

PREDICTION STUDY — ROCK SOCKETED PILES

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SYNOPSIS

Telecom Plaza, a multi-storey building in central Sydney, is supported on large diameter bored piles. The piles, carrying loads of up to 24,000 kN, were drilled through weak sandstone (Mittagong Formation) and founded on or socketed into strong sandstone (Hawkesbury). Two of the piles were instrumented to measure settlement and load transfer. Participants were asked to predict pile settlements and distribution of load down the shaft.

1. INTRODUCTION

Telecom Plaza is a 35 storey building in Pitt Street, Sydney, which differs from most similar structures in that it has no basement construction. The presence of major cable tunnels traversing the site necessitated the use of piles located between and around them. Large diameter bored piles were used, socketed into the underlying sandstone. During the construction, the opportunity was taken to instrument two of the more heavily loaded piles (each in a 2 pile group) to measure settlement and load transfer.

Participants in the prediction exercise were provided with the site investigation data and asked to predict:

- . settlement at the top of the pile - in mm/MN.
- . distribution of load down the pile shaft - as the proportion of total loading in the pile at varying depths.

2. SITE INVESTIGATION

The site investigation for the building comprised cored boreholes to depths of up to 25 m at all of the major column locations.

Relatively uniform conditions were encountered, and the conditions at the piles under consideration were:

- 0 m - 5 m Clay and ironstone - medium strong red and brown ironstone with interbedded clay.
- 5 m - 13.4 m Mittagong Formation - weak to medium strong fractured to slightly fractured brown and grey sandstone with bands of extremely weak and very weak rock.
- 13.4 m - Hawkesbury Sandstone - medium strong to strong slightly fractured light grey medium grained sandstone.

The interface between the Mittagong and Hawkesbury Sandstones was clearly defined by a 0.2 - 0.3 m weak shale zone immediately above the Hawkesbury Sandstone. The ground water table level was at about this level.

Rock strength tests were made on core samples in both unconfined compression and using the point load strength test. The results of all tests are plotted in Fig. 1, with differing scales assuming $UCS = 20 I_s(50)$.

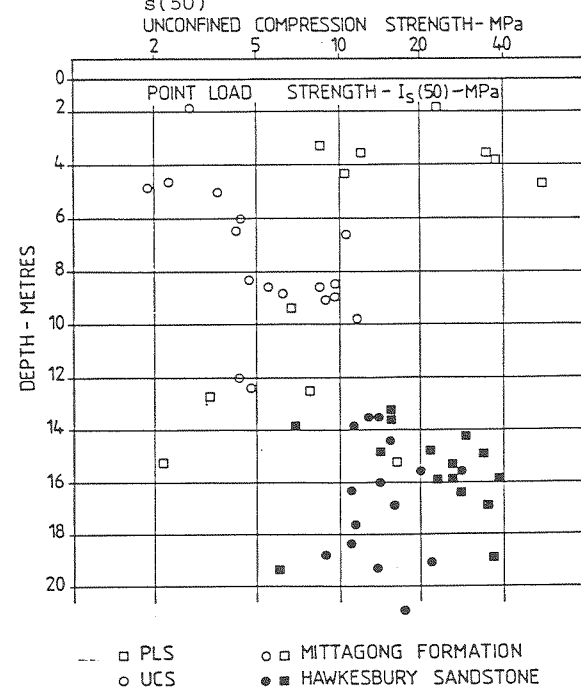


Figure 1. Rock Strength Test Results

3. PILE DESIGN AND CONSTRUCTION

The piles were designed to carry unit loads of up to 24 MN. 1500 mm diameter bored piles were adopted and the following design parameters used:

- Shaft adhesion in upper clay - 0 - 4 m 0
- Shaft adhesion in Mittagong Formation 220 kPa
- Shaft adhesion in Hawkesbury Sandstone 600 kPa
- End bearing pressure in Hawkesbury Sandstone 6000 kPa

For most of the piles in the project (which were generally less heavily loaded than indicated above) sufficient capacity was achieved by carrying the 1500 mm diameter pile just to the surface of the Hawkesbury Sandstone. For the

more heavily loaded piles, a socket of 1 - 3 m was extended into the sandstone.

The piles were constructed by Frankipile Australia Pty. Ltd., with drilling accomplished using a Soilmech drilling rig, mounted on an Atlas 35 tonne crane. Only a very slow rate of progress was achieved in the Hawkesbury Sandstone, generally around 0.5 m/hour. After drilling, a temporary liner was installed to a depth of about 5 m and hand cleaning of the pile walls and face was carried out. The walls were sprayed by a high pressure hose so as to remove most of the cuttings adhering to the walls. No special procedures or equipment were used to roughen the pile socket. Pile bases were cleaned by hand methods and concrete was placed through a central delivery tube.

The two piles which were instrumented were each part of a 2 pile group at 1.9 m centres, with the cut-off at a depth of about 2.3 m and the pile toe at a depth of 16.2 m, 2.6 m into the Hawkesbury Sandstone. The reinforcement steel comprised 0.9% of the cross-sectional area for the first 6 m, and 0.46% thereafter.

4. INSTRUMENTATION

The instrumentation comprised:

- Concrete embedment strain gauges - types Kyoma KM120-H2-11 and TML PML-60. Because of the potential construction difficulties and the risk of damage to gauges affixed to the reinforcement cage, the use of concrete embedment strain gauges was considered to be the lowest risk approach. They were lowered and placed in the concrete at varying levels after it had been placed. Gauges were also placed in the concrete above the pile cap as it was poured.
- Telltals - these comprised a sleeved rod which was fixed to the casing at the lower end. These were installed within the reinforcement cage and taken to depths of 5, 10 and 17 m. A reference measurement was obtained by providing a 50 mm diameter casing through the pile and subsequently drilling to depth of 8 m below the pile toe to install rod which was grouted into the sandstone at that level.

Measurements of the strain gauges were made using a Wheatstone bridge. Measurements of relative deflections on the telltals were made by using a comparator dial gauge on the head of the pile.

Measurements were taken at intervals as building construction progressed.

5. PREDICTIONS

Predictions of performance were made by eight participants and a variety of methods of analysis was indicated. These ranged from "crystal ball" by two eminent members of the "Department of Parapsychology" of the University of W.A. to: "Elastic continuum analysis via programme Tapile, with allowance for pile soil slip", by the joint author of a well known text book on pile design. The latter estimated "soil" modulus as $175 \times q_u$, pile modulus as 33,000 MPa, skin friction values of 100 - 200 kPa in ironstone, 400 kPa in Mittagong and 1000 kPa in Hawkesbury.

Predicted settlements from the participants ranged from 0.17 to 0.65 mm/MN.

The range of predictions of settlement response and load distribution are given in Figs. 2 & 3.

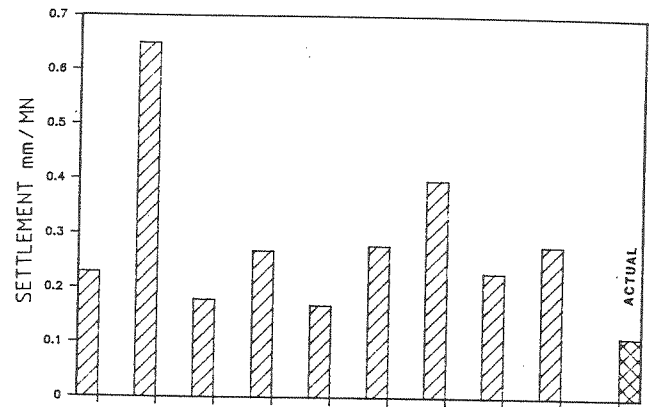


Figure 2. Predictions of Settlement

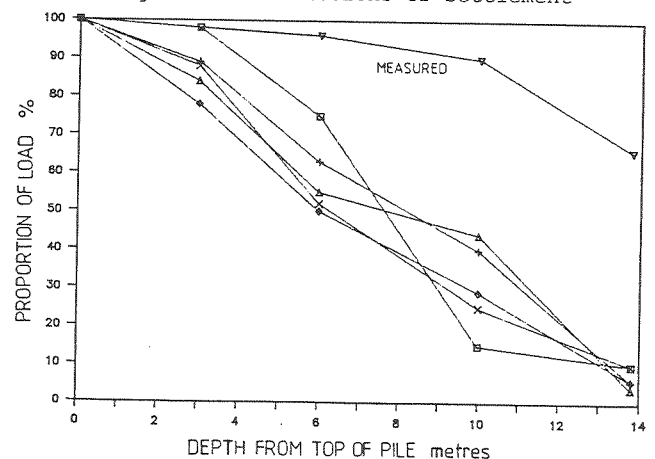


Figure 3. Load Distribution on Shaft

6. SITE MEASUREMENTS

As is common to all attempts to measure performance during construction, there were several significant problems:

- One of the piles was located substantially out of planned position, resulting in unequal distribution of load in the 2 pile group, the need for a massive rectifying beam, and an increase of around 20% in the load in the pile.
- Apart from the normal hassles in working on a busy and constricted building site, all of the strain gauge leads were cut off at one stage.
- The strain gauges appeared to work satisfactorily for about one-third of the building period, after which most of them gave nonsense results, due apparently to some form of "aging".
- The telltals performed satisfactorily but actual deflections were somewhat lower than anticipated, with the result that temperature movements (affected by heat of hydration) may have been of sufficient magnitude to have influenced the early measurements.

After consideration of all results, it was concluded that the overall measurements of pile head settlement (as assessed by the telltale measurements) were reasonably reliable, with a potential experimental error of $\pm 15\%$. Due to failure of the strain gauges, the load had to be assessed from the structural engineer's calculations.

The average result of the two piles indicated a deflection response, which was approximately linear, of 0.12 mm/MN.

From the results of the early strain gauges and from attempted integration of the telltale results, it has not been possible to determine load distribution with reasonable reliability. In Fig. 2 is shown the best estimate from the results obtained, but this does not fit with either the measured deflection or with anything like expected performance. The pile was substantially "stiffer" than would be expected if all of the load was transferred to the base. Thus, a substantial proportion of the load must have been transferred over the shaft length.

7. DISCUSSION

Whilst it is at least comforting to note that all predictors favoured the conservative side, it is also disturbing to note the relatively wide discrepancies, very much greater than occurred in say the pile prediction exercise, where a large number of results were within 25%.

It is considered that the reasons for the discrepancy were almost certainly in regard to the modulus values selected, rather than in the theoretical approach adopted.

Recently published information (Pells, 1985) relates secant modulus to uniaxial strength for Sydney Sandstones. The ratio ranges from about 90 for low strength rock (around 10 MPa) to about 200 for medium strength (around 50 MPa). These are for core samples, and some reduction would have to be applied to determine the bulk modulus, but it has also been shown (McMahon, 1980) that this reduction factor is very low in sandstone which is reasonably free of jointing.

Based on the measured rock strength and applying these values, leads to an in-situ modulus of around 500 MPa for the Mittagong rock and around 3000 MPa for the Hawkesbury Sandstone. These values are much higher than were used by most of the participants.

If the pile is analysed using Randolph's equation (Randolph, 1982), in which it is assumed that the modulus varies from 500 MPa at the top of the pile to 1000 MPa at the base of the pile and is thereafter 3500 MPa, the calculated pile settlement is 0.14 mm/MN, very close to the measured result.

8. CONCLUSIONS

1. All participants overestimated pile settlements, by a factor ranging from 150% to 550%. Although quite sophisticated analyses were carried out in some instances, it is suspected that the main problem was in the selection of data, with underestimation by quite a large amount of the modulus values.
2. The "Murphy" of measurements during construction struck again! Meaningful results could not be obtained (of load distribution) from strain gauging in the piles. Telltales through the piles however, proved a reliable means of measuring very small deformations.

Given that the "predictions" all overestimated the expected settlements, it is likely that the same predictors who are carrying out a "design" would introduce significant further conservatism. Thus, it is likely that current practice in design of large diameter bored piles is still overly conservative, notwithstanding recent attempts to modify practice.

9. ACKNOWLEDGEMENTS

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10. REFERENCES

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