8164

DISCUSSION

**Application of geotechnics to the solution
of engineering problems—essential
preliminary steps to relate the structure
to the soil which provides its support**

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Some years ago, while preparing a talk on foundation engineering, I took the opportunity of going back through my files on a number of projects that I had been associated with. It became clear that in the majority of cases the major foundation design decisions were based primarily on a knowledge and detailed description of the soil profile. In many of these cases the decisions were followed up by more detailed quantitative testing and analysis but these were used to confirm the basic designs and refine them. This is the background to my views which the Authors generously quoted in the introduction to the Paper.

71. In order to illustrate and support the simple and pragmatic views expressed in the Paper I would like to describe two recent projects in which the major design decisions were based purely on a detailed inspection of the soil profile. Both of the structures are in London where one might be tempted to conclude that enough is known about the ground conditions to dispense with a detailed soil description. These examples demonstrate that even in London where the ground conditions are well known such a conclusion would be thoroughly misconceived and at times dangerous.

72. The first example is the new London Central YMCA in Tottenham Court Road. The building consists of a hotel, in the form of four diamond-shaped towers, over a 16 m deep basement containing sports and leisure facilities.²¹ The geological succession on this site consists of 7 m of sand and gravel overlying London Clay to a depth of approximately 25 m below the surface; this in turn overlies the Woolwich and Reading beds. The foundation decisions were difficult and challenging for two reasons. Firstly, the facilities in the basement necessitated large clear areas and to achieve this each tower was to be founded on a maximum of eight columns grouped in pairs carrying up to 2200 t each. Secondly, for important financial reasons, it was essential to complete the hotel as quickly as possible and this necessitated installing its foundation prior to commencement of the major excavation works.

73. An obvious choice of foundation for the hotel towers was large diameter under-reamed piles. However, it soon became clear that the use of such piles in the London Clay was out of the question as the magnitude of the loads would have necessitated enormous underreams which would have overlapped with the adjacent piles.

DISCUSSION

74. At this stage the consulting engineers, Kenchington, Little and Partners, sought the advice of the Building Research Station. After considering a number of alternatives it was suggested that the underlying Woolwich and Reading beds might provide a suitable founding stratum. The problem was that very little was known about the founding properties of these beds and there was a belief among many engineers that they contained water under artesian pressure. The decision was therefore taken to bore a 1 m dia. shaft to a depth of 32 m to inspect the various strata. A detailed visual inspection was carried out by the writer in conjunction with the consulting engineers and the profile has been reported by Willbourne.²¹ The inspection showed that the basement beds of the London Clay were very silty, with a considerable amount of seepage and consequent softening taking place. In contrast the upper levels of the Woolwich and Reading beds consisted of dry, very stiff, intact silty clay.

75. On the basis of this information, the decision was taken on the same day that the inspection was carried out to found in the Woolwich and Reading beds. It was judged on the basis of the visual inspection that a bearing pressure of about 1000 kN/m² could be used and this was subsequently confirmed by means of plate loading tests carried out in the first piles to be constructed. This approach not only led to a quick appreciation of the founding properties of the various strata but also to a direct knowledge of the construction conditions which could not have been obtained from soil samples.

76. The second example in which visual inspection of the ground had a major influence on foundation decisions is the underground car park at the Palace of Westminster.^{22,23} The car park is some 18.5 m deep and the ground conditions consist of 10 m of alluvium, sand and gravel overlying London Clay which extends to a depth of about 64 m below ground level at this site. The water table is at a depth of 6 m and the water pressures are hydrostatic with depth.

77. A number of small diameter holes were sunk and the majority of the cores were split and examined in the manner described in § 26 of the Paper. The visual examination revealed that immediately beneath the lowest level of the excavation there existed a number of sand and silt partings in the London Clay for a depth of about 10 m. Beneath this layer was a 4 m thick stratum of stiff intact clay.

78. The discovery of the stratum with sand partings containing water under hydrostatic pressure had a major influence on the basic design decisions. In view of the critical location of the excavation and the inherent uncertainties in any seepage analysis it was decided to take the diaphragm retaining walls down into the intact clay stratum, thereby cutting off all horizontal seepage and eliminating the risk of hydraulic uplift in the base of the excavation. Similarly the underreamed bored piles supporting the floors of the car park were taken down to this stratum to avoid possible construction difficulties in forming the underreams in the stratum containing the sand partings. As in the case of the London Central YMCA, detailed testing and analysis was later carried out to confirm the design decisions, but it was a knowledge of the soil profile which governed these decisions.

79. I hope that these two examples have served to reinforce many of the points made by the Authors. The key thing is for the designer to become intimately involved in the site investigation. He should inspect and handle the ground himself (in the company of his soils advisor if he has one) and pose questions about its origins and its likely response during and subsequent to construction. No amount of laboratory testing or sophisticated analysis can compensate for a lack of direct knowledge of the soil profile based on visual inspection.

Mr. L. L. Kenchington, Kenchington Little & Partners

Jennings and Brink have rendered a great service to the whole of the construction industry, and those it serves, for they have shown how easy it is to establish the order of magnitude of the likely response of unknown soils, as well as of well known soils, to the removal or addition of load; and to forecast the changes that may well follow. Their

contribution is of particular relevance to all those who exercise engineering judgement on probable soil-structure interaction.²⁴ This Paper would be of great value to members of the Institution of Structural Engineers and the RIBA, to whose attention it could now be drawn.

81. A practising engineer rarely needs accuracy in assessment of characteristic soil properties for he is mainly concerned with the stiffness of the soil in comparison with that of the structure under consideration. The latter changes very greatly during construction with the addition of each new level, as well as with the introduction of non-loadbearing elements. There is also time-dependence, for some consequential movements will have taken place before each new element is built. Qualitatively, it may be easy to comprehend these patterns, but quantifying such movements will not be meaningful for they depend significantly on time, and sequence of operation.

82. A practising engineer, then, needs the order of response from the soil and may often be well advised to reduce the risk of distress by other means, rather than those of strengthening elements of structure, their connections and/or the foundations. When close to the borderline of possible local distress, economy has more often been obtained in the past by the avoidance of undue stress concentrations such as those caused by ill-conditioned patterns of openings in stiff elements, such as walls; the changing of specification of brittle finishes to ones far more ductile; the isolation of stiff non-loadbearing elements from all less rigid structural framework, or by their subdivision, to achieve a shedding of unbearable loads; and the postponement of application of brittle finishes until after the majority of movements have taken place, and to the time when with increased structural stiffness, future movements will no longer impose unbearable strains.

83. So, the Authors have given practising engineers a very powerful list of priorities to enable them to assess and, when needed, mitigate the effects of movement generated by structure-soil interaction.

Dr R. F. Legget, Consultant, Ottawa, Canada

This Paper is a refreshingly 'down to earth' contribution to the literature. With its emphasis on good field observations and the exercise of sound judgement, it will be of real assistance to all engaged in ground engineering who will use it as a guide.

85. The Paper is especially welcome coming from two such experienced practitioners in an area where the problems of residual soils predominate. This adds interest to the Authors' reference (§ 42) to the 'pebble marker' (or pebble bed) which distinguishes their soil profiles. Is this a widespread feature in southern Africa, or is it peculiar to the area of Johannesburg?

86. Would the Authors not agree that in recording the depth to the water table ((a) of § 44) at a site under investigation, every effort should be made to determine the range within which this varies throughout the year? Groundwater is rarely static. Although its slow horizontal movement may be of little consequence in civil engineering, the annual vertical movement of the water table can have serious consequences if not anticipated.

87. In § 19 the Authors point out the possible value of information on local history. In some cases, when well recorded, such 'archival material' can yield geological information of real value. Would the Authors not agree that a search for any such archival material that may be available should be a part of all site investigations, especially those in urban areas?

88. The dominating importance of geology in all site investigations is rightly a continuing theme throughout the Paper. It is so important that I venture to suggest that § 5 might well have been worded: 'The simple approach to problems of and in the soil starts with a review of the geology of the site, followed by a good look at the soil . . .' I am led to make this suggestion since, while the Authors were probably writing their Paper, I was engaged in preparing the 1977 Terzaghi Lecture for the American Society of Civil Engineers.²⁵ So similar are the approaches of these two papers to the general

DISCUSSION

subject, in case anyone should compare them it should be recorded that they were prepared quite independently of one another.

89. The Authors refer appreciatively to the philosophy of Terzaghi. Will they accept, in discussion, an early quotation from this pioneer to set the seal of his approval on their Paper? Writing in 1955, Terzaghi said: 'The geological origin of a deposit determines both its pattern of stratification and the physical properties of its constituents . . . Therefore, the knowledge of the relation between physical properties and geological history is of outstanding practical importance.'²⁶

Dr Jennings and Dr Brink

The Authors find themselves in complete agreement with all points raised by contributors to the discussion. We agree with Dr Legget that every effort should be made to determine the range within which the water table fluctuates throughout the year: for this purpose we often advocate the installation of piezometers. It has been our experience that such fluctuation is of greatest magnitude where the water table is shallow, and particularly where it is 'perched'. Deep water tables tend to have a much lower range of fluctuation, unless they are confined within small groundwater compartments from which water is being pumped in large quantities.

91. We also agree with Dr Legget that a search for any archival material should be a part of site investigations, especially in urban areas. Ideally such records should be stored in local geotechnical data banks for ease of future retrieval.

92. Dr Legget asks whether the pebble marker is a widespread feature or peculiar to the area of Johannesburg. The pebble marker, which we have defined as a layer of gravel forming the horizontal boundary between transported soils and the underlying residual soil or bedrock, is a widespread feature of the soil profile throughout Africa, and indeed throughout South America and Australia. The recognition of this feature during the course of soil profiling is of vital importance as it represents the boundary between soils of totally different origin and thus totally different engineering characteristics. From place to place the pebble marker is highly variable. It varies in thickness from a thin bed of scattered stones to an accumulation of gravels and boulders tens of metres thick. But where the constituent gravels are of easily weatherable rocks they may have become entirely decomposed and care must then be taken to identify their original outlines. In some situations gravels, as such, may be absent and the boundary between the transported and residual zones may be marked by no more than a thin layer of coarse sand. The pebble marker varies in age from Tertiary to Recent. As stated in § 42 it varies greatly in origin too; and, depending on the origin, the constituent gravels or boulders may vary in shape from well rounded to completely angular. Thus, although it is not a regular stratigraphic horizon, the pebble marker represents the level of the most recent major geological unconformity from place to place beneath the earth's surface. As such we would venture to suggest that it may even be represented in glaciated areas by the 'very tough glacial till (which) is often encountered just above the level of bedrock (and) which is sometimes of considerable thickness'—the material which, in earlier days, was often designated by the unfortunate term *hardpan*.²⁷ Indeed we are so convinced both of the widespread occurrence of the pebble marker and of its engineering significance that we would greatly welcome observations about its occurrence in different geological settings, and particularly from observers in the northern hemisphere.

93. Dr Legget's quotation from Terzaghi's paper²⁶ is most appropriate, namely that 'The geological origin of a deposit determines both its pattern of stratification and the physical properties of its constituents . . . Therefore, the knowledge of the relation between physical properties and geological history is of outstanding practical importance.' But in the design of engineering structures there are factors which must receive equal attention: know your structure, its functions and its special requirements; appreciate its deformation characteristics and what limits of cracking or other signs of distress in the structure are of significance; know what changes in the surroundings and

possibly in the structure itself are likely to take place during the life of the structure. In short, know your structure and the site and make your marriage of the two compatible.

94. It is noteworthy that as geotechnical engineers advance in age they turn more to the geological implications in their work and to simplicity in testing. This was certainly the case with Terzaghi and now the second generation of geotechnical engineers are following the same pattern. The Paper evoked many personal letters which did not find their way into this formal discussion and this line of thinking set out by Terzaghi appears to apply throughout the world.

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