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Shallow Foundations - General Report

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1 INTRODUCTION

The sixteen papers available at the time of reporting cover a wide range of structures and soil types. Most authors have attempted to include comparisons between performance and prediction. Half of the papers address problems of settlement and bearing capacity of soft soils while others cover such diverse topics as data processing or analysis of stresses in buried pipelines. To assist delegates in the selection and comparison of papers of interest to them, this general report groups the papers into six categories, briefly identifies some of the main points in each paper and comments on some interesting or controversial aspects.

In his presidential address to the First International Conference on Soil Mechanics and Foundation Engineering in 1936 Terzaghi contrasted soil engineering with bridge engineering noting that .." as soon as we pass from steel and concrete to earth the omnipotence of theory ceases to exist." "In soil mechanics the accuracy of computed results never exceeds that of a crude estimate, and the principal function of theory consists of teaching us what and how to observe in the field". He also anticipates that: "Our theories will be superseded by better ones, but the results of conscientious observations in the field remain a permanent asset of inestimable value to our profession." Against this background, suggested key questions for this session are (with respect to the types of problems discussed in the papers):

(1) What are the most appropriate techniques for defining soil profiles at a site and are there any general guidelines as to how to select an idealised soil profile for design purposes?

(2) What are the most appropriate methods of determining deformation, strength and in-situ permeability (C_v) properties and for selecting characteristic values of these properties for design?

(3) What is the potential role of post-Terzaghi geomechanics theory, either by way of quantitive improvement or by way of providing a qualitative conceptual framework for design, observation and interpretation? (For example elasto-plastic analyses, critical state mechanics, probabilistic methods .....?)

2. SITE INVESTIGATION AND DATA PROCESSING

Crampton, Bell and Pettinga provide an informative description of investigation procedures and of predictions of the soil and rock profile for a short length of cut and cover pipeline construction in steep terrain in which volcanic bedrock is overlain by up to four metres thickness of loess-colluvium. Predictions are then compared with the characteristics of the materials encountered during construction. Case histories emphasising this most crucial stage in any geotechnical engineering project are extremely valuable.

Truong describes some applications of spreadsheet programs for processing geotechnical data using microcomputers. Quite recently, engineers ruled up tables and proceeded laboriously throughout them with a hand calculator, column by column, row by row. Electronic spreadsheets can now do this for us, allowing us to concentrate on the end results and on the sensitivity of these results to variations in critical parameters. The author provides some examples of geotechnical applications of a tool which is rapidly becoming part of normal design office procedures.

3. SOFT CLAYS AND PLASTIC SILTS

All of the papers refer to construction of surface foundations and/or embankments on weak, compressible strata. Some of the papers present valuable case histories. It may be of interest to identify some features which recur throughout these papers because this gives a guide to the current state of implementation of the art in this field. Common features include: use of the eletric cone penetrometer to define the soil profile; use of conventional 1-D settlement models and slip circle (undrained) stability analyses for design and for interpretation of field observations; use of Asaoka's method of establishing the end of primary compression; installation of pneumatic piezometers to monitor pore pressure and the use of surface settlements as the main basis for decisions on preload removal.

The first three papers to be reviewed describe preloaded, Recent, soft sediments at sites within a five kilometres radius, near the mouth of the Brisbane River. Truscott and Ilievski describe preloading and surcharge) of up to 15 m thickness of loose sand with closely spaced interbeds of soft clay of variable thickness to prepare a site for construction of large aeration and settling tanks on economical, flexible, raft foundations. Preload design criteria were: elimination of all primary plus twenty years of secondary compression of the soft clay; achieving a factor of safety of at least 1.2 (based on lower bound corrected vane shear strength values) for stability of the fill and avoidance of local shear failure beneath the edges of the fill. Special care has been taken to ensure that the soil profile was well defined across the site by using electric cone penetrometer probes supplemented by continuous piston sampling and to ensure that magnetic extensometers and pneumatic piezometers were located so that they monitored consolidation of critical clay layers. Preload consolidation time has been estimated from the known behaviour of preloads on geologically similar deposits within five kilometres of the site after checking that this time is generally consistent with observed layer thicknesses at the site. As settlement estimates for these slightly over-consolidated clays are sensitive to changes in pre-consolidation pressure, it would have been useful to know how laboratory compression curves have been corrected for sample disturbance and how overburden, pre-consolidation and applied pressures have been assumed to vary with depth at the site.

This is a very useful and well documented case history. The techniques and design approach are typical of those which can be applied successfully to improvement of a wide variety of soft soil sites. Further information on the behaviour of the completed plant must be obtained before the success of the project can be confirmed.

Larmour considers the magnitude of differential settlement of shallow footings on sand fill overlying highly compressible soft clays which have been preloaded and surcharged. It is not an exercise in prediction of total settlement or rate of settlement. Instead, it summarises several type B predictions of the differential settlement over 8 to 16 metres span between adjacent column locations for one particular site.

The building design criterion was a maximum differential settlement of 50 mm between adjacent columns. Observations and predictions are:

	Total Settlement	Differential Settlement of Adjacent Columns
Observed along Existing runway (not surcharged)	400 mm	not > 25 mm over 10m
Observed at Existing building (not surcharged)	80-210 mm	0-50 mm
New building on surcharged area (20 year prediction)	180 mm average	2.8 percent to exceed 50 mm over 8 m span.

Further data on the nature and variability of the soil profile at the site is needed before others could decide whether similar behaviour could be anticipated at other sites.

Litwinowicz and Smith discuss the investigation, design and monitoring of various measures applied to reduce settlement and maintain stability of road embankments on up to 20 metres of soft, normal to lightly overconsolidated clays in which sand drainage layers are often evident but discontinuous and are absent in some areas. Measures include preloading and surcharge (with wick drains) to reduce settlement and stone columns and steel mesh reinforcement to maintain embankment stability. At the East-West Arterial road site, 50 kPa of excess pore pressure is recorded and a further 1000 mm of settlement expected even though other data has been interpreted as showing that primary consolidation was 90 percent complete after 100 days. Various interesting phenomena are suggested for this extraordinary creep behaviour but perhaps further consideration should be given to whether interpretation of the magnitude and rate of consolidation is valid.

At Schulz Canal there was quite remarkable agreement between predicted and actual consolidation times. Are these type 'A' predictions? Without details on critical assumptions with respect to drainage paths, the validity of using the 90 percentile of laboratory C_v values and of adopting various design parameters for wick drains is difficult to establish. Were the wick drains effective? Truscott et al report t_{90} values of about 100 days without wick drains at each of three other soft soil sites in the lower Brisbane River estuary. Within the same region, the Reporter has encountered t_{90} values for thick, soft clays ranging from a few weeks to in excess of 60 years!

The authors have also briefly reviewed safety factors for short term stability of embankments and indicate that they used values of 1.6 to 1.9, based on undrained strength. It would be useful to know how this strength was measured and what characteristic value was adopted for design because safety factor recommendations are critically dependent on such information.

The authors have backfigured a correlation between static cone resistance and compressibility which has been applied successfully at two of their sites.

Gammon and Nelson describe preloading (with surcharge) of a thick, soft, highly compressible layer of plastic, diatomateous silt to prepare sites for construction of stiff raft foundations for a swimming pool and for large wastewater treatment tanks. Scanning electron microscopy was used to define the special, porous nature of the clay-sized particles. Pneumatic piezometers confirmed that consolidation occurred rapidly as the soil was loaded. As a result of this rapid consolidation, preload settlements were underestimated. Once the special nature of the soil had been determined for the first site preload, design for the second site was simplified to determination of the soil profile using an electric cone penetrometer and estimation of 1-D compression assuming rapid consolidation. A minimum preload period of six weeks is used. The authors have presented a very useful case history which illustrates a general approach to site investigation and improvement as well as details of specific techniques and parameters for diatomaceous silts.

Peaker and Ahmad discuss the behaviour of a flexible, large tank foundation on soft to firm organic silt containing fine sand and peat layers. Staged loading has been applied to progressively consolidate the subsoil while maintaining adequate safety with respect to bearing capacity failure. The soil profile was defined by exploratory boreholes from which samples were taken at 0.5m intervals. A pressuremeter has been used to evaluate soil stiffness and strength and a range of settlement estimates made using laboratory consolidation and pressuremeter test results. The authors consider that settlement prediction based on oedometer test results is unreliable for this type of material. Uncertainty with respect to the actual distribution of applied stress through the subsoil is emphasised. Variations in soil profile around the tank are used to estimate the magnitude of differential settlements. The various settlement predictions and observations appear to be as summarised in the following table.

Consolidation rates and pore pressures are not discussed but rather contradictory results of standpipe piezometer readings are tabulated. The paper emphasises the need for close control of the staged loading to ensure that it conforms with the design schedule.

	Total Settlement	Differential Settlement
Type A Prediction (extreme upper limit)	900 mm	300 mm
Type A Prediction (realistic upper limit)	450 mm	150 mm
Type A Prediction (Pressuremeter)	270 mm	< 30 mm
Actual (Under about half of full load)	300 mm (approx)	50-60mm (approx)

Wesley, Sinclair and Rogers' fourth case history describes foundation design for an ore stockpile wich applies up to 400 kPa rapid loading to the surface of twelve metres of firm clayey silt. Unlike the preceding cases in which the soil can be slowly loaded and consolidated to avoid bearing capacity failure, sudden ore loads are repeatedly applied. The solution which has been adopted is a slab supported on a grid of cast-in-situ piles transferring the load down to the underlying medium dense sand stratum. Predicted pile settlements were less than 50 mm and no undue settlement has been detected since the stockpile began operating.

Das applies existing theories to predict the bearing capacity of a strip footing on a granular trench in a weak cohesive soil. Predictions are compared with the results of small laboratory model tests. This work is important because it highlights three possible failure mechanisms: general shear failure similar to that beneath a strip footing on an homogeneous soil; a bulging failure similar to that which occurs with stone columns and a strip pile failure in which the granular strip retains its shape as it pushes down through the soil. In all model tests there was lateral bulging of the trench. For the particular combinations of clay and sand which were tested, the ultimate bearing capacity increased with relative depth of the trench up to a threshold value at $L/B \simeq 3$. This threshold value was in good agreement with that predicted for the bulging failure mechanism. While this is most interesting, one wonders how the critical strength parameters for the clay and the sand have been determined. Undrained shear strength cannot be defined independently of how and where it has been measured and how a characteristic design strength has been selected. The results of this work cannot be applied in practice until there is a better understanding of the factors controlling the threshold value of L/B.

More extensive evidence that linear interpolation from the bearing capacity of a surface footing to the bearing capacity at this threshold value gives a conservative estimate of bearing capacity is also required. Further work in this field could be very fruitful.

Resl, Fock and Sadlier have investigated the surface drainage of a consolidating "saturated clayey sandy silt of semi-liquid consistency" covered by various geotextiles and loaded by a static surface load in the laboratory. As in the previous paper, important characteristics of the soil have been omitted. Readers would benefit from a knowledge of the shear strength, consistency limits and liquidity index of the soil.

Also it is not quite clear what is being simulated. Is the semi-liquid soil a remoulded surface layer above a soil which is strong enough to support a 50 kPa surcharge? What are the implications of repeated and dynamic loads during construction? Wouldn't the outflow from 2 to 5 metres of consolidating clay be much greater than that from a 100 mm thick laboratory specimen?

The paper is important in that it emphasises the effect of surface drainage inside the outer edge of the embankment on foundation stability. It seems that the critical width for surface drainage to improve stability will extend inwards from the edge for a distance equal to about 1 to 1.5 times the thickness of the weak clay layer.

Comparison of the results obtained in the present tests for various interfaces shows that there is not a very big difference between the various materials. Average C_v values vary by +33% to -18% about the mean and the degree of consolidation at 30 hours only varies from 75 to 90 percent. These relatively small differences may result from the not very demanding nature of the laboratory simulation as discussed above.

General Comments

It is extremely difficult to present a complete account of prediction and performance within a conference paper. Some authors have succeeded but others have severely limited the breadth of application of their work by omitting essential data on the nature and variability of the soil profile and/or the engineering properties of the soil. These are critical omissions because, even though it may be argued that deterministic models are our only practical design tools, the most critical steps in the design process are:

(i) assembly of variable site conditions into an idealised soil profile and

(ii) selection of characteristic values for the variable engineering properties.

For those who are less familiar with this area of geotechnical engineering or less aware of some of the pitfalls the Reporter would like to add the following basic references to those given by the authors.

Bjerrum, L. (1973), "Problems of Soil Mechanics and Construction on Soft Clays" State of the Art Report, Proc. 8th Conf. I.S.S.M.F.E., Moscow, Vol. 3, pp. 111-159.

Tavenas, F. and S. Leroueil (1980) "The Behaviour of Embankments on Clay Foundations", Canadian Geotech. Jl, Vol. 17, No. 2, pp 236-260.

Rowe, R.K. (1984) "Reinforced Embankments: Design and Analysis", Jl, A.S.C.E. Geotechnical Div., Vol. 110, pp. 231-246.

Leonards, G.A. (1982) "Investigation of Failures", 16th Terzaghi Lecture, Jl, A.S.C.E. Geotechnical Div., Vol. 108, pp. 187-246.

Leroueil, S. and F. Tavenas (1982) "Pitfalls of Back-analysis", Proc. 10th Conf. I.S.S.M.F.E., Stockholm, Vol. 1, pp. 185-190.

Magnan, J.P. et al (1981) "Difficultes du Controle in situ des Calculs de Tassement (Settlement)", Proc. 10th Conf. I.S.S.M.F.E., Stockholm, Vol. 1, pp. 191-194.

4. STIFF CLAY AND WEAK ROCK, CEMENTED SAND

Wesley, Sinclair and Rogers discuss foundations for three buildings: a 6-storey structure founded on strip footings on stiff clay; a 29 storey structure on a stiff grid foundation on weak sandstone and a 7 storey structure on a raft on erratic deposits of firm to stiff clay, scoria gravels and boulders. Settlement predictions are presented. Actual settlements for the first building were less than predicted from oedometer tests. Various possible explanations are given. It would be interesting to know whether the authors use Skempton and Bjerrum's correction factors when estimating settlements of stiff clays. These three clear, concise case histories detail three circumstances in which appropriate geotechnical investigations have enabled surface foundations to be used instead of piling.

Allman, Poulos, Carter and Yeung are interested in prediction of the end bearing component of the load capacity of piles in cemented calcareous soils. Apparently they have successfully applied cavity expansion theory (for a dilatant, elasto-plastic material) to uncemented sands. In the present paper they test the application of this relatively simple model to sands with varying degrees of cementing, subjected to a range of overburden pressures. Although the predicted limit pressures were of the same order as those measured for model footings, the simple theoretical model could not reproduce the significant effects of loss of cohesive strength and variation of rate of volume change with shearing. Despite the partly negative outcome, this is an excellent paper which could be taken as a model for documentation of essential data, referencing of previous work and careful statement of the underlying assumptions and limitations of the work which has been undertaken.

5. RUBBLE AND ORGANIC FILL/ENVIRONMENTAL PROBLEMS

Ahmad and Peaker's contribution is one of the most interesting and valuable. As part of an urban redevelopment scheme, embankments have been constructed from and on top of earthfill contaminated with rubble, chemicals and organic matter. Environmental protection criteria governed the selection and placement of embankment fill. These criteria are discussed and embankment construction and control procedures detailed. Embankment settlement predictions and observations are given. Further details of prediction procedures would have been of interest.

6. SOIL/STRUCTURE INTERACTION

The first two papers discuss stresses and buckling failure of buried pipelines while the third considers the practical problem of preventing loss of soil from behind reinforced earth wall elements.

Fourie and Beer apply their non-linear finite element program to calculate stresses in a linear elastic steel pipe surrounded by homogeneous, isotropic "sand" and subjected to a surcharge loading. They carry out a parametric study, showing that slip at the pipe-sand interface, yielding of the sand and the assumed yield criterion all have a significant effect on predicted pipe stresses.

Moore describes experimental and theoretical studies of the buckling of buried pipelines and shows how his design approach can be applied in practice. Design is based on estimation of the critical hoop force which will cause buckling of the wall of the pipe and comparing this with the estimated maximum hoop force due to the loads applied to the pipe. In situations such as the shallow, surcharged pipe considered by Fourie and Beer the hoop force is non-uniform, varying considerably around the periphery of the pipe. Moore makes an important contribution by considering the effect of such non-uniform hoop forces on critical hoop force. Correction factors are given for shallow pipes without surcharge but it appears that experimental data on buckling of shallow or heavily surcharged pipes is sparse. Some further comment from the author on verification of the design method for these circumstances would be useful.

Hausman, Adler and Boyd are concerned with maintaining the structural integrity of reinforced earth construction. They describe a rather alarming case history in which voids up to 550 mm deep developed behind the panels of a vertical reinforced earth wall. The primary cause of backfill loss was transport by water flow from the backfill, out through the joints in the facing. More severe conditions must be encountered where walls are partly submerged and subjected to waves or tides or where inclined walls support uncovered mineral stockpiles. This is a valuable paper which outlines remedial measures for existing open joints and which details criteria for selection of an effective geotextile filter cloth for placement behind new walls.

7. ANCHOR UPLIFT PREDICTION

Pinto and Mahler's contribution is nearly identical to that presented to the 11th ICSMFE in San Francisco by Barata et al. It is an interesting example of the limitations of Type C predictions. Several years later, under new authorship, the data and conclusions are essentially the same but the predictions have changed even though the same methods have used for prediction. For example, the measured uplift capacity of Foundation D was 154 kN and estimated load capacities using the Grenoble and Rowe methods were 98 and 66 kN, respectively in 1985 and 198 and 136 kN, respectively in 1988. The authors continue to conclude that predictions are conservative even though the Grenoble method overestimates load capacity in 50 percent of cases.

The work is important because it demonstrates failure modes, indicates the critical role of strong backfill and shows that the grillages behaved as plates.