ORDINARY MEETING.

10 February 1942.

Professor CHARLES EDWARD INGLIS, O.B.E., M.A., LL.D., F.R.S., President, in the Chair.

Discussion on

"Soil Mechanics and Site Exploration." [1]

and on

"Soil Mechanics in Road and Aerodrome Construction." [2]

Mr. Cooling, in introducing his Paper, said that the subject of site exploration was one which had always been of prime practical importance to the engineer concerned with the design of foundations and earthworks. The knowledge of soils and soil behaviour which had been rendered available during recent years by the science of soil mechanics could be of such practical assistance to the engineer that it should be more widely known and appreciated.

In his brief description of sounding methods, in the advance proof of his Paper, he had referred to a Paper by Mr. G. B. R. Pimm, M. Inst. C.E. It had been pointed out that the description was not an accurate account of Mr. Pimm's method, and the footnote reference would therefore be deleted from the Paper as published in the Journal. There was no doubt that, with a sufficient background of experience, methods of that type could furnish valuable data in particular cases.

He would like to add a little to what he had said in the Paper about the contributions which soil mechanics could bring to the consideration of practical problems, particularly with regard to site exploration. For convenience, those contributions could be considered under four main headings: (1) recognition of soil types; (2) mechanical properties and tests; (3) theoretical methods of analysis; and (4) systematic collection of data.

With regard to the recognition of soil types, in the preliminary examination of a site a knowledge of geology was often very helpful. Much depended upon the judgement of the engineer in recognizing types of

[1] L. F. Cooling, "Soil Mechanics and Site Exploration," Journal Inst. C.E., vol. 18 (1941–42), p. 37 (Mar. 1942).

[2] A. H. D. Markwick, "Soil Mechanics in Road and Aerodrome Construction," Journal Inst. C.E., vol. 18 (1941–42), p. 62 (Mar. 1942).

soil which were likely to cause trouble. Soil mechanics could give valuable assistance in that connexion, and would probably be more helpful as the volume of data increased. For that purpose very simple tests—the " index-property " tests—such as natural water-content, liquid limit, and compressive strength, had been found by him to be very useful. They could be easily carried out and yielded quantitative results which indicated soil type and consistency.

A knowledge of the mechanical properties of soils was useful from the point of view of site exploration, in enabling the value of samples which were obtained by various methods of boring to be assessed and in aiding recognition of site conditions which might have an important influence upon a particular problem. A study of the mechanical properties also brought out the important influence of the water in the pores of a soil in modifying the mechanical behaviour. That pointed to the need for making, during boring, observations of ground-water levels and of the pressure in the water at the various levels, and also for noting and recording the position of permeable strata through which water could move readily. Tests on soils in general were, of course, obviously important, especially when the results were used for purposes of analysis.

Theoretical methods of analysis were available, using measured values of soil characteristics, and they served for the consideration of most of the important problems of foundation engineering ; but from the point of view of site exploration their main importance was that they gave an insight into the probable behaviour of the soil and so indicated the kind of information which was required for the study of a practical problem. For that reason he had devoted a substantial part of the Paper to a description of investigations made in connexion with specific practical problems. It was true that all the problems he had dealt with were of one type, that was, they were concerned with the stability of footings and earthworks, but it was not possible to include in a short Paper all the various problems which came within the scope of soil mechanics.

The systematic collection of data by soil mechanics methods was an aspect of considerable importance in the development of a subject which was comparatively new. The methods of soil mechanics laid stress on quantitative measurements for recording the behaviour of structures (for example, settlement readings, pressure measurements, etc.) and also on quantitative measurements for expressing soil properties, and, by so doing, they enabled an individual to gain advantage from the practical experience of others.

Most of the examples given in the Paper were concerned with failures, but he thought it would be agreed that the thorough examination of failures was a means of obtaining very valuable information.

Mr. Markwick said that he wished to make his introductory remarks complementary to those of Mr. Cooling, so far as possible. He showed a series of lantern slides, and observed that one of the first problems which

had to be faced when the engineering properties of soils began to be seriously studied was to find quantitative methods of classifying soils. Soil consisted mainly of fine mineral particles and water, and many common soils, for instance, clays, were much finer than Portland cement. Standard tests had been evolved and considerable progress had been made in relating their results to the engineering behaviour of the soil.

He wished to refer briefly to the methods of carrying out soil surveys. There had been a good deal of development in that respect during recent years. The Road Research Laboratory used very simple tools for the soil investigations that it carried out, namely, a 5-inch auger, a 4-inch auger and a special kind of auger known as a gravel auger, which was used in stony ground. A great deal of work could be done with very simple tools of that kind, without having to employ the more complicated and difficult technique of lined borings.

In addition to providing an inventory of soil types, information on the natural drainage of the site could often be obtained from the ground-water levels.

From whatever aspect the bearing capacity of the soil was considered, adequate drainage was essential to prevent water from entering the soil and causing it to soften. In draining an aerodrome, the object was to remove surplus water before it had had an opportunity to enter the pores of the soil. That which entered the soil had to be dealt with by natural or by subsoil drainage and might travel either through the pores of the soil or through cracks and fissures. In a relatively pervious soil the water would percolate down to the water-table through the pores of the soil, and it had been shown by experiment that the water-table took the form shown in *Fig. 8*, p. 57, *ante*. Dr. Keen, of Rothamsted, had, however, pointed out to him that in stiff clays, which were relatively impervious, most of the soil water probably found its way to the subsoil drains through cracks and fissures in the clay. The importance of that lay in the fact that such water was still mainly "free", that was, it was not bound to the soil particles by capillary suction, so that it was capable of flowing into any drain which was suitably placed, without necessarily having to travel to the water-table level. To that extent, therefore, he would like to qualify the statement made in the Paper that subsoil drains could be effective only when they were at or below the water-table level, although it remained true that capillary water in the pores of the soil could not be removed by drains which were above the water-table level.

He wished to refer briefly to soil compaction in relation to embankment construction. The most important facts to note were the following. Firstly, the degree of compaction could be readily determined both in the field and in the laboratory and was measured by the weight of soil particles per cubic foot. Secondly, for a given mechanical effort there was in general an optimum moisture-content at which maximum compaction was obtained. Thirdly, for cohesive soils the limits to compaction were the

mechanical resistance of the soil for low moisture-contents (when the soil was stiff) and the moisture-content of the soil at high moisture-contents (when the soil was soft), since compaction only forced the air out of the soil.

The study of soil problems in road and aerodrome construction was still a young science, in which there was a great deal to be learned, but he hoped it would be considered that, at any rate, a promising start had been made.

Professor R. G. H. Clements observed that the difficulty in soil mechanics was partly due to the terminology which was growing up around the subject. That terminology rather tended to put it out of sight of the practising engineer, whereas it was really a subject which ought to come more and more within his purview and form a day-to-day tool for use in constructional work. It was, in fact, a recognition in principle of the fact that the soil itself was an agent in the construction. Therefore all aspects of soil mechanics were important, but the engineer was most concerned with the one that he could take into everyday life and practice and provide an answer to his problems rapidly and simply.

The technique of soil mechanics had grown up on extremely elaborate lines. The mechanical tests referred to by Mr. Cooling numbered about twenty, but in the long run most of the information required was obtained from the liquid limit, the plastic limit, and, in another connexion, the compression test. A clear distinction should be made between the conditions which were related to research and to the examination of a scientific problem or a field of science and the conditions relating to the ready assessability of methods of test which would serve engineers easily and readily. As an example, tests could be carried out to establish the character of the soil in an undisturbed condition, and could be recorded and used as a guide to the method of consolidation to be adopted and the extent to which that consolidation should go before the soil could be considered as suitable for the construction of the embankment. Further tests could then be carried out on the embankment, as consolidated, to establish the extent to which the specification limits of consolidation had been attained; that was, the extent to which the soil had attained its original undisturbed state of compaction. That might appear to be a counsel of perfection, but it was, in fact, a practice which was followed, and he believed that the standard of compaction accepted for certain classes of embankment work was 80 per cent. of the compaction of the soil in its original state. Whatever that percentage might be, at least there was a direct and definite connexion between the soil test of the undisturbed sample and the test applied to the embankment on consolidation.

He did not like the Author's use of the expression "time of concentration" on p. 73, *ante*. That expression had become associated in the minds of engineers with a specific meaning, namely, the time at which a flood discharge or run-off could be collected at a particular control-point; but it had not quite the same meaning in the Paper, where the Author was dealing with the coefficient of surface discharge.

With regard to drainage as a whole, soil mechanics did not deal with the condition of the soil alone, but with the condition of soil plus water, and the variation of the water-content, either seasonal or accidental, was a factor which influenced the condition at any moment. Mr. Markwick, in dealing with the water-level contours on a certain aerodrome site (*Fig. 7*, p. 69, *ante*), had referred to one place where there had apparently been seasonal flooding. Professor Clements was sure that the water-table had been subject to seasonal rise and fall, and that therefore the soil within that area had similarly been subject to change in state due to the water/soil relationship.

He believed that the subject of soil mechanics would be of particular interest to the younger generation of engineers. and he considered that it should be brought into the curriculum during their early training; he knew that was being done at one university, at least.

Mr. A. J. Lyddon said that the advantage of soil surveys as a preliminary to or a corollary of ordinary surveys was undoubted, but what was particularly needed was some additional knowledge as to what could be done to certain soils in the way of stabilization—in other words, a Paper similar to the lecture delivered by Dr. L. Casagrande to the Institution of Highway Engineers[1], when, in reply to the question: "What do you do with clay in your circumstances?" the Author's answer was: "We introduce sand."

What information could be obtained in regard to the stabilization of soils which were admittedly unstable for certain purposes, namely, aerodromes and runway construction? During the past year Mr. Lyddon had carried out some runway construction, and that had introduced the subject to his mind rather forcibly. With some soils, such as sand, certain possibilities had been opened up; but other soils did not admit of easy stabilization, and a wide field existed, not only for research but also for exploration generally. A good deal of experience had been gained in America; but the conditions in Great Britain differed considerably from those in the United States, and in some respects it was difficult to obtain from the American results much information on the type of soil stabilization to which he referred.

Mr. Markwick had suggested that in the future soil surveys should be regarded not as a matter of research, but as a part of the routine survey. Mr. Lyddon subscribed entirely to that view, but he did not altogether agree with some of Mr. Markwick's remarks on drainage. One still came back to that unfortunate material, clay, which presented many problems in regard to its use as a foundation. That applied not only to roads but still more forcibly perhaps to runway construction.

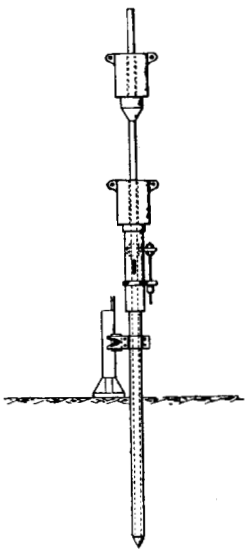
Mr. G. B. R. Pimm observed that he wished to express his gratitude to Mr. Cooling for withdrawing the reference to his Paper, made in the

[1] "Soil Mechanics in Road Construction," Bull. Instn. Highway Engrs., No. 11, May 1938.

advance proof. The opinion appeared to be fairly general that laboratory methods, to be of real value, must be supplemented by information obtained in situ as to the behaviour of the ground. Mr. Pimm would go farther and say that, whatever laboratory tests were considered necessary, they must be determined by prior knowledge of the behaviour of the ground as ascertained by in situ tests. Mr. Cooling had conceded that such information might be of value, but, in failing to do justice to the available methods of obtaining it, he had perhaps also fallen short in his estimate of the value of the information when obtained.

Fig. 1 illustrated a method of sounding which Mr. Pimm had described

Fig. 1.



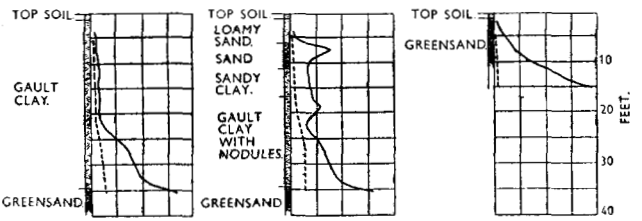
in 1938 [1]. The apparatus consisted of a tube with a mandrel running through it and terminating in a point, which was shouldered out to the same diameter as the tube, so that the whole apparatus could be driven as a pile by means of the lower hammer, or, alternatively, the mandrel could be driven alone by means of the upper hammer. An incidental advantage was that the presence and depth of a fissure were immediately revealed by the fall of the mandrel. Two instruments, one on the right and the other on the left, provided alternative checks upon the total bearing resistance.

[1] "Recent Developments in Deep Ground Testing", *Structural Engineer*, vol. 16, p. 210 (July 1938).

The same result should be obtained from each, and actually that was the case, with the qualification that one recorded the set and the compression, whilst the other gave a direct reading of the resistance, and so the difference between them was simply the coefficient which was introduced into the formula used. Then there was a loading test, either for the whole apparatus or for the mandrel alone, and finally a check on the frictional resistance was applied by registering the pull necessary to extract the tube by means of a statimeter.

Fig. 2 showed the kind of information obtained: that on the left was obtained from borings, which were not an essential part of the method: the frictional resistance and the toe resistance were also shown. The tests were made on one bridge site, only 15 feet apart, and each was typical of a number of tests. With three groups of tests of that kind a preliminary picture of the ground conditions was obtained, which, he thought, was of

Fig. 2.



considerable value in indicating the programme of soil mechanics tests to be followed. A great saving of time was effected by such a preliminary picture, which could be studied at leisure to enable one to decide where to have the samples taken for tests in the laboratory.

Dr. W. L. Lowe-Brown observed that many experienced engineers regarded soil mechanics with considerable scepticism, but he felt that Mr. Cooling's Paper had demonstrated that the methods were sound and, when judiciously applied, could be of the greatest assistance. That was his own experience, based upon personal connexion with the first example given in the Paper. He only became associated with that work after the trouble had occurred, but he knew that everyone concerned was very pleased with the businesslike way in which the Building Research Station had attacked the problem and with their assistance when various schemes for overcoming the trouble were being considered. The building had been in continual use since the remedial measures were completed, more than 18 months ago, and the result was considered eminently satisfactory.

The Author's outstanding achievement was that he had covered a difficult subject without obtruding the mathematical machinery which it was necessary to employ in order to secure the results. Many

experienced engineers distrusted the parade of mathematical gymnastics which bulked very largely in some of the writings of its exponents.

Another factor which perhaps had impeded the more general use of soil mechanics by British engineers was the torrent of articles that had appeared on the subject, owing to the rapid advances which had been made by the very large number of enthusiasts who had been working at it. The very bulk of the printed matter (his own files contained eighty articles) in so many different publications and languages had been far beyond the capacity of the ordinary engineer to absorb, and he hoped that the Building Research Station would collect into one volume the results of all the valuable work that had been done by the Station—so that those results might be available in an easily accessible form. If that could be done it would do much to make soil mechanics methods more generally used in Great Britain.

He considered that the Building Research Station should be consulted in the early stages of every important work where any question arose about the ground that was to be built upon.

Mr. Guthlac Wilson considered that Mr. Cooling's Paper should do much to stimulate interest in, and more frequent use of the art and science of soil mechanics at the design stage.

The Author had dealt fairly comprehensively with cohesive soils, but cohesionless materials were dealt with less thoroughly. Some reference might have been made to the cases in which it was necessary to determine whether the naturally occurring density of strata of sand below a structure was above or below the critical. The importance of that had been shown by Professor Casagrande [1] and Mr. J. D. Watson [2]. The taking of " undisturbed " samples of cohesionless material presented some difficulty, but it had been overcome by the use of the freezing process [3]. Reference might also have been made to the determination of the coefficient of permeability of sandy strata in situ by the device of pumping water into boreholes and observing the changes produced in the phreatic surface [4].

With regard to the method of sounding by means of a rod enclosed in a pipe, it would be interesting to know whether attempts had been made to correlate the results of such soundings with the index properties of cohesive strata passed through.

A question arose from an examination of *Fig. 4*, p. 47, *ante*. Mr. Cooling had observed correctly that " the nearer the natural water-content is to

[1] Report on Critical Density. Appendix B of the Report on " Compaction Tests and Critical Density Investigation of Cohesionless Materials for Franklin Falls Dam." U.S. Engineer Office, Corps of Engineers, U.S. Army, Boston.

[2] Report on Investigations of Critical Density of Sand from Franklin Falls, N.H. *Ibid.*

[3] T. A. Middlebrooks. " Fort Peck Slide." Proc. Amer. Soc. Civ. Engrs., vol. 66, p. 1729 (Dec. 1940).

[4] H. Weber. " *Die Reichweite von Grundwasserschwankungen mittels Rohrbrunnen*," Berlin, 1928.

the liquid limit the softer is the soil." In fact, if the natural water-content exceeded the liquid limit the soil was, for practical purposes, liquid. According to *Fig. 4*, that condition occurred in the sandstone stratum at the bottom. How could that be ? The index properties, the plastic and liquid limits, had no meaning when applied to materials such as sand and sandstone. The strata "sand and shells " and " brown sand " shown in *Fig. 4* might have contained sufficient clay to make them more or less plastic.

Triaxial compression tests were rapidly superseding the box shear test in the United States, as it had been found that the results of the latter were largely dependent upon the size of the box.

The portable apparatus for compression tests described in the Paper was paralleled by an even more compact piece of apparatus devised by Dr. M. J. Hvorslev, which could be carried in an attaché case and which tested samples of the size of a thumbnail. Dr. Hvorslev had used that apparatus before 1938, and had correlated the results with tests on specimens of normal size.

Mr. H. J. B. Harding observed that there had been a danger of soil mechanics falling into disrepute in some circles as being too theoretical. Certainly some Papers of great brilliance had been published, containing pages of calculus, but they had been described as " chamber music " ; they were for cultured tastes and not for everyone. Another side of the subject had now been presented. Mr. Cooling was one of the few English writers whose work on soil mechanics was published in the United States of America. His Paper was very practical, and there was not a differential equation in it.

Before engineers tried to follow the Authors in the higher flights of soil mechanics, it was very desirable, now that the value and scope of the work was so evident, that they should re-examine themselves and make certain that they had a simple, sound geological background and a more lively and vivid sense of the variety of sediments and their condition of deposit than was noticeable at present. The fundamentals of the soil had to be understood before the science of soil mechanics could be built on a proper foundation. Engineers should first realize the existence and nature of their problems, and then they could go to Mr. Cooling and other experts for the solution of those problems. He ventured to dissent from Professor Clements' suggestion of early specialization in soil mechanics, and he agreed with the opposition to early specialization which the President had expressed in his Address[1]. It was far better for a student to spend his time at college in obtaining a sound knowledge of geology, together with some practical experience ; he could attempt the higher flights later.

For several years Mr. Harding had been brought into contact with many people who were examining problems connected with the soil and

[1] Journal Inst. C.E., vol. 17 (1941–42), p. 1 (Nov. 1941).

site exploration, from leading members of the profession down to small municipal men and also what geologists would call some useful cross-sections exposing architects and builders. Therefore, whilst his remarks might be a little controversial, they were based upon experience.

He considered that the technical training of engineers was still unbalanced. Many were masters of design in steel and concrete, but had had no geological training; consequently they did not appreciate the complexity and the constantly changing conditions of the soil over long periods of time during which the formation of unconsolidated sediments took place, and, instead of approaching the problem with the proper humility due to Nature, they were wont to dictate to the ground how it should behave, as they did to their steel and concrete material. Certainly a course of geology did not make a man into a geologist, but it lifted the scales from his eyes and gave him more ability to appreciate and respect the vagaries of Nature, which were well shown in Mr. Markwick's *Fig. 3* (p. 67, *ante*).

When the elder Brunel was building his amazing Thames tunnel and was held up by a simultaneous collapse of the tunnel and of his funds, he received no fewer than five hundred suggestions for overcoming his difficulties. None of them was of any use, and he complained bitterly in his Journal that in every case " they made the ground to suit the plan and not the plan to suit the ground." That was 120 years ago, and in spite of the technical development which had taken place, human nature remained unchanged. In the steady stream of designs which had to be tendered for innumerable cases occurred in which the plan bore no relation to the ground. Brunel's words: " Make the plan to suit the ground " should be in every drawing office. It was as wrong to design without regard to the construction as it was to construct without any proper design.

One cause of trouble in site exploration was that borings were not big enough, deep enough, or frequent enough. That was not the fault of the boring contractors, who were very competent and helpful, but was due to the system under which they were compelled to work. Competitive prices were insisted upon for this sometimes vital work, and great was the indignation if their price was more than a few shillings per foot. Therefore all the boring contractor could afford to do was to put an intelligent labourer in charge of such cut-price and intermittent work. Yet engineers accepted the reports and were indignant if those turned out to be wrong. In fact, the approach to the problem was truly British; it was a mixture of wishful thinking and reckless economy. On any work of importance competitive boring should be prohibited: A proper and sufficient sum should be allowed (if he were asked what was a sufficient sum he would say " Think of a number and double it ") and time and trouble taken over the borings, which should be supervised by an engineer with both a practical and a geological background. Proper steps should be taken to study the ground-water levels and their variations, and filter-tubes should be left in

the borings when the boring-tube was taken out, so that the variations could be studied. He had been privileged to see a sheet of borehole records made under the supervision of one of Mr. Cooling's colleagues, which were a model of what borehole records should be, and he suggested that a similar sheet should be reproduced in the Journal.

There was a first-class Geological Survey in Great Britain, but its existence was little known. He considered that its scope should be widened and that borehole results should be reported to it. Further, financial support should be accorded to enable the Geological Survey to provide young geologists, with a knowledge of their particular neighbourhoods, to supervise the borings, and thus to benefit both the Survey and the community. He believed that in the State of New York all site explorations had to be carried out by the State, and that seemed a very sensible idea. Many people were unaware of the 6-inch Geological Survey maps of the London area, which contained a wealth of information for those who could read them.

Because boreholes were made by a few specialist firms, very few engineers had had actual personal experience of boring, and many hardly knew a shell from an auger. That was one reason for the lack of appreciation of boring problems. It would be no bad thing if engineering colleges equipped themselves with a 6-inch hand boring gear. Students would learn a great deal by putting down a 50-foot bore in some suitably varied strata and would obtain much healthy exercise.

The absence of any geological sense and knowledge on the part of clients, promoters, and committees responsible for commissioning work prevented proper expenditure on site exploration, and their opposition had to be overcome by the engineer. From his own observation it had been brought home to him very forcibly that the small man, however willing he might be to carry out proper site exploration, was in need of protection and assistance to overcome the opposition of his clients or of committees of very hard-headed business men to this expenditure, in a way that was not the case with the big engineer. That support could and should be given by The Institution, and he suggested that leading members should from time to time make definite statements or pontifical utterances upon the need for proper investigation, so that the less influential engineer could quote them and so obtain the support of which he was in need.

Another man in need of support was the engineer working with, and far too often under, an architect. The architect mind started at ground-level. The architect could design and build the most beautiful structures, but anything below ground was psychologically abhorrent to him. He wanted to get on with his porticos and his pilasters, his parapets and his plumbing. Any deep foundation work merely added to the cost and delay, whilst the work done was not visible, so that he was not so sensitive to the need for site investigation. Moreover, when an engineer was called in by an architect to deal with some question of a leak in a basement or

some other defect in an existing structure, it was often very difficult to find any record of the strata upon which the structure was built.

Mr. R. V. Allin observed that the insistence on obtaining undisturbed samples was doubtless essential, but it seemed to require some qualification, because it tended to obscure the fact that the ground under deep open foundations in clay was usually disturbed *after* the preliminary sample had been taken. The chief causes of disturbance were swelling and vibration from pile-driving, both of which were exaggerated by contact with water. An undisturbed sample taken before excavation operations had commenced would not be characteristic of the condition of the soil under load.

That aspect of the subject had already been dealt with by Messrs. Cooling and Skempton [1], who had stated that "the compressibility of clay is more than doubled if the clay is allowed to swell and soften in contact with water." Their tests on samples indicated that swelling of highly consolidated clays took place when the original overburden of those clays was reduced: that would occur in the case of excavation. They also stated that London clay, with its fissured structure, was likely to be particularly sensitive to such disturbance as pile-driving. The opening up of the fissures, and the consequent softening of the soil in contact with water, tended to alter the properties to an important extent. Some or all of those conditions must frequently prevail in deep open foundations in clay, however carefully the work was carried out. Even if it were possible to keep the bottom dry, which was often very difficult, it would be brought into contact eventually with the wet concrete of the foundation slab, and then all the elements required for swelling of the clay would be present. In some deep foundations of that description with which Mr. Allin had been recently connected it had been proved by site observations that appreciable swelling commenced at foundation-level when the excavation had reached only about 6 feet above that level. That swelling continued until the foundation had been poured. It followed that the clay under the foundation must have been in a swollen condition for at least that depth when the slab was poured.

In order to investigate the disturbance caused by pile-driving on an open foundation on highly-fissured London clay, he had recently carried out some very rough laboratory experiments.

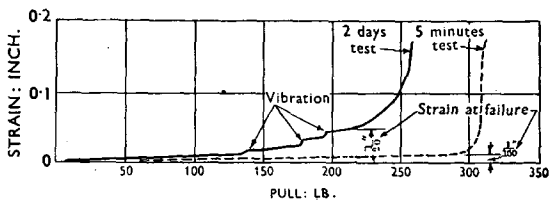
With a Langtry Bell shearing-machine a comparison was made between the behaviour of clay samples under ordinary test conditions (in about 5 minutes and with steady load) and the behaviour of clay samples sheared in 48 hours, during which the table was slightly vibrated at intervals to simulate adjacent pile-driving. The test was intended to give an idea of what would happen if fissured clay was shaken up with pile-driving adjacent

[1] L. F. Cooling and A. W. Skempton, "A Laboratory Study of London Clay." Journal Inst. C.E., vol. 17 (1941–42), p. 251 (Jan. 1942).

to a deep open foundation. In both cases the samples were kept under a normal pressure equal to the overburden load of the clay at foundation-level. *Fig. 3* illustrated the results in the two cases. The heavy line showed the result of the test which was intended to simulate the conditions of vibration from close pile-driving: it lasted 48 hours, during which intermittently a very slight vibration—much less than that effected by pile-driving—was applied to the table holding the machine. The other test was a perfectly normal one, conducted for 5 minutes with steady load. The results were as follows. The vibrations started a premature plastic flow, which finally reached its ultimate, and the sample collapsed at 75 per cent. of the value of the steadily sheared specimen; the plastic flow of the specimen which had undergone a slight vibration was $\frac{1}{20}$ inch, whereas the plastic flow of the steadily sheared specimen was $\frac{1}{100}$ inch.

No finality could be claimed for those results, because the experiments were rather rough, but there seemed to be no doubt that vibration, by inducing strains in the clay—especially fissured clay—weakened its struc-

Fig. 3.



ture and reduced its resistance to shear. The results were of particular interest having regard to the close relationship shown by Mr. Cooling to exist between shear and settlement. It appeared that all the characteristics of clay which controlled its stability under load might in actual practice be adversely changed for some distance below the foundation-level during constructional operations, and that therefore undisturbed samples taken within that zone before those operations had been commenced would give unduly optimistic results, which would require correction in the light of site observations.

Mr. G. T. Bennett said that one of the chief uses of soil testing on the site should be to determine, in the case of roads and aerodrome runways, what could be done by stabilizing unsatisfactory soils as an alternative to the provision of a satisfactory foundation by removal of the soil to a certain depth and its replacement by imported material. There was also the possibility, with more suitable soils, of providing both foundation and running surface by stabilization. In view of the need for economy in the use of imported material during the war period, because it meant economy in time, that was perhaps the most important question on which

guidance was sought at present, and the Papers were chiefly valuable in so far as they helped to give such guidance. The engineers who designed the German *Autobahnen* were meticulous in testing their soils, but somewhat vague in their descriptions of the bearing of the tests upon their practical decisions.

The aim should be to devise tests upon which the practical decisions would be positively dependent.

Dr. E. B. Bailey observed that any inquiry that came to the Geological Survey would be answered free of charge and the best available information with regard to the nature of sites would be given. That would, of course, save much work and expense in connexion with preliminary exploration. The Geological Survey did not possess the detailed information necessary to answer all the inquiries that might be made, but it had very much more information than appeared in any of its publications, and it was willing to supply that information to anyone who needed it. In the case of any work that bore upon the war effort, he was prepared to send out a man specially for two or three days, on payment of travelling expenses and field allowance.

*** **Mr. F. M. G. Du-Plat-Taylor** observed that the surface drainage of aerodrome runways was important from the aspect of non-interference with operations and also from that of camouflage. It was well known that even a thin film of water was visible in moonlight, and therefore it was important that the surface should be kept dry. With a rigid type surfacing of concrete that could be ensured only by a sufficient camber or cross-fall to discharge the rainfall to side drains.

A honeycomb type of asphaltic surfacing used as a carpet to a normal concrete base would absorb rainfall up to its capacity, which depended upon its thickness, and transmit it laterally to side drains; but in order to meet the requirements of the heaviest rainfall on a runway 150 feet wide a considerable thickness was required, as the rate of lateral transfer was necessarily low. On the other hand, asphaltic surfacing of that type was very efficient when used as a flexible surfacing laid direct upon pervious soils, and in combination with under-drains.

Experiments had been made with pervious concretes composed of aggregates ranging from $1\frac{1}{2}$-inch to $\frac{3}{4}$-inch gauge with a small sand-content. Those concretes were perfectly pervious and had a reasonable compressive strength. They were, however, deficient in tensile strength, owing to the area of contact between units of the aggregate being so small, and would be likely to fail under load if required to act as a rigid surfacing.

In the civil aerodrome at Singapore [1] perforated precast concrete slabs were used in the tarmac area to transmit rainfall to the drains beneath, and that appeared to be the best method of combining adequate strength with free transference of rainfall to the drainage system. It was, however,

*** This and the following contributions were submitted in writing.

[1] Journal Inst. C.E., vol. 12 (1938–39), p. 69 (June 1939).

open to the objection that the perforations might soon become clogged by dirt and so cease to function. It would be interesting to know what had been the experience at Singapore.

In Mr. Du-Plat-Taylor's view the ideal rigid surfacing should consist of perforated concrete covered with a layer of pervious asphalt. The perforation of concrete laid in situ appeared, at first sight, to present serious difficulties; but he thought that by employing vibration applied to the bars used mechanically for perforation those difficulties could be overcome without serious expense.

Mr. R. Glossop observed that as soil mechanics was a new subject much research was in progress, and many of the Papers published were intended for the specialist. They were often mathematical in form and the practical application of their conclusions was not always obvious; therefore many engineers regarded the subject as highly theoretical and inapplicable to everyday foundation problems. That was a mistake, and the importance of Mr. Cooling's Paper lay in his emphasis of the value of certain simple soil tests, and of their interpretation by methods involving nothing more difficult than the elementary theorems of statics. Formerly the measurement of shear strength by compression tests required cumbersome laboratory apparatus, but the apparatus illustrated in *Figs. 5*, p. 49, *ante*, could be set up beside a borehole and values of the shear strength of the soil, sufficiently accurate for most purposes, could be obtained as boring proceeded. The examples described formed a convincing proof of the value of that technique, of the accuracy of its results, and of its wide field of application. Indeed the fact that four out of five of the examples described were "post-mortem" examinations after the failure or partial failure of a structure, showed how much scope there was for that essentially practical branch of the science of soil mechanics.

That certainly justified Mr. Cooling's approach to the subject of site exploration, but as a result of it he has confined himself, in his examples, to cases involving one only of the two main soil groups, the cohesive soils. Those contained a high proportion of clay and owing to their low permeability reacted slowly to changes in their state of stress. As a rule they were easy to excavate, and to support during excavation, but settlements might continue for a long time after completion of the structure.

Examination of soil conditions on a site, apart from questions of stability, was also of value in determining the best method of construction, which, in turn, should influence the design of the structure. That aspect of site exploration was chiefly concerned with the properties of the non-cohesive soils—gravels, sands, and silt, which were characterized by a high coefficient of permeability, wide range of particle-size, and absence of plasticity. In contrast to the cohesive soils, they usually formed a stable and reliable foundation. It was during, not after, the construction period that troubles arose, for the high permeability permitted of a heavy flow of water through the soils, whilst their lack of cohesion resulted in sand

being carried to the excavation by the inflowing water, so that settlement of the ground adjacent to it might follow.

Numerous precautionary methods were available for carrying out excavation in such soils; the most important were sheet-piling, compressed air, open caissons and cylinders, freezing, and injection processes, the latter including the injection of cement, clay, or bentonite grouts, bituminous emulsions, and finally the process of chemical consolidation based upon the injection of soluble silicates. Although many factors influenced the choice of method in any case, the properties of the ground were always of decisive importance, for the design and method of construction had to be adapted to the ground, since the ground would not accommodate itself to the method. When deep excavation had to be carried out in non-cohesive soils, carefully supervised borings followed by mechanical analyses and permeability tests on the samples should be made, so that a logical combination of design and construction could be formulated.

Methods of boring and sampling varied with differing soil types. To take undisturbed samples of a sand was difficult, although it could be done; fortunately it was rarely necessary, and reliable samples could be taken with a standard boring tackle. The casing should be driven well ahead of the bottom of the hole, and the ground, as removed with the sand pump, emptied into a tub from which the water could be decanted after the fine material had settled. Mechanical analyses of such samples were very instructive, and as they could be so easily carried out it was unfortunate that they were not more widely used in Great Britain. All too often accounts of difficult excavation described the ground in vague and general terms. A semi-logarithmic plot from a sizing analysis would yield precise information, in a form easily comparable with that from other cases, as was shown in *Fig. 4*. Curve No. 1 represented gravel from the Thames flood plain terrace at Millbank, the familiar Thames ballast, and the composite curve was characteristic of such material; curve No. 2 was of a beach sand from Hayle, Cornwall; an attempt to treat that material with cement injection failed, as might have been expected, since the material was too fine to be treated even by chemical injections; curve No. 3 was of well-known Cretaceous sand from Leighton Buzzard, which could be easily consolidated by chemical injections; curve No. 4 was of a river sand from a valley in the Keuper marls of Staffordshire; that fine sand was successfully drained by ground-water lowering by means of well-points. It was evident that much could be learnt by merely comparing the curve for a soil with those of materials whose response to various forms of treatment was known, such as those illustrated.

Mr. Glossop's experience of the unconfined compression test agreed with that of Mr. Cooling, namely that it was not well suited to the examination of stiff fissured clay, such as London clay. The following rapid procedure yielded useful information with such soils. Four or five samples

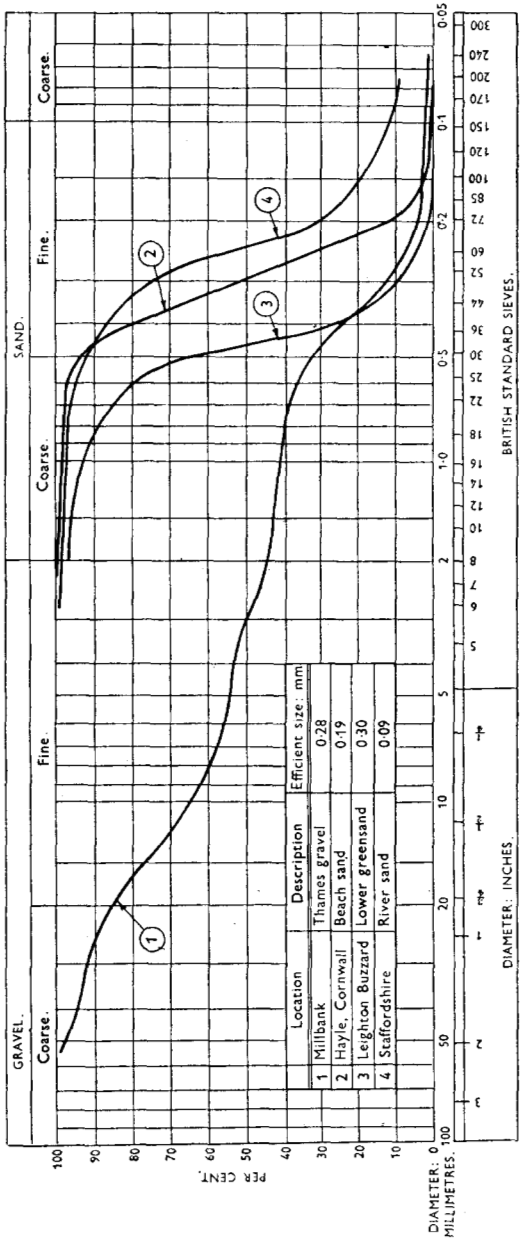


Fig. 4.

should be taken in a group as close together as possible ; the groups might be spaced at about 5-foot intervals of depth, or whenever a change in the soil was observed. Examinations of the type of failure in the test-pieces of each group would lead to the rejection of those in which failure had obviously taken place along a pre-existing plane of weakness.

Boring, sampling, and testing should all be carried out under the immediate supervision of the engineer responsible for the investigation. Satisfactory results could not be expected if samples were taken in a haphazard manner by a foreman, and submitted to routine tests by a laboratory worker unfamiliar with the geological conditions at the site.

Mr. H. Q. Golder observed that soil sampling was of such importance in soil mechanics work that a few remarks on some practical points might be of value.

The simple method of site exploration described by Mr. Cooling really was simple, but it could give results of very great value. One point to watch was that when sampling in very soft materials the soil at the bottom of the hole might soften up in the time occupied in withdrawing the rods, replacing the auger by the sampling-tool, and taking the sample. To overcome that difficulty it was necessary to have two sets of rods, so that the sample might be taken immediately the auger was withdrawn and before any appreciable softening had taken place. At the other extreme, in hard clay, if the weight of two men failed to push the sampling-tube into the clay, its compression strength was probably more than 25–30 lb. per square inch, which was usually adequate in problems which could be satisfactorily treated by that method of site exploration.

When boring with well-boring equipment it was usual to employ a specialist firm ; but it was well to bear in mind the difference in outlook of the soils engineer and the ordinary well-boring foreman. The latter was usually interested only in boring a hole by the quickest possible means, whilst the soils engineer was not interested in the hole, but in the material through which the hole passed. That difference in outlook was very important, for unless the foreman had that fact impressed upon him and was sufficiently intelligent to realize its importance, the engineer had to be constantly on the job during the boring operations, or poor samples would result. Even with an intelligent foreman it was essential that the engineer should spend considerable time on the job in the early stages of a project of any magnitude, inspecting the material brought up, supervising the sampling, and collecting information about water-levels. When he was satisfied that the foreman was thoroughly conversant with the method of sampling and would carry out his instructions conscientiously, his attendance on the job could be reduced.

Boring should be done dry, and on no account should water be poured down the hole to make boring easier. The levels at which water flowed into the hole should be carefully recorded, together with the level to which the water rose in the hole and the time taken for that rise to occur.

Sampling was an operation which required some care. The sampling-tube should be finished with a smooth surface inside and out and should be kept clean and free from rust and scale. Before use it should be oiled all over. The blow used to drive in the tube should not be too violent. The tube should not go into the soil in ½-inch jerks; $\frac{1}{10}$ inch was more the order of movement required. From that point of view the practice of using the weight of the rods to drive in the tube might not be good in soft material when sampling at considerable depths. Possibly the best system to use for driving in the tube would be to have a sliding monkey working on the bottom rod and driving direct on to the top of the head of the sampling-tube, the monkey being operated from the surface by a rope.

In Appendix I of Mr. Markwick's Paper, the Author had stated that "When friction is present the ultimate bearing capacity of the loaded circular area is about twice that of the loaded strip." That statement was based solely upon the results of theoretical analysis, but tests which Mr. Golder had made to test the point [1] had shown that the statement was untrue, and that a square (or circular) area on a frictional soil would support only the same pressure as a strip of the same width.

The difference shown in *Figs. 13*, p. 83, *ante*, was not the difference between a circle and a strip, but the difference between two different methods of analysis, since although Mr. Markwick had based his analysis upon Terzaghi's method, the assumptions he had made regarding the circumferential stress *Pt* probably invalidated the comparison. It was interesting to note that if the coefficients for Prandtl's formula for a strip footing were plotted in *Fig. 13*, they lay very close to, or above, the Author's value for a circular area.

Mr. A. W. Skempton observed that the art of obtaining undisturbed samples of soil was, perhaps, not widely practised in Great Britain. It was, however, widely acknowledged as being a basic requirement in site exploration; and its importance was due to the fact that the properties of a soil could be completely altered by disturbance. A good illustration of that was provided by the soft blue clay shown in *Fig. 6*, p. 52, *ante*, which lost rather more than 75 per cent. of its strength when it was remoulded in the fingers; and any calculations based upon even a partially remoulded sample would clearly be of little practical value. But in a site exploration it was not sufficient merely to obtain good samples. It was also necessary to make observations in the field on all the factors which might influence the constructional operations or the finished structure. Mr. Cooling had mentioned some of those factors on pages 38 to 40, *ante*, and outstanding among them was the observation of ground-water levels.

The significance of ground-water levels was, in many cases, quite obvious. Thus if any excavation had to be carried through alternate layers of sand and clay, it was advantageous to know the head of water

[1] Journal Inst. C.E. vol. 17 (1941–42), p. 161 (Dec. 1941).

which would be encountered in the sand. It might, however, be desirable to know the water-pressure in a sand layer below foundation-level; that point was brought to notice, particularly, in the investigation of example IV, *Fig. 9* (p. 59, *ante*), of a small building which became severely cracked. The cracking was due to the excessive deformations of an underlying layer of soft clay; and the deformations were, in their turn, due to the unbalanced weight of the banks surrounding the building. The remedial measures were very properly carried out by cutting back the banks and thereby reducing the stresses in the soft clay.

Both the remedy and the explanation of the failure were thus quite straightforward. But it was thought that the mode of occurrence of the soft clay was rather curious. The facts relating to the soft clay were therefore assembled and were found to be as follows:—

(1) The soft clay lay on a bed of sand and silty clay, containing artesian water which overflowed in all the borings, including boring B at ground-level.

(2) The soft clay extended in the form of a flat pocket beneath the excavated area; but it did not appear to extend beneath the banks. Thus it was found in borings E and VII, but not in borings B and VI.

(3) There was no significant difference between the type of clay constituting the "soft clay" and the "medium-soft clay" in *Fig. 9*; and it was probable that they were deposited in an ice-dammed lake during the retreat of the glaciers from England.

(4) The building became cracked 6 months after construction.

It might be asserted that any relation between those facts was coincidental; but the following tentative explanation of the occurrence of the soft clay was, at least, not at variance with any of them.

Considering the clay at the position of core B in boring E below the centre of the building: before excavation took place it was about 32 feet below ground-level and was therefore under a total downward pressure of about 4,000 lb. per square foot. But the water in the silty clay, lying just below core B, was under a head of at least 32 feet, since it overflowed in boring B at ground-level. There was, therefore, an upward pressure on core B of at least 32 feet of water, and the net pressure acting on the clay was therefore about 2,000 lb. per square foot. Excavation then took place, and 18 feet of clay was removed. This would approximately halve the total downward pressure, whilst no change would occur in the water-pressure, since the sand lay entirely below foundation-level. It would therefore be seen that the net pressure on core B was reduced to zero and, in fact, there was a slight tendency for the clay to be lifted off the sand since the water-pressure was rather greater than the weight of the clay alone. The result of that reduction in net pressure was that the clay would start softening: and the softening would continue for many months, or even years, gradually spreading upwards and reducing the strength from about 1,000 lb. per square foot to 350 lb. per square foot. The latter strength was con-

siderably lower than the stress set up by the weight of the banks, and deformations would therefore occur, increasing with time, and ultimately being sufficiently large to crack the building. The period of heavy rain mentioned by Mr. Cooling would accelerate the process by temporarily increasing the shear stresses.

If that explanation were correct, the soft clay was a consequence of excavation. It therefore followed that where there had been no excavation there should be no soft clay; and that had been mentioned already as a fact. It also followed—and that was the important point—that if the borings had been made before excavation no soft clay would have been found; but only "medium-soft clay" with a shear strength at least double that of the existing soft clay.

That example therefore demonstrated the need for observing water-levels and for taking into account the changes brought about by constructional operations. In itself the example was not important, since the building was easily repaired: but a similar set of conditions could easily be imagined in the case of a quay wall, where the results would be disastrous unless foreseen and allowed for in design.

Mr. J. S. Jackson observed that he had noted with some misgiving that more than one speaker had referred to soil mechanics as a suitable subject for study by young engineers, or even students. They seemed to regard it as a matter that could be left to the next generation. He dissented strongly from that view and regarded the subject as of urgent importance. As Mr. Lyddon had said, there was immediate scope for the application of a knowledge of soil mechanics in connexion with the construction of aerodromes and military roads. Soil stabilization methods were already available and had yielded very promising results, not only in the laboratory, but also in practical field trials. He felt, therefore, that those methods should be thoroughly explored on an extensive scale, so that suitable plant might be chosen and assembled and as much practical experience as possible gained. It was obviously in the national interest that the accumulated knowledge of soil stabilization should be rendered available for practical use as quickly as possible. It was conceivable that successful soil stabilization might have a critical influence upon the nation's military fortunes in its world-wide operations, since it was obvious that the rapid construction of roads and aerodromes from readily available materials was of fundamental importance.

He had no doubt that if the Government could be persuaded to invest £100,000 on research work on soil stabilization a very large dividend would be paid within the course of two or three years.

Mr. Cooling, in reply, thanked the members for the way in which they had received his Paper and for the very helpful remarks which had been made in the discussion. He had been particularly gratified by Dr. Lowe-Brown's remarks with regard to the example given in *Fig. 6*, p. 52, *ante*. He was glad to know that the action taken by the Building Research Station in that

case had proved to be satisfactory. News of the performance of structures with which they had been connected was always of interest to those engaged at the Station, and more especially in those cases where the actual behaviour differed from that forecasted, for the research man, like the engineer, learned most of all from his mistakes.

Some speakers had suggested that there was in the minds of many engineers an impression that soil mechanics was a highly theoretical subject. That was definitely a wrong impression and he hoped that his Paper had gone some little way towards correcting it. As a further step he would suggest a reference to the Presidential Address given by Professor Terzaghi in 1936 to the First International Conference on Soil Mechanics [1] in which the progress achieved and the outlook adopted in soil mechanics was dealt with in more authoritative terms than he could hope to give.

Whilst it was true that many soil mechanics publications were of a specialist nature, in which mathematical methods assumed some prominence, he thought that that was a necessary aspect and an inevitable result of the intensive study devoted to the subject. That feature, however, should not obscure the fact that broad progress in the subject as a whole depended upon the closest possible contact with practical problems and the continued study of the behaviour of soils in the field. An essential requirement of such progress was the active co-operation of the practising engineer, a point which was illustrated by the few practical examples quoted in the Paper, the study of each of which owed much to the collaboration of the engineers in charge. The teaching of soil mechanics, which was mentioned by Professor Clements, was also an important aspect. That had been gone into in some detail in the United States, and he thought that the Proceedings of the Purdue Conference on Soil Mechanics (July 1940) would provide valuable information for those interested in that aspect.

The suggestion put forward by Dr. Lowe-Brown relating to the publication of the results of investigations carried out at the Building Research Station would certainly be borne in mind, but there were difficulties in putting that work in hand at present.

Many speakers had quite rightly emphasized the value of a knowledge of the geology of a site as a preliminary to site exploration. He thought, however, that it was necessary to point out that for purposes of design, geological information should be supplemented by quantitative data obtained from soil tests.

The need in Great Britain for a better appreciation of the necessity for, and the value of, adequate site exploration had been dealt with in masterly style by Mr. Harding, and Mr. Cooling wished to express his thanks for a valuable and entertaining contribution.

[1] Proceedings of the First International Congress on Soil Mechanics and Foundation Engineering, vol. iii, p. 13.

He agreed with Mr. Pimm that the results of laboratory tests should always be considered with an adequate background of information obtained by field observations. Such observations could be made during sampling—a point which had been amplified by Mr. Golder. The brief description of Mr. Pimm's method of sounding was interesting, but he thought Mr. Pimm would agree that for some problems the information it gave was strictly limited, and that for most problems the interpretation of the results needed considerable experience and a knowledge of the soil strata obtained either from geological records or from borings. For instance, he did not know how the nature of a soil stratum could be inferred from penetration resistance alone, or how the method could give information relating to ground-water pressures in the various strata, a factor which might represent a very important hazard during construction. In reply to Mr. Guthlac Wilson's question on sounding methods, he could only state that, so far as he knew, no systematic attempt had been made in Great Britain to correlate the results of such soundings with the index properties of cohesive soils.

He agreed with Mr. Wilson that perhaps cohesionless soils had not been treated adequately in the Paper; but it was difficult to include all aspects of the subject when space was limited. On that account he welcomed both Mr. Wilson's and Mr. Glossop's comments, which indicated the troubles most likely to be encountered with soils of that type. It was true that index properties had less meaning when applied to sands or to the material brought up by boring into sandstone. *Fig. 4*, p. 47, *ante*, showed the results of routine tests on samples from a soil profile, but naturally those would be considered in the light of boring records, and the results given for the sandstone samples in *Fig. 4* would be ignored.

He was interested in the details given by Mr. Wilson of Dr. Hvorslev's portable compression apparatus. That apparatus was mentioned in Hvorslev's Paper[1], but no details had been published so far as he knew.

He thought Mr. Allin had made a valuable point in drawing attention to the fact that important changes might take place in the ground as the result of constructional operations such as deep excavations and piling. The example quoted by Mr. Skempton was a further illustration of that point, and the suggested explanation of the formation of the soft clay layer was particularly interesting.

Mr. Cooling thought that measurements of the swelling of clay in deep excavations such as those made by Mr. Allin constituted a valuable contribution to the science. The explanation of the results of the laboratory test described by Mr. Allin was interesting, but the experiment could hardly be considered conclusive. A very slow shear test under small normal loads usually gave a lower strength than a quick shear test, and possibly the increased deformation following vibration might be due to a

[1] M. J. Hvorslev, "The Present Status of the Art of Obtaining Undisturbed Samples of Soils," *loc. cit.*, p. 13.

seismic effect on the weights used to supply the shear load which temporarily increased the shearing force.

Mr. Markwick, in reply, said that he had not dealt with the problem of soil stabilization because he had recently presented a Paper on that subject to the Institute of Petroleum[1]. A number of soils could be dealt with by stabilization. Mr. Lyddon had successfully constructed runways at a number of aerodromes by stabilizing the natural sand, and Mr. Markwick had come across a number of sites where other types of soil could have been successfully stabilized, whereby a good deal of effort and expense would probably have been saved.

Professor Clements had observed that a soil survey was a lengthy process. As a matter of fact, about two weeks' work on the site by an engineer and possibly one or two labourers was required for the soil survey for an aerodrome, and the total cost of that survey, including the tests in the laboratory, was about £150. There would probably be 200,000 or 300,000 square yards of surfacing to be done on the aerodrome, costing about £100,000—£150,000, so that the cost of the soil survey would be about 0·1 per cent.; and the value of that expenditure, as an insurance against unsatisfactory foundation conditions not otherwise apparent, was considerable.

The Road Research Laboratory always made use of the drift maps of the Geological Survey before starting on a soil survey, because the information given was a useful indication of the conditions which would be met at the site.

Professor Clements had pointed out that soil was one of the principal constructional materials used by civil engineers. In the Author's view that alone justified Professor Clements' proposal that soil mechanics should be brought into the curriculum of young engineers as a part of their early training. Mr. Harding, however, had dissented from that view, advocating that the civil engineering student should acquire a sound knowledge of geology instead. The Author would be the last to question the necessity for a grounding in geology, but the view which Mr. Harding had put forward suggested that he had failed to appreciate the essential difference between geology and soil mechanics. The former was essentially a descriptive science, but soil mechanics endeavoured to explain the phenomena with which it was concerned in quantitative terms, and was thus closely allied to structural engineering. There was, however, an important difference: unlike mild steel, soil was a variable material, and it was therefore necessary in every case to assess the properties of the soil by means of tests on samples taken from the site. The very basis of "soil mechanics" was the combination of laboratory experiment with applied mechanics, and that had been responsible for the rapid developments in knowledge of the engineering properties of soils. It was interesting to

[1] See reference 3, p. 86, *ante*.

recall that Mr. Bell [1] had been one of the first—if not the first—to study foundation problems by means of tests on samples taken from the site.

Mr. Jackson had urged that, however desirable as a subject of study for young engineers, soil mechanics was also of urgent present importance. The Author felt that by their support at the present meeting and at all the previous meetings when soil problems had been discussed, members had made it clear that they agreed with Mr. Jackson, and were, as Mr. Bennett observed, particularly eager to acquire knowledge upon which practical decisions could be based. That raised the question of the dissemination of a knowledge of soil mechanics among engineers. Dr. Lowe-Brown had pointed out that the latest information was frequently contained in numerous technical Papers and articles. It was to assist engineers to cover that technical literature with the minimum of effort that the various abstract journals existed. Soil mechanics was covered in three journals, "Road Abstracts," "Building Science Abstracts," and "Aerodrome Abstracts," the titles of which would be familiar to members. Summaries of information in readily usable form were sometimes given in Papers on particular aspects; whilst yearly summaries of research on road problems had been included for a number of years in the year-book of "Roads and Road Construction." Although a British textbook was not yet available, there were a number of American textbooks, two of which had been already referred to [2].

There seemed to be general agreement among engineers as to the desirability of adopting improved methods of investigating soil conditions, and the Author hoped that more might be done in the future to carry out investigations which had been agreed to be desirable. Those ideas were by no means new, and since he had written the Paper the Author had been very interested to notice in a book on road construction [3], published in 1833 by an Honorary Member of The Institution, an account of practice said to have been followed by Telford. The following quotation might be of interest:

> "A vertical section should be made, and the nature of the soil or different strata should be shown over which each apparently favourable line passes, to be ascertained by boring; for it is by this means alone that the slopes at which cuttings and embankments will stand can be determined and calculated. . . .
>
> "If bogs or morasses are to be passed over, the depth of the peat should be ascertained by boring; and the general inclination of the country for drainage should be marked."

[1] See reference (22), p. 87, *ante*.

[2] See references (1) and (2), p. 86, *ante*.

[3] Parnell (*Sir* Henry), *Bart.* A treatise on roads. London, 1833. (Longman, Rees, Orme, Brown, Green and Longman), p. 40.

In reply to the query regarding the propriety of using the term "time of concentration" on p. 73, *ante*, that term had been used in the sense defined by Professor Clements, namely, for the time after commencement of rain at which maximum run-off occurred in the main arterial drains.

The use of porous concrete of the type referred to by Mr. Du-Plat-Taylor was of considerable interest. The Author believed, however, that by attention to the grading of the aggregate it was possible to obtain a satisfactory open-textured concrete surfacing, that did not need to be covered with a bituminous carpet. The Author was not quite happy, however, about Mr. Du-Plat-Taylor's proposal to lead the run-off directly into the soil because of the danger of softening it, although there were, no doubt, cases where that form of construction could be adopted with safety.

Mr. Golder had asserted that his tests had shown that on a frictional soil the bearing capacity of a circular area was the same as that of a loaded strip of the same width irrespective of its length; but his Paper [1] showed that those tests had been carried out on square and rectangular footings, and not on circular areas. Mr. Golder's evidence was, therefore, inconclusive, especially as Terzaghi [2] had quoted two sets of experimental data on the bearing capacity of circular areas on sand which supported his formula. Hence the conclusion given in the Paper.

The Author was glad that Professor Clements had referred to the application of controlled methods to embankment construction and had agreed that that application of soil mechanics was not a counsel of perfection but a method of considerable practical value. It was, perhaps, fortunate for contractors that although the Resident Engineer now had a method of assessing the degree of compaction which reduced the scope for argument, modern constructional methods based upon scrapers and tractors were capable of meeting quite stringent requirements without undue cost and as a part of the ordinary construction routine. Those methods of control had been welcomed in America, and the Author did not think that contractors had anything to fear from them.

In thanking members for their kind reception of his Paper, he wished to express his regret, in view of the wide interest expressed, that it had not been possible to deal with soil stabilization. He had already indicated the primary reason, and he agreed that it was a subject of national importance.

The following corrections should be made to the Paper as printed in the Journal:—

Page 70, Conclusion (3), line 3. *For* "(wheel-load$_4$)" *read* "(wheel-load$^{\frac{1}{4}}$)."

Page 82, Equation (9). Insert = sign between first two terms.

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[1] *Loc. cit.*, p. 173, *ante*.

[2] See reference (23), p. 87, *ante*.