Evaluation of Tertiary Age Gravel Deposits Using Plate Load Tests

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SUMMARY Plate load testing has been carried out to assess settlement characteristics of a gravel deposit present beneath the footings of an existing buidling. Applied stresses of up to 1500 kPa were applied, with Youngs Moduli of in excess of 300 MPa measured. As a result of these tests, settlements due to increased footing loads resulting from refurbishment of the building could be confidently predicted.

1. INTRODUCTION

Planning for refurbishment of an eight storey building, with a single basement level, indicated the applied loads on the existing footings would increase by up to about 30 percent. The resulting applied bearing pressure would exceed the design value adopted when the building was constructed. As a consequence additional geotechnical investigations were undertaken.

The original foundation investigation for the building indicated that its footings would be expected to found on weathered siltstone. However, the subsequent investigation undertaken for the refurbishment showed that some footings were founded on several metres of gravelly soil. The response of these soils under the increased loads was uncertain and further more detailed testing was ordered.

Plate load testing was considered to be the most appropriate method of assessing the deformation properties of the gravelly soils. These tests were performed at several locations within the basement of the building and the test results were used to evaluate the strength and Youngs Modulus of the gravelly soils.

It was concluded that the ultimate bearing capacity of the gravelly soil was in excess of the maximum pressure of 1500 kPa applied during the plate load tests. For estimating the likely settlement of the footings under the effect of the proposed increase in loads, a design Youngs Modulus of 300 MPa was adopted for both the gravelly soil and the weathered siltstone.

2. STRUCTURAL CONSIDERATIONS

The existing building is an eight storey reinforced concrete structure with a single basement level. The columns are located on an 8.5 m by 8.5 m grid, and are supported on pad footings and an edge beam. The pad footings are typically about three metres square and are founded about 1.3 m below the basement floor slab.

The footings were designed using an allowable bearing pressure of 500 kPa for pad footings and 400 kPa for strip footings, when founded on highly weathered siltstone. The bearing pressures imposed by the footings, under the original building loads, were estimated to be in the range of 360 kPa to 470 kPa. After the refurbishment the imposed bearing pressures are expected to be in the range of 420 kPa to 625 kPa. The highest pressure is 25% above the previous design allowable bearing pressure. The increased footings loads were expected to cause settlement of the affected footings, resulting in differential settlement between these footings and other footings not subjected to an increase in load. This differential settlement would impose additional movements and shears in the existing superstructure, the magnitude of which would be dependent on the magnitude of the settlements. It therefore was important the settlement characteristics of the founding soils were established.

3. FOUNDATION INVESTIGATION

The foundation investigation performed before construction of the building involved drilling of four boreholes to depths ranging from 7.3 m to 12.5 m below street level. The locations of these boreholes is shown on Figure 1. The boreholes were advanced by continuous flight solid augers through the soils, and by continuous diamond coring through the weathered rock. Standard penetration tests were performed in the soils.

The subsequent investigation for the refurbishment involved drilling of nine boreholes, and the excavation of four test pits, through the basement floor slab. The locations of these boreholes and the test pits are also shown in Figure 1.

The boreholes were advanced to depths ranging from 1.55 to 7.65 m below the basement floor level, which is about 3 m below street level. It was expected from the design drawings that all footings would be founded on weathered siltstone, with the difference in depth between the design and actual founding levels made up in low strength concrete. Consequently, continuous coring was adopted as the drilling method. The first three boreholes were drilled through the footings, and revealed that at these locations the footings were founded on clayey gravels and gravelly clays. Other drilling methods were then attempted, but it was not possible to obtain undisturbed samples of these materials, or to evaluate their strength by downhole testing. Core recovery in the underlying variably weathered mudstone was also difficult due to the highly fractured nature of this rock. Varying thicknesses (up to four metres) of clayey gravels and gravelly clays were encountered in four of the other six boreholes, which were drilled through the basement floor slab. It therefore was unclear how many of the footings were founding on mudstone and how many on these soils.

Four test pits were then excavated to obtain a better assessment of the clayey gravels and gravelly clays, than was possible from the boreholes. The pits were excavated adjacent to pad or strip footings, at the locations shown in Figure 1, to establish the founding depth of the footings.

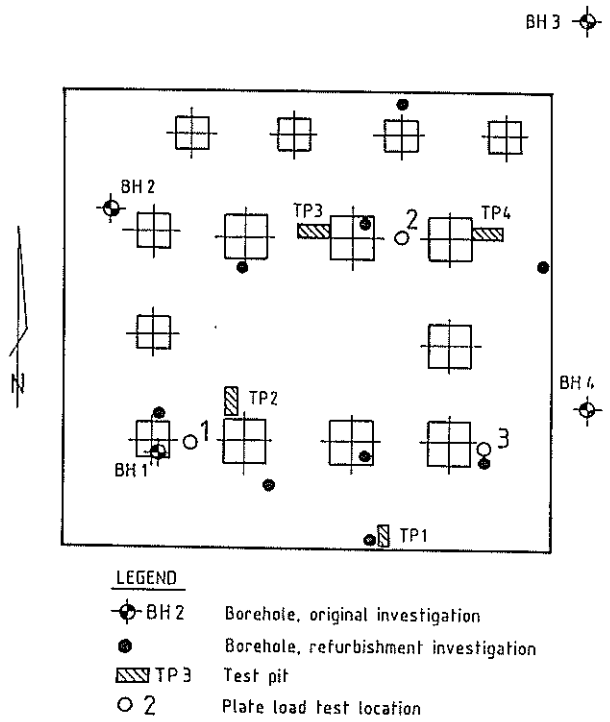

Figure 1 Site Plan

4. FOUNDATION CONDITIONS

The sequence encountered below the basement floor slab generally consisted of a minor thickness of fill immediately below the slab, over dense clayey sand, and clayey gravel, or very stiff and hard gravelly clay, overlying extremely weathered and highly weathered mudstone. The depth to the mudstone ranged from zero to 5.7 m below the basement floor level. The depth was generally greater along the north south axis of the building reducing to zero along the eastern and western sides of the building.

The geological mapsheet of the area indicates that the general area of the site is located on Silurian Age sedimentary rock, consisting of calcareous shale, limestone, sandstone and tuff. This is overlain in parts by Tertiary age gravels and sands. The soil and rock encountered in the boreholes was consistent with the geological map indications.

The footings were exposed to the founding level in three of the test pits. The strip footing exposed in Test Pit 1 was founded on clayey gravel at a depth of 1.25 m below the basement floor level. The pad footing in Test Pit 2 was founded on extremely weathered mudstone at a depth of 1.25 m, and the pad footing in Test Pit 3 was founded on gravelly clay at a depth of 1.30 m. It was not possible to obtain undisturbed samples of these founding materials using conventional sampling methods, and hence it was not possible to evaluate the strength or compressiblity of these materials by laboratory testing. In-situ testing within the boreholes using a pressuremeter also was not possible, as the boreholes could not be drilled in the gravelly materials to the close tolerances necessary for pressuremeter testing. Hence it was concluded that the only practical means of quantitatively evaluating the strength and compressiblity of the gravelly soils was by plate load testing in the bottom of the test pits.

5. METHOD OF PLATE LOAD TESTING

When planning the plate load testing it was considered that the tests should be carried out up to a pressure equal to three times the original design bearing pressure of 500 kPa to allow a check on whether a factor of safety of 3 on bearing capacity was exceeded. A loading system capable of allowing an applied pressure of 1500 kPa on a 500 mm diameter plate was therefore proposed. This also allowed the pressure-displacement behaviour of the founding soils to be monitored well beyond the planned increase in applied bearing pressure.

Three test locations were selected, based upon the variability in the founding conditions observed during the geotechnical investigation. The test locations are shown on Figure 1. The basis for selecting these locations was:-

- Test Location 1
  Extremely to highly weathered mudstone present at founding depth. Footing response on this material expected to be different to that on gravels. Desirable to have data on the deformation characteristics of the mudstone, to allow size effects to be considered when extrapolating from the 500 mm dia. plate to the prototype footings (up to 3.3 m square). Testing carried out at founding level, 1.35 metres below existing basement floor level.

- Test Location 2
  Founding soils predominantly gravelly clay/clayey gravel. Testing of this material at both founding level and at about two metres depth carried out. Tests at two levels proposed to allow any marked change in property with increasing depth to be observed, and therefore included in the subsequent analysis.

- Test Location 3
  The borehole near this test location indicated sandy clay soil present at founding depth. As this material was judged likely to have differing engineering properties to the gravelly clay it was considered prudent to test this material also. Testing at two levels, as for Test Location 2 was carried out.

Space restrictions within the basement precluded providing the required 300 kN reaction with kentledge, and ground anchors would have been difficult to install with the available headspace. It therefore was decided to use the existing building superstructure for reaction.

The design, fabrication and installation of the reaction system was arranged by the Structural Consultant. The adopted system comprised two 610UB101 beams spanning between column locations, then propped against the floor slab above, at the column location. The beams were supported about 600 mm above basement floor level, and a jacking column then suspended from beneath these beams, and extending down to the level of the top of the proposed jack. This arrangement is schematically shown on Figure 2.

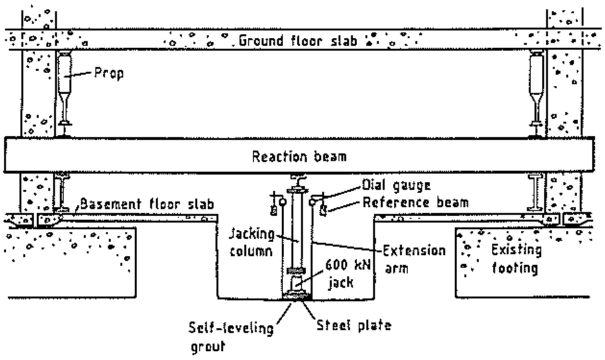

Figure 2 Plate Load Testing Arrangement

Three 25 mm thick steel plates were used to transfer the load to the soil. These plates were successively 500, 400 and 300 mm in diameter. Where necessary a 175 mm diameter spacer plate was also used.

Prior to assembling the test plates and jack, the test area surface was excavated to the required depth and made as level as practical. To provide a smooth and level surface on which to seat the 500 mm diameter plate, a thin layer of self levelling grout, 505 mm in diameter, was cast on the ground surface and allowed to harden prior to the test being carried out. The use of this self levelling grout proved to be extremely convenient, and allowed the subsequent testing to be successfully carried out without apparent seating errors. The grout used was HILTI CA1c80F, a fast setting two part epoxy. However, in the cool temperature prevailing in the basement of the building, the grout still had to be warmed by radiators and blow heaters to accelerate the setting. Up to about 4 hours was required. However, the resulting prepared surface was smooth and flat, making subsequent set up of the testing equipment relatively easy.

Vertical displacement during loading was measured by dial indicator gauges, mounted on simply supported timber reference beams, 3.6 m long. Measurement was made at four locations equally spaced around the lowest plate. To facilitate measurement at floor surface level extension rods were mounted the plate. Figure 2 also shows this arrangement.

The loading sequence adopted for the tests was as follows.

Load Cycle 1:- 0 to 165 kPa to 0. Assumed to be a seating cycle, with zero displacement for the test taken as that on completion of this cycle.

Load Cycle 2:- 0 to 500 kPa to 165 kPa. This was intended to simulate the initial loading of the building footings. The applied pressure of 500 kPa held for 10 minutes to observe any creep.

Load Cycle 3:- 165 kPa to 665 kPa to 165 kPa. This provided data on the anticipated response of the footings under increased load. The applied pressure of 665 kPa was held for 30 minutes and creep settlement observed.

Load Cycle 4:- 165 kPa to 1500 kPa to 165 kPa. To obtain the pressure-displacement behaviour beyond the anticipated design pressure and to allow an assessment of the available bearing capacity of the materials being tested.

During each load cycle, the pressures were incrementally applied using a calibrated hand operated jack.

6. TEST RESULTS

The results of the tests are summarised in Table 1, with the results of tests 2A and 2B also presented graphically as Figure 3. These two test results are typical of the other three, and illustrate how the use of the high strength self levelling grout almost eliminated seating effects.

Upon completion of each test, a sample of the material from immediately beneath the test location was taken. The results of laboratory index testing carried out on thee samples are presented in Table 2.

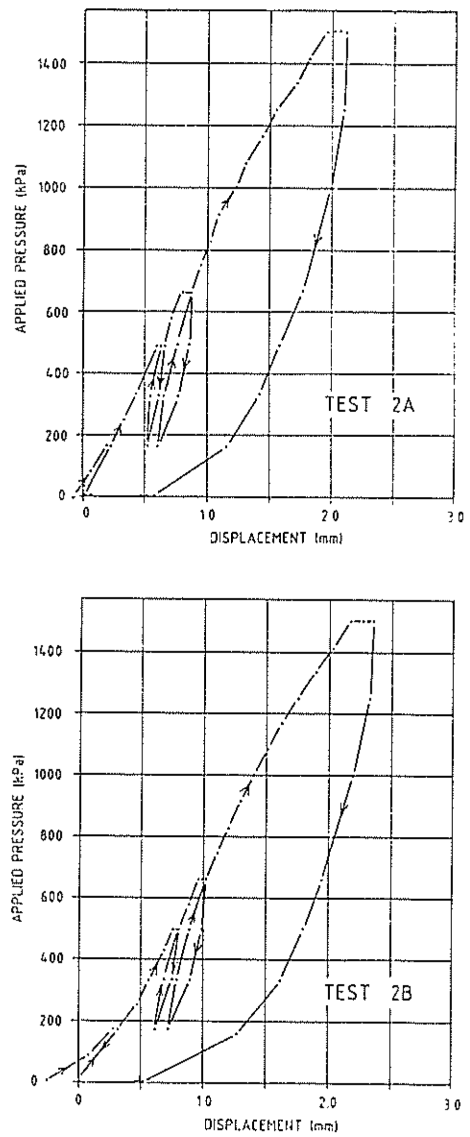

Figure 3 Pressure-Displacement Response

TABLE 1

RESULTS OF PLATE LOAD TESTS

Test No.	1	2A	2B	3A	3B
Depth below basement floor (m)	1.38	1.37	2.01	1.36	2.02
Initial Displacement at 500 kPa (mm)	0.50	0.60	0.78	0.84	0.72
665 kPa (mm)	0.70	0.82	0.98	1.05	0.85
1500 kPa (mm)	1.76	1.97	2.16	2.34	1.93
Creep over 30 mins @ 665 kPa (mm)	0.08	0.05	0.05	0.05	0.01
Creep over 10 mins @ 1500 kPa (mm)	0.13	0.15	0.18	0.16	0.16

TABLE 2

LABORATORY TEST RESULTS

Test No.	1	2A	2B	3A	3B
Particle Size					
% passing 75 mm	-	94	100	100	100
% passing 19 mm	-	59	90	91	99
% passing 2.36 mm	-	34	77	50	93
% passing 75 μm	-	22	17	12	18
Atterberg Limits					
Liquid Limit	-	34	40	36	31
Plasticity Index	-	18	25	20	17
Moisture Content	17.4	9.4	9.5	8.8	8.6
Material Classification	HW Siltstone	Clayey Gravel (GC)	Clayey Gravelly Sand (SC)	Clayey Sandy Gravel (GC)	Clayey Sand (SC)

These test data have been used to calculate the Youngs Modulus of the founding materials, assuming a rigid circular plate acting on the surface of a semi-infinite elastic material of constant modulus (Perloff 1975). However, the plate load testing was actually performed within a pit, about 1.5 m wide, rather than on the surface. Approximate solutions for circular plates acting below the surface (Pells, 1983), indicate that the "true" Youngs Modulus is unlikely to differ by more than 10 per cent from the values calculated by the adopted method.

The Youngs Modulus calculated for several of the load cycles in each of the tests, and over pressure ranges relevant to the building performance, are presented in Table 3.

To check on long term creep effects, the displacement observed whilst the applied pressure was held constant for 30 minutes at 665 kPa was plotted against log of time, a common means of evaluating creep. For the tests carried out, the creep rate with respect to log of time was found to be decreasing and after about 15 minutes creep had virtually ceased. It therefore was concluded long term creep effects will be small and can be satisfactorily accounted for by adoption of secant modulus values.

TABLE 3

YOUNG'S MODULUS VALUES

Load Cycle	Pressure Range (kPa)	Youngs Modulus (MPa)				
		Test 1	Test 2A	Test 2B	Test 3A	Test 3B
2	165-500	360	315	285	250	320
3	165-500	1530	875	585	645	585
3+	500-665	560	360	380	380	470
3*	500-665	320	280	290	290	470
4	330-665	875	535	510	470	525

\+ Initial loading modulus value
* Secant Modulus value

7. ESTIMATE OF FOOTING SETTLEMENT

Each of the tests indicated similar deformation properties for the various materials tested. The test results also indicated the ultimate bearing capacity of the soils and weathered rock encountered at this site appears to be well in excess of 1500 kPa for the adopted 500 mm dia. loaded area.

Direct application of the results of the plate load tests to an elastic analysis of predicted footing movement was considered appropriate. For design purposes, a Youngs Modulus of 300 MPa was adopted, and considered to be uniform with depth. Using his value, it was predicted the maximum likely additional settlement of any footing under the refurbishment loads would be about 2 mm.

Because this predicted settlement was small, no attempt was made to refine the estimate to allow for probable increased stiffness with depth, due to reduced weathering of the basement rock.

8. CONCLUSIONS

Investigation of gravelly soils to obtain strength and compressibility data is difficult using routinely adopted methods of investigation. As a consequence, conservative bearing values and estimates of settlement are frequently recommended. At this site it was necessary to be able to predict with confidence the likely settlement under planned increased in load of existing footings founded on up to several metres of predominantly gravelly soil.

Plate load testing was successfully used to obtain deformation properties of these gravelly soils. This testing had to be performed within the existing basement of the building and using relatively high applied loads. The use of the existing building as reaction for the test, and the use of the fast setting self levelling grout to prepare the test surface, are considered to have been significant factors in allowing the tests to be successfully performed.

The tests showed the Tertiary Age gravel deposits present at the site are of low compressiblity, similar to that of highly weathered siltstone.

REFERENCES

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