Settlement Determination on Sand

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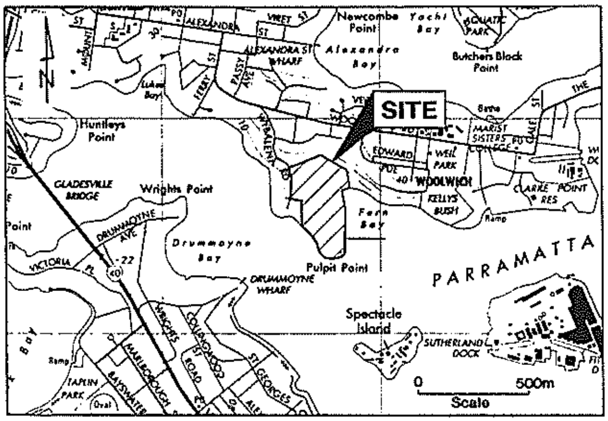
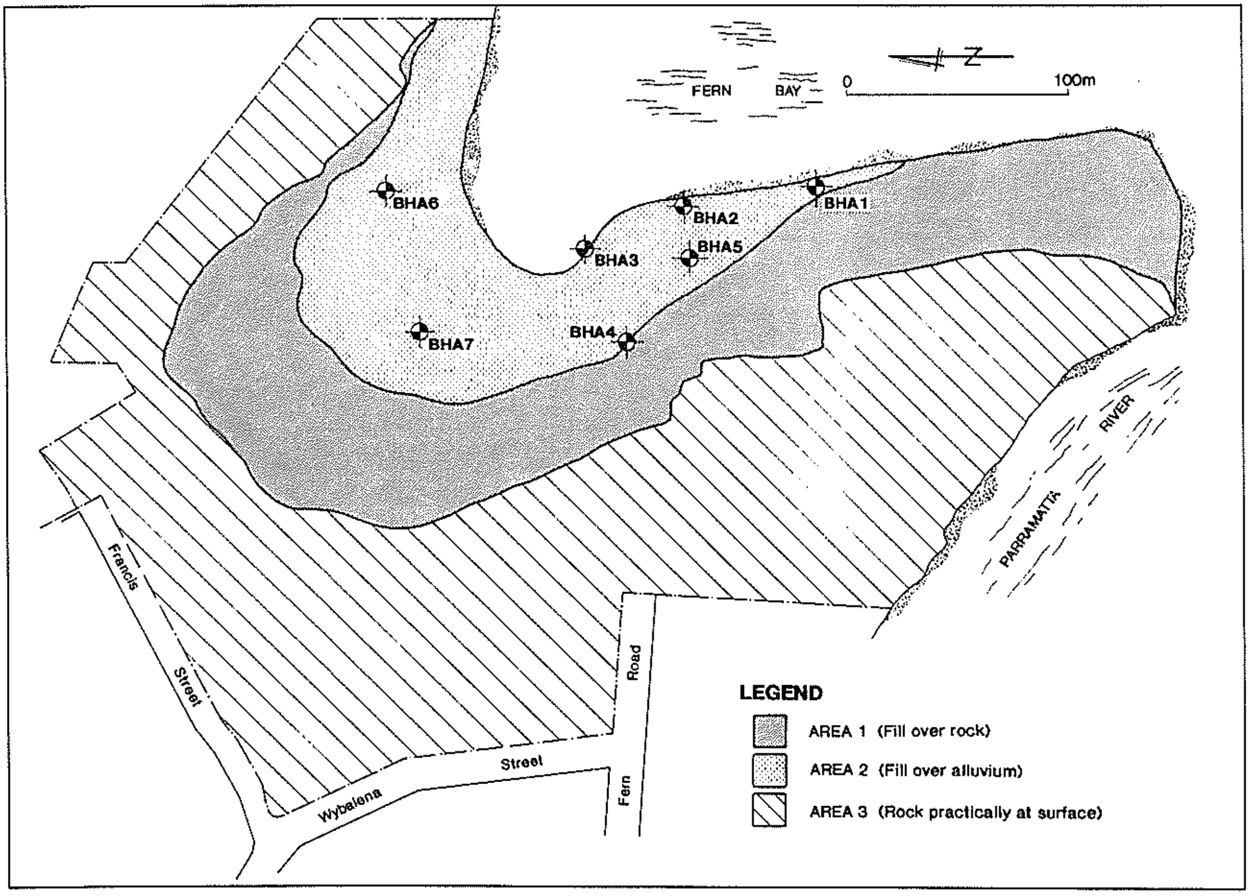
SUMMARY Settlements of alluvial sands on a site in Sydney were predicted using an elastic method. Moduli were determined from standard penetration test blow counts. Rather than use published correlations, a limited number of in situ screw plate tests were undertaken at depth in a borehole to relate elastic modulus to blow count. Settlements were monitored as construction proceeded and were found to be in good agreement with predictions.

1. INTRODUCTION

Located in Sydney's historic Hunters Hill, the 12 hectare Pulpit Point site (Fig. 1), formerly the Mobil Oil Terminal, is located partly on a sandstone peninsula extending into Sydney Harbour and partly on fill placed over alluvium. During 1990 it was developed as a residential estate of 132 luxury dwellings and 32 vacant blocks. In order to provide building platforms and access roads, considerable reshaping of the site was required.

Site investigations, mainly in connection with environmental studies, had been undertaken at various times prior to development. The available information was correlated and additional investigation undertaken to determine the properties and thicknesses of the fill, alluvial and residual soils found





over the lower areas of the site, as well as depth to bedrock and its strength.

Over 2 m of new fill was placed over old fill and alluvium in one part of the site (Area 2 on Fig. 2), to provide a level platform for the construction of a community centre and an open area. The community centre was one of the few light weight, single storey buildings on site and high level foundations were preferred. However, because of the variation of rock level around the site, it was also one of the few buildings to be constructed over as much as 15 m of alluvium. A prediction of alluvium settlement was required for foundation design and to determine the effect on services.

Considerable scatter of site data and lack of precise methods for estimating settlements of a thick layer of compressible material made selection of shallow footings for an extensive single storey building too large a risk to take. To improve the accuracy of settlement predictions and reduce the risk inherent in selecting high level foundations, a small number of in situ screw plate tests were correlated with SPT data. The resulting Young's moduli were higher than would otherwise have been adopted and were shown to be appropriate by monitoring settlements of a trial fill.

2. SITE HISTORY

Prior to the current development, Pulpit Point was a major local centre for petroleum and associated products. Significant changes to the natural landscape had taken place to allow for the positioning of large chemical and oil storage tanks. A wide flat area fronting Fern Bay had been created by cut and fill in the sandstone bedrock and reclaiming some of the harbour by the placement of fill over alluvium.

Over a long period of time small amounts of leakage and spillage of petrochemicals had led to pollution of the fill and upper alluvial soils on the site. A total cleanup was undertaken involving the removal of large volumes of polluted soils and their replacement with clean fill.

3. SITE INVESTIGATION

A site investigation was carried out comprising 7 boreholes (Fig. 2) in addition to earlier holes that had been drilled prior to the cleanup operations.

Apart from defining the variable succession of fill, alluvium and rock on the site, one of the main aims of the investigation was to predict settlements in Area 2. The method adopted was to drill several boreholes and carry out in situ testing and sampling at regular intervals. Screw plate tests were performed in one borehole selected to be typical of the area, in order to correlate standard penetration test (SPT) results with in situ Young's modulus.

4. CORRELATION OF IN SITU TEST RESULTS

Fill, alluvial deposits and residual soil overlay rock at depths of up to 15 m.

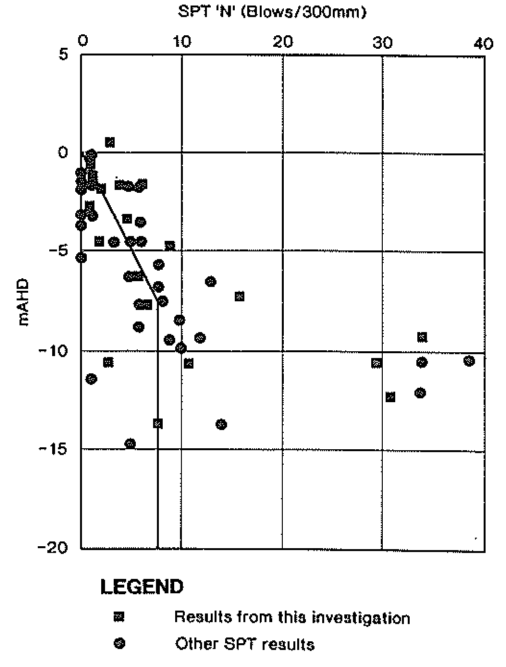
Due to the sandy nature of the alluvial and residual materials, SPTs were the main form of in situ testing. Results are shown plotted against depth on Figure 3. A general trend of linear increase with depth is apparent. It is noted that reported SPT results were not corrected for overburden pressure.

In addition, five screw plate tests were carried out at depths of 2.28, 2.52, 3.65, 6.47 and 8.0 m beneath the ground surface using the device described in Appendix A. The first two tests were found to have been carried out in fill, so the results were ignored for the purposes of correlation.

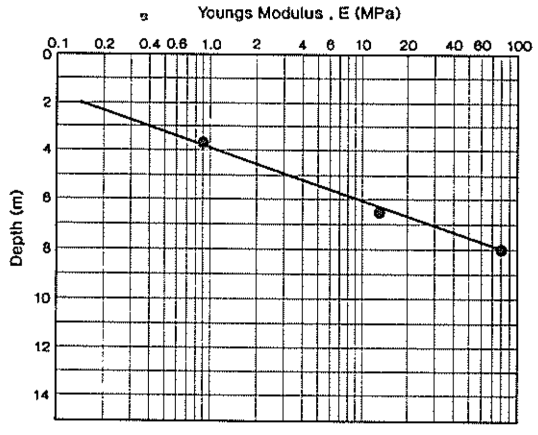
The values of Young's modulus calculated from the three tests in alluvium were 0.9, 13.5 and 79.1 MPa respectively. These results are plotted against depth on Figure 4 with the curve showing the assumed form of variation of modulus between the measurement points.

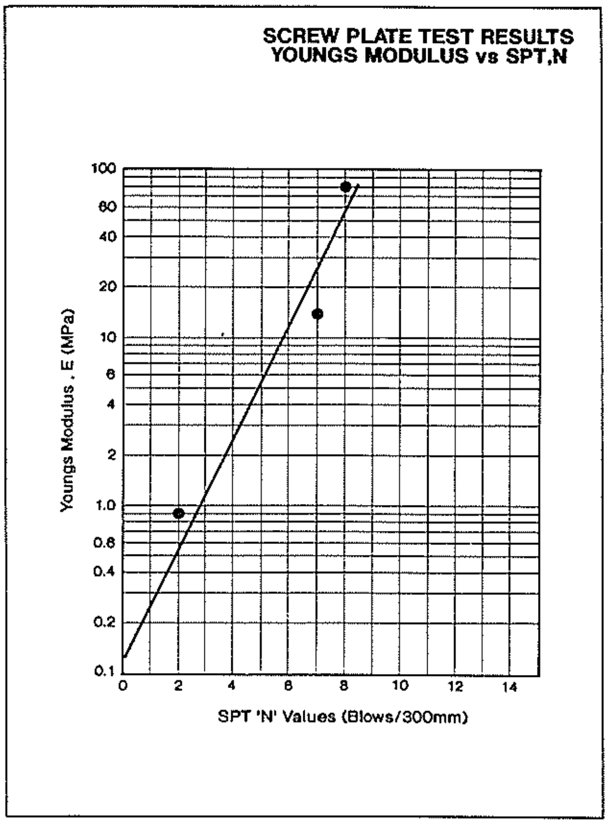
To make more general use of the values of modulus from the screw plate tests, they were correlated directly against the

SPT RESULTS



**SCREW PLATE TEST RESULTS
YOUNGS MODULUS v DEPTH**





SPT N values from a borehole 2 m away, to produce the curve of SPT versus modulus (Fig. 5). To smooth scatter in the data a design line, as shown on Figure 3, was adopted to represent the N values in the alluvium.

It will be noted that young's modulus increases rapidly with SPT blow count in a non-linear fashion. This was an unexpected result.

5. SETTLEMENT ASSESSMENT

Surface settlements were determined under the applied fill load using OASYS computer program VDISP. This allows horizontal soil layers with a varing soil modulus to be analysed using a Mindlin's approach. Individual settlement predictions were made at different locations by calculating the central settlement of a 50 m square loaded area.

6. MEASURED SETTLEMENTS

Following the site cleanup, a total of 25 settlement plates were placed on top of the alluvium throughout the area where large settlements were expected. This number of plates was installed because it was expected that a percentage would be damaged during the earthworks. Clean fill was subsequently placed on the site to depths up to 3 m and level readings on the settlement plates were taken weekly. Of the total of 25, only eight plates appeared to be undamaged by the time filling was complete. The measured and predicted settlements on these eight plates are compared on Table 1. Settlements appeared to be virtually instantaneous.

On the whole predicted settlements were very close to the observed actual settlements. Significant over-prediction of settlements only occurred in the case of Settlement Plates 10 and 12. A possible explanation for these differences could be an over-estimation of the depth to rock for the calculations as the depth to rock was interpolated from the widely separated borehole information. The only under-prediction was for Plate 14 and amounted to about 5%.

TABLE I
COMPARISON OF MEASURED AND PREDICTED SETTLEMENTS

Settlement Plate	Measured Settlement	Predicted Settlement
	mm	mm
7	105	110
10	65	100
12	80	130
14	190	180
15	165	180
16	150	155
19	100	110
20	100	100

7. CONCLUSION

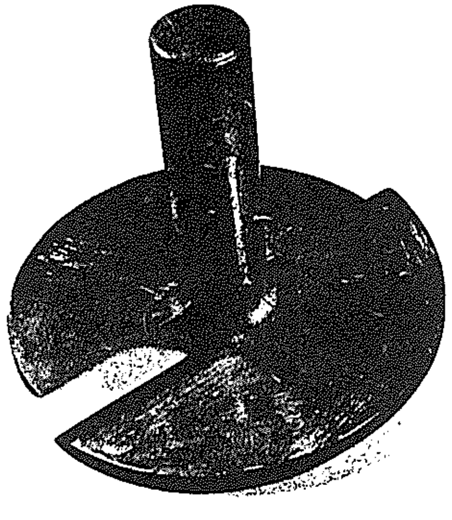
The comparison of predicted and measured settlements using a site investigation which consists of a large number of economical standard penetration tests, combined with a small number of in situ screw plate tests to "calibrate" the conversion of SPT results to values of modulus, is a very cost efficient method' for enabling settlement predictions of satisfactory accuracy. This enables the accuracy of settlement predictions to be improved markedly and the level of risk reduced.

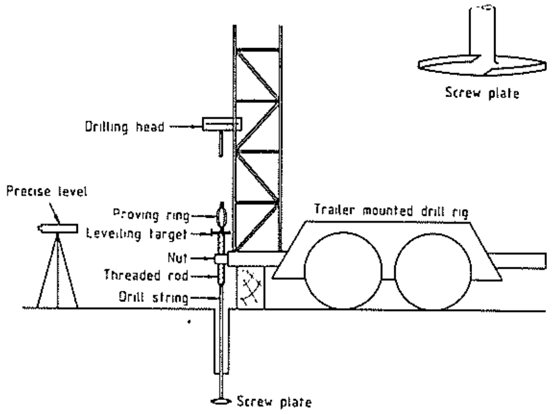
In this particular case Young's modulus have a non-linear relationship to SPT blow count, but the measured settlements appear to justify its adoption. This may not be a general rule and it is recommended that the relationship sould not be used for other sites.

APPENDIX A

Screw Plate Tests

The screw plate test is a means of carrying out an in situ determination of soil compressibility in a borehole to large depths. The screw plate used consists of two half flights of a helix, with the two cutting edges at the same level, and is shown in Figure 6 (photo) and the inset in Figure 7 (drawing of drill rig). Two cutting





edges are used in order to avoid the unbalanced torque from one cutting edge which tends to make the screw plate wander during insertion. The screw plate is 100 mm diameter, 5.5 mm thick and has a pitch of 20 mm per revolution.

Insertion of the screw plate is controlled by a threaded rod whose pitch is also 20 mm per revolution, which forces the screw plate to enter the soil at exactly the pitch of the helix, and so ensures good contact between the plate and soil.

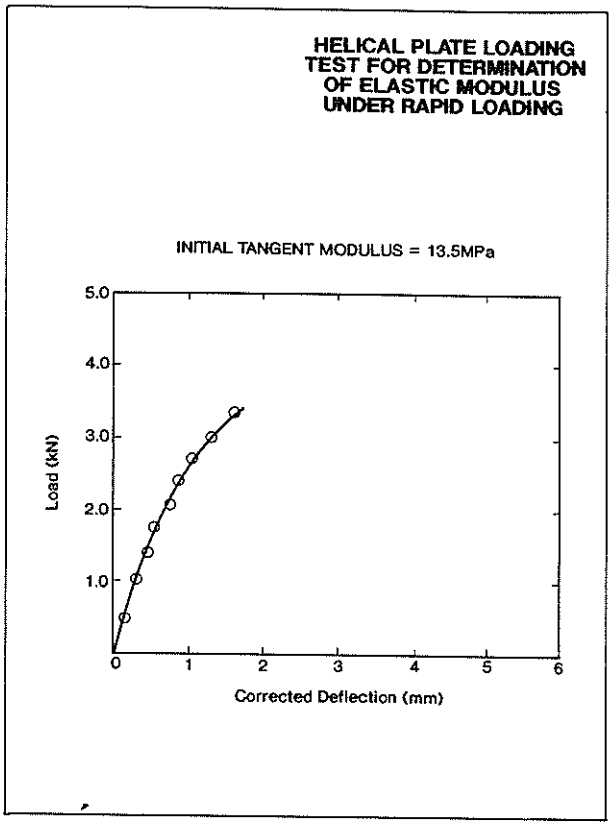
Test Procedure

A mud-filled hole of 120 mm diameter is first drilled to a depth about 200 mm less than the depth at which it was intended to carry out the test. Then the drill bit is withdrawn and the screw plate is attached to the end of the drill string, and lowered to the bottom of the hole. The threaded rod is attached to the top of the drill string, and the nut on the threaded rod is bolted onto the drill rig. Then the threaded rod is rotated through ten revolutions to bring the screw plate 200 mm below the bottom of the hole, unless the torque required for insertion reached 5 kg/m in which case insertion is discontinued in order to avoid the possibiliy of damage to the screw plate by excessive bending.

The nut on the threaded rod is then detached from the drill rig and consequently the weight of the drill string is applied to the screw plate. The proving ring and levelling target shown in Figure 7 are attached to the top of the drill string and load increments are applied by the drilling head using the hydraulic system of the drill rig, and measured by means of the proving ring. Displacements are measured by means of a precise level to an accuracy of a few hundredths of a millimetre, using a level placed about 4 m from the borehole in order to minimise interaction of the loading system with the displacement measurement system. A minimum of four load increments are applied in order to demonstrate by their consistency that the measurements are satisfactory. A typical load displacement curve is shown in Figure 8.

Interpretation

The interpretation of the measurements involves correction of the displacement readings for the axial shortening of the drill rods, which had been determined by laboratory compression tests on the rods. Correction for bending of the screw plate is made possible by the results of a finite element analysis. The corrected displacement is then substituted in the equation



$$\frac{wE}{pa} = \frac{\pi(3-4\nu)(1+\nu)}{16(1-\nu)}$$

derived by Collins (1962), for a rigid circular plate in full bonded contact with the soil, where w is the displacement, E is the Young's modulus, p is the average loading pressure applied to the plate, a is the radius of the plate and ν is the Poisson's ratio of the soil.

REFERENCE

Collins, W.D. (1962). Some Axially Symetric Stress Distributions in Elastic Solids Containing Penny Shaped Cracks. I. Cracks in an Inifinite Solid and a Thick Plate. Proc. of the Royal Society, Series A, Volume 203, pp. 359 - 386.