only.

The large vertical faces at the bottom of the cylinder referred to by Mr Hamilton had existed before the Author's firm had started underpinning operations. That was one of the main reasons why so much trouble had been experienced during the sinking of the cylinders. The loss of ground was largely attributable to a tendency of the Chinese contractor, when meeting sandstone boulders or coral, to undercut the edge of the cylinder for several feet. The Author understood that during the sinking of the cylinders very little inrush of soil had occurred when the cutting edge was near the bottom of the excavation, and it had been the invariable experience that large soil inrushes stopped when the excavation was filled to the cutting edge.

The Author agreed with Mr Hamilton that the conditions shown in *Fig. 6*, facing p. 418, were rather alarming, and when the Author's firm had underpinned the cylinders they had never excavated more than about 18 inches below the cutting edge; that had given sufficient clearance to insert one segmental ring.

Only one reference had been made to poling because that had been the worst case. There had been other similar cases but they had been neither serious nor numerous. A great deal depended on the effectiveness of the grout keeping the ground behind cylinders tight. If that object was not achieved then the ground was more liable to collapse when undercutting behind the segments. The Author said he could quote a number of cases where between 100 and 200 bags of cement had been used for back-grouting only two or three rings, without any sign of having reached saturation point. Apart from poling, gunny sacks and clay had sometimes been packed behind the segmental rings for stemming the flow of ground and water. That method had been adopted for less serious cases.

The Author said that when his firm had been awarded the contract for underpinning the cylinders there had been no reference in the specification suggesting that another attempt might be made to sink any of the cylinders. The decision to underpin the cylinders had been the result of consultations held between the owners and the Municipality of Singapore together with their respective consultants. No further sinking of the cylinders had been contemplated owing to the alarming situation which had developed during the subsidence of the ground. Furthermore, underpinning of the cylinders had been considered by the Municipality to be the most acceptable method of continuing the work without jeopardizing the safety of the buildings in the vicinity. The Author wished to point out, however, that Mr Steen Sehested had been of the firm opinion that with controlled water-keeping and reasonable care the cylinders could have been sunk to the bottom formation without appreciable loss of ground and subsequent danger.

The Author regretted that he was unable to give further information about the sinking of the cylinders, but as he had pointed out in the Paper, that work had been carried out by another contractor and the records were not available. A comprehensive report on that work would have been interesting.

Apart from the four deep bores in cylinders A1, A4, B2, and E5, no further bores had been made at the bottom of the cylinders on reaching formation level. It had been felt that the results of the second soil investigation had yielded sufficient information to make it unnecessary to explore the subsoil further.

The settlement of the cylinders under test load prior to concreting the raft would have proved interesting but unfortunately the contract had not asked for such tests. The Author's opinion was that a number of such tests should have been carried out.

With regard to the close proximity of the two air-locks on cylinders E12 and E15, the Author pointed out that those two cylinders had been selected because they represented the worst cases. In actual fact the air-lock over cylinder E15 was not put into operation until the work in E12 was fairly advanced.

He agreed that the air compressor was large, or at any rate he had thought so when making comparisons with plant used in Great Britain for similar purposes, but when they began to experience the air losses to which he had referred earlier, he had been glad that the compressor was so large. There had been instances when the loss in pressure was so severe that it had been impossible to carry on with the work until the leaks had been stopped. With both air-locks in use it had been necessary to operate the compressor at full capacity.

It had been known that a substantial volume of air escaped through the joints in the segmental lining, and the Author agreed with Mr Wild that the concrete segments should have been provided from the start with proper packing and grummets. The difficulties encountered as the result of leaks mentioned on p. 433 would have been considerably minimized.

The Author admitted that there had been a good deal of oil in the low-pressure air entering the air-lock, proving quite a nuisance at times. That excess oil had been partly the result of difficulties experienced with the compressor during the early state of the work when one of the radial blades had seized in the rotor and, to avoid a similar occurrence, the quantity of lubricating oil had been increased. Reference to the introduction of oil removers was made on p. 442.

Mr Hamilton had asked why the low-pressure pipe had been taken down to the bottom of the cylinder. Originally the outlet end of the pipe had been located near the top of the cylinder and it had been found that the cool air escaped through the relief valve in the side of the air-lock without ventilating the bottom of the shaft. The working section of the cylinder had become extremely hot and sticky, producing unbearable working conditions. The deeper the cylinder the worse the conditions. Undoubtedly in the original scheme the cool air had tended to float to the bottom of the shaft but it had been overpowered by the hot and humid rising air, which very effectively reversed the cycle of operation of the air-conditioning plant.

Mr Wild had asked if any hard coral had been encountered. It had, but not in very large quantities, and it was not so hard as the sandstone boulders.

With regard to runs of beach in those cases where the shafts had been underpinned in the open, the Author could not say that they had been serious—if they had been, compressed air would have been laid on. What made the work difficult in certain cylinders was the excessive flow of water mentioned on pp. 425 and 433.

He was afraid that no check had been kept on the amount of water pumped out of the cylinders. That would have been quite interesting, but rather a laborious and expensive undertaking if reliable results were to be obtained. One noticeable feature during the construction of the foundations had been the wide variation in the amount of water encountered in individual shafts. In general it had been found that all shafts at the north-west end of the site (the K.P.M. building side) were comparatively "dry," whereas all those on the south-east end (towards Raffles Quay) were very "wet." It should be pointed out, however, that most cylinders on the north-west side were through the beach formation, which was not the case on the south-east side, and that the watertightness of the cylinder walls probably accounted for the comparative dryness of those shafts. Nevertheless, cylinder A1 which had penetrated only 10 feet into the ground was found to be very "dry" throughout its depth.

The Author wished to emphasize his remark in the Paper on the impossibility of keeping the bottom of the excavation even comparatively dry when excavating in the clay. During concreting of the base slabs of the cylinders, precautions had been taken to ensure that no free water was trapped between the slab and the clay. A pump had been kept running continuously in a central sump thus localizing the accumulation of water. Unfortunately the water, as it gravitated towards the sump, had softened the surface of the clay, forming a slurry of the consistency of a thick cream, an inch or two in thickness. It had been anticipated that as the full weight of the building came to bear on the clay, that thick slurry would be gradually squeezed out from under the cylinder bases, resulting in a settlement of the foundations in excess of that caused by the normal consolidation of the clay. Grout had been injected under the base slabs with a view to introducing stresses similar in magnitude to those which would eventually develop when the full load of the building came to bear on the cylinders. It had been hoped that the grout would partly push out the clay slurry from under the bases and partly stabilize it by combining with it. The Author admitted that the experiment had been speculative, but it had seemed the best they could do under the circumstances. That was what he had meant by "prestressing" and he regretted the misunderstanding created. He agreed with Mr Wild that the normal consolidation of the clay could not be stopped by grouting.

Mr Wild had asked if it would not have been possible to build a deep raft foundation by driving steel sheet-piling round the site. The Author did not think so. In almost every cylinder they had underpinned they found sandstone boulders very close to the top of the clay formation. Driving steel sheet-piles in that type of ground would have proved a very hazardous operation. The boulders they encountered varied considerably in size from 2 or 3 feet to 12 feet or more. The Author remembered a particular case where a boulder extended throughout the bottom of the excavation of cylinder B1. That cylinder had an external diameter of 13 feet 6 inches. That answered Mr Little's query as to whether closely spaced steel joists could not have been driven a short distance into the clay.

The Author agreed that £300,000 was a great deal of money to spend on a foundation of this size, and probably a deep raft foundation could have been built at a much cheaper cost if the problem of boulders could have been overcome.

As Mr Little had suggested, the penetrometer proved unsuitable for the type of ground encountered, but then that could not be known until the subsoil had been explored. Furthermore at that time there had not been a great selection of equipment in Singapore suitable for subsoil exploration or carrying out proper laboratory tests.

Mr Little had asked if the clay was a true clay or a laterite. That was a little difficult to answer because the term "laterite" was often used rather loosely. The Author had encountered both clay and laterite in Malaya, which were distinguishable by their appearance. The weathered triassic shale encountered under the Asia Building was definitely not what was generally known by the term " laterite " and exhibited all the physical properties of a true clay.

The Author said that so far as he knew, no special precautions had been taken in the superstructure to deal with the overall differential movement of the foundations as the result of the consolidation of the subsoil.

He could give no satisfactory answer to Mr Little's question about the water table, because he had not been personally responsible for the measurements, which had been taken before he had become acquainted with the project. No subsequent systematic observations had been made. So far as he knew no definite relationship had been established between tide and water level. It was probable that high tides affected the water table during heavy rainstorms in so far as they reduced the rate of discharge of surface and ground-water into the monsoon drains and the Singapore River, which discharged out to sea. No analytical tests had been carried out on the ground-water, and the Author could not tell whether it contained any salt. It was not thought advisable to taste it owing to a suspected leaking sewer in the vicinity.

The closing date for Correspondence on the foregoing Paper has now passed without any contribution being received.—SEC. I.C.E.