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A Large Scale Cable Jacking Test for Rock Mass Modulus Measurement, Lucas Heights, Sydney

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Summary: A large scale rock mass modulus test was performed on the Hawkesbury Sandstone bedrock at the location of the Neutron Guide Hall at the Replacement Research Nuclear Reactor, Lucas Heights, Sydney. Extremely movement-sensitive instruments are to be used within the Guide Hall. The movement of these instruments was therefore dependent on the modulus of the foundation bedrock, in particular within an area where a geological fault extends through the site and where the sandstone bedrock is more weathered and possibly more compressible than the bedrock away from the fault. The purpose of the test was to measure the Young's Modulus of the rock in this area. A cable jacking test was performed comprising a 1.5 m diameter concrete loading "plate" and a short anchor designed so as to cause interaction between the surface load and the anchor zone.

INTRODUCTION

A research nuclear reactor is currently being constructed at Lucas Heights, Sydney, to replace the existing nuclear reactor which commenced operation in 1960. The new reactor is due to be completed in 2005. The foundation for the structure comprises Hawkesbury Sandstone bedrock.

Scientific experiments performed within the Neutron Guide Hall will involve the use of extremely movement-sensitive instruments. Also, heavy shields are to be manoeuvred around the instruments. Therefore there is the potential for the movement of the shields to disturb the instruments. The description of acceptable deflections was more complicated than for common structures, though one of the criteria limiting differential movement could be interpreted to equate to 0.05 mm over a metre.

Initial numerical modelling performed by others, based on conceptual load configurations, indicated that if the mass Young's Modulus of the foundation bedrock is greater than about 3000 MPa, then all that would be required is a concrete slab of nominal thickness over the bedrock. However, if the Young's Modulus were substantially less than about 3000 MPa then it would be extremely difficult to devise a foundation system to contain movements to the specified criteria. An initial assessment reported in Coffey (1999) suggested a mass modulus of 1000 MPa.

During excavation work, two very old, near vertical faults were encountered which ran through the Neutron Guide Hall. It happened that the faults were in the same position as that proposed for many of the sensitive instruments. The sandstone bedrock between and adjacent to the fault is slightly more weathered and possibly more compressible and of lower strength than the bedrock away from the fault, and it was considered that the modulus would probably be lower in this area than elsewhere beneath the building. The mass modulus test was located in the centre of the faulted zone, such that if the measured modulus was acceptable there, then the remainder of the Neutron Hall site (i.e. away from the fault) would be unlikely to pose a particular problem for foundation design.

The mass modulus of Hawkesbury Sandstone is a parameter seldom measured because even very conservative estimates of this parameter usually give rise to computed settlements and tilts well within the acceptable range for most structures.

The main difficulty in the assessment of mass modulus lies in the fact that the deformation behaviour of the rock mass is dominated by defects within in it. Small intact specimens of rock (termed the rock substance) will exhibit a significantly larger modulus than the overall rock mass. Any accurate measurement of the rock mass modulus needs to encompass a sufficiently large volume to include a representative proportion of defects.

The test described is a type of plate bearing test designed to provide a result representative of a large volume of rock (Pells, 1983). The force on the plate is provided by a cable anchored at shallow depth in the rock. The effect of the anchor being shallow is that the regions of stressed rock beneath the plate and around the anchor bond zone overlap, resulting in a single, large region of stressed rock. Extensometers are used to measure displacements within the rock mass, in addition to measurement of movement of the plate itself and adjacent ground surface. The special feature of the test undertaken at the Neutron Guide Hall is that very small movements had to be measured accurately to provide confident calculation of a relatively stiff rock mass.

GROUND CONDITIONS

Geotechnical investigation of the reactor site was performed by Coffey Geosciences Pty Ltd. The Hawkesbury Sandstone bedrock which underlies the Neutron Hall was generally classified as Class II/III Sandstone, with some minor Class IV Sandstone, in accordance with Pells et al (1998). Correlation of the rock substance modulus testing with point load strength index data reported in Coffey (2002) suggests the following relationship:

$$E = 4500 \text{ to } 6000 \, . \, I_{s(50)} \tag{1}$$

where E = Tangent Young's Modulus at 50% of ultimate strength (MPa)
$I_{s(50)}$ = Point load strength index (MPa)

The mass modulus test was located within the faulted zone, and six cored boreholes were drilled within a 1.7 m diameter circle (i.e. around the perimeter of the plate). The boreholes extended to depths ranging from 1.3 m to 8.3 m and were drilled with a "LTK56" single tube core barrel which produced 42 mm core and a 57 mm diameter borehole. No core loss was experienced in any of the holes. Closely spaced point load testing was performed on the recovered core, as shown in Figure 1.

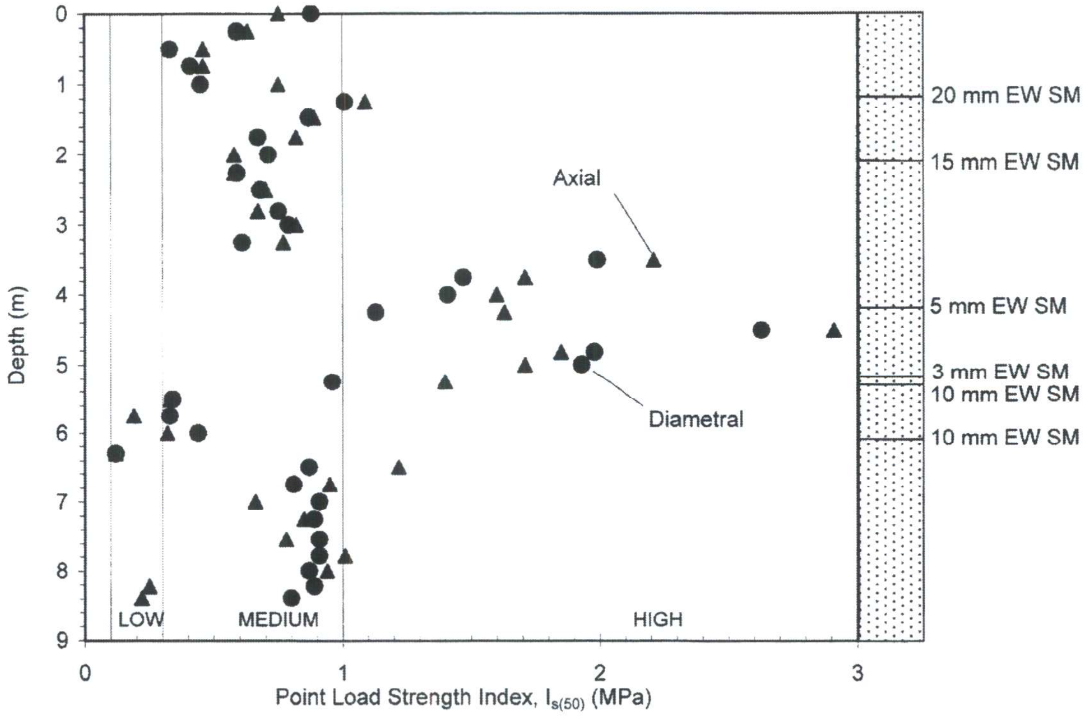

Figure 1. Summary of strength test results and major defects.

Application of the Pells et al (1998) classification system shows that in general the rock corresponds to Class II Sandstone, though the detailed test results shown in Figure 1 indicate that the strength criteria was not met for this Class within two zones, each of about 1 m thickness.

TEST COMPONENTS AND METHODOLOGY

The test was designed specifically to allow measurement of rock mass modulus up to a maximum value of 3000 MPa. Initial calculations showed that the maximum movement at a peak load of about 6000 kN would be at the plate itself and would be in the order of 0.9 mm, and would be significantly less at other measurement locations. Therefore the emphasis in designing the test was on achieving accurate deflection measurements as well as providing sufficient measurement data to achieve a high level of redundancy.

The test layout is shown in Figure 2.

Prior to setting up the test the sandstone bedrock at slab founding level was carefully trimmed. The anchor and extensometer holes were then drilled to the required depths. Details of the test components are described in the following sections.

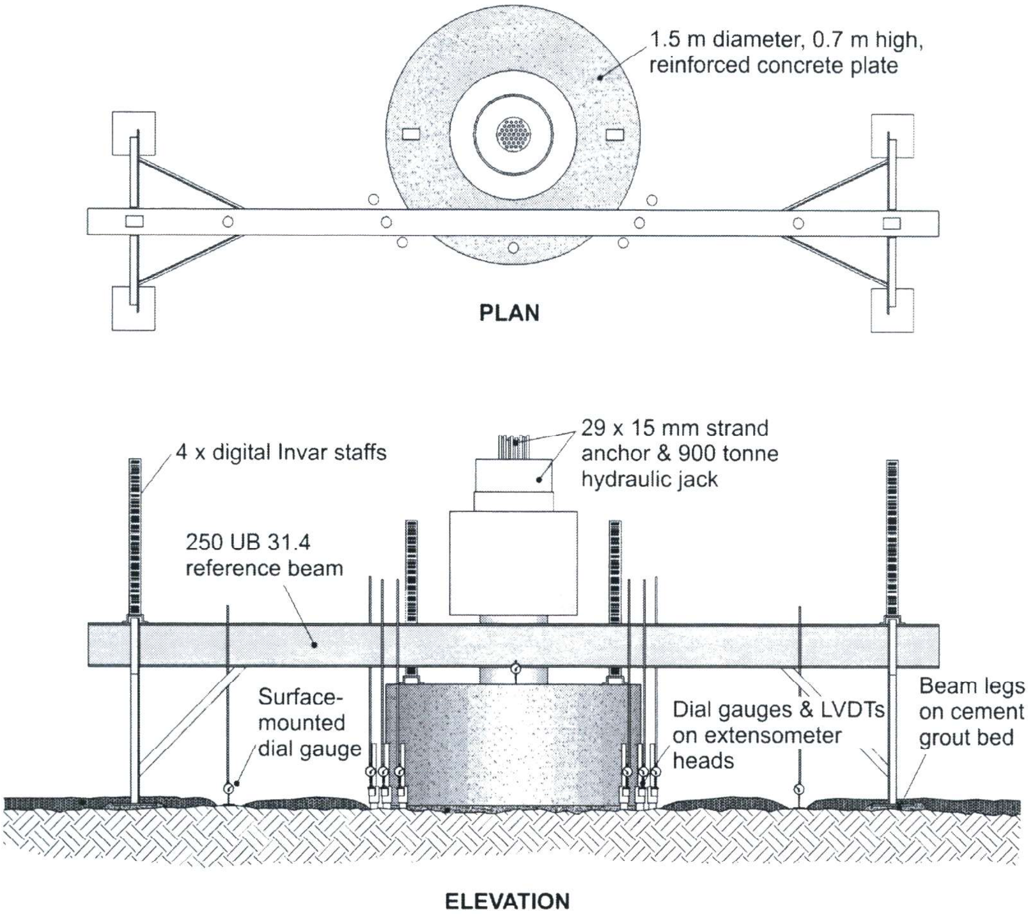

Figure 2. Sketch of test configuration (below ground components not shown).

Anchor

The anchor details are as follows:

- Working force of 6000 kN.
- Comprises 29 strands of 15 mm diameter each.
- Anchor hole is 0.20 m diameter and 6.9 m deep.
- Strands extend 6.5 m below the ground surface, with the upper 3.0 m individually sheathed in polyethylene tube.
- Tremmie grouted with a cement grout, with the upper 2.3 m left void.

During the test a 900 tonne capacity hydraulic jack was used to stress the anchor.

Reinforced Concrete Plate

A reinforced concrete plate of 1.5 m diameter and 0.7 m height was used to apply the load to the rock surface. A hole was left through the centre of the plate for the anchor strands.

Prior to installing the plate, the rock surface was thoroughly cleaned and a thin bed of cement-based levelling compound spread over it. A plaster of Paris bund was formed to contain the levelling compound.

A 40 mm thick steel plate was epoxied to the top of the concrete plate to reduce stress concentrations within the concrete.

Immediately prior to lowering the plate onto the prepared bed, a 0.175 mm thick plastic sheet was placed on the bed to act as a bond breaker, and then a fluid mix of cement grout was poured over the sheet.

Extensometers

Six single point extensometers were installed around the perimeter of the plate within individual boreholes. The extensometer anchors were fixed at depths of 1.15 m, 2.15 m, and 8.15 m on each side of the plate.

A Linearly Variable Displacement Transducer (LVDT) was installed at the top of each of each extensometer. The LVDTs used had a resolution of about 0.003 mm, which is a poorer resolution than would usually be expected for LVDTs. They were connected to a data logger, with readings recorded every 5 minutes for the two days prior to the test, and every 20 seconds during the test. A laptop computer was also connected to the data logger to allow real time monitoring of the extensometer movement during the test.

The particular value of the extensometers is that they provide a precise measure of relative movement between anchor points at different levels and between the surface and each anchor point.

Reference Beam and Dial Gauges

A 5 m long steel reference beam was constructed for the test as shown in Figure 2. Each of the four feet was cement grouted to the rock surface.

Nine dial gauges were mounted on the reference beam. Six of these were used to measure the movement of the extensometer heads. The dial gauges were read to 0.001 mm, though the reading accuracy was probably also ±0.001 mm.

The plate and reference beam had been enclosed in a 6 m by 6 m tent for a few days prior to the test to reduce temperature variations of the rock mass, steel beam, and extensometers.

Accurate Levelling

During the test four digital Invar staffs were mounted on the reference beam and plate. These were read with an accurate digital level, which reads to 0.01 mm. The level was mounted on a vertical steel beam about 10 m from the plate. The base of the beam was concreted into the sandstone bedrock. Measurement of any movement of the datum beam is essential in order to obtain accurate absolute movement of the plate and ground surface.

Test Programme

The test commenced at 8:30 pm to avoid large temperature variations occurring during the test, and finished about 5 hours later.

The anchor load was increased in a series of increments up to 4000 kN, back to zero load, then back up to 6000 kN, prior to terminating the test. At each increment the load was held constant for 15 minutes, with readings taken with all instruments at 1, 2, 4, 8, and 13 minutes after each change in load. Finally, a load of 2000 kN was applied and held constant for 90 minutes, with regular movement readings taken.

RESULTS

It should be noted that the test comprised the following independent measurements of rock mass movement:

- Settlement of plate and points on the rock surface – 7 points;
- Settlement of heads of extensometers – 6 points;
- Movements of anchors of extensometers – 6 points.

Taking into account that both differential and absolute displacements could be used for back-figuring the modulus, the test provided some 20 largely independent measurements of the mass modulus.

The plate itself moved a maximum of 3.7 mm, while the ground surface at 0.9 m, 1.75 m and 2.3 m radius moved 1.9 mm, 0.6 mm, and 0.3 mm respectively. The extensometer anchor points at 1.15 m, 2.15 m, and 8.15 m depth moved an average of 0.5 mm, 0.0 mm, and 0.1 mm (upwards) respectively. During the final creep phase of the test, the plate moved 0.05 mm over a period of 90 minutes.

The near surface of the rock may have been disturbed during excavation, and therefore measurement of plate and surface movements may have been affected. Conversely, movement of extensometer anchor points would be unaffected, although being much smaller are difficult to measure accurately.

Average movements of the plate is summarised in Figure 3.

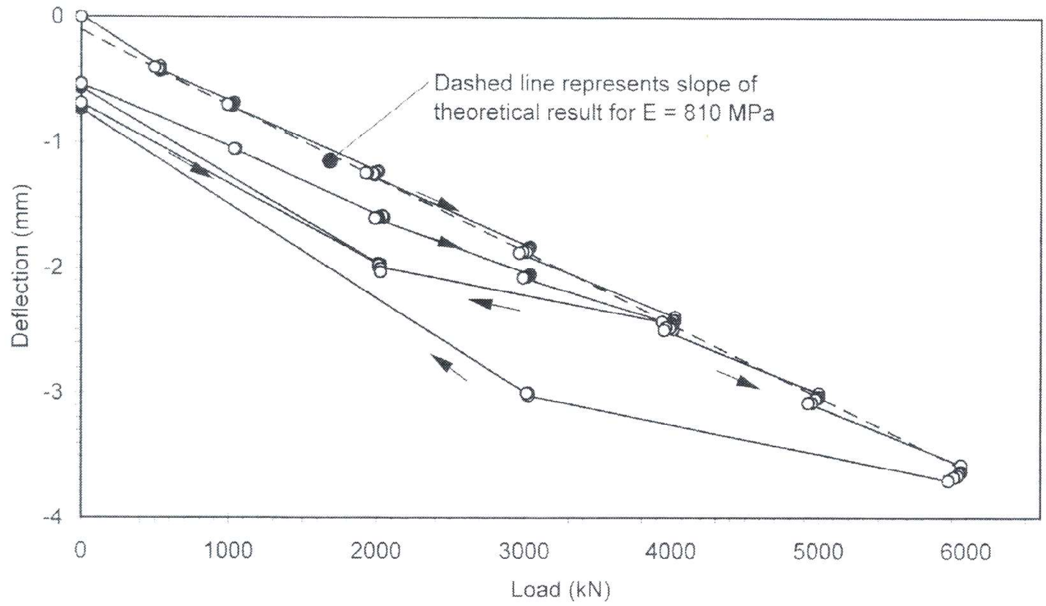

Figure 3. Plate movement

INTERPRETATION

The theory of elasticity requires two parameters, normally Young's Modulus and Poisson's Ratio, and it is not possible to compute both parameters from a single test. However, Poisson's Ratio is known to lie between about 0.20 and 0.25 for Hawkesbury Sandstone, and furthermore foundation settlement computations are very insensitive to this parameter. If one assumes a value of Poisson's Ratio (0.20 in this case) then the theory of elasticity gives the following equation for the displacement at any point on, or within, the rock mass:

$$\delta = \frac{Q}{DE} I_f \qquad (2)$$

where
δ = Displacement, or differential displacement
D = Diameter of the plate
Q = Load
E = Young's Modulus
I_f = Influence factor which is a function of the test geometry and the point where the displacement is measured

Numerical modelling of the test configuration was used to back-figure the Young's Modulus of the sandstone bedrock for each measuring point by, in effect, calculating the influence factor for each measurement point. Two separate axisymetric models were used:

- Phase2
- FLAC (Fast Lagrangian Analysis of Continua, by Itasca Software).

An example of the vertical movements calculated using FLAC is presented below in Figure 4. This shows downwards movement near the surface, and upwards movement around the anchor bond zone and an effective loaded thickness of about 5 m.

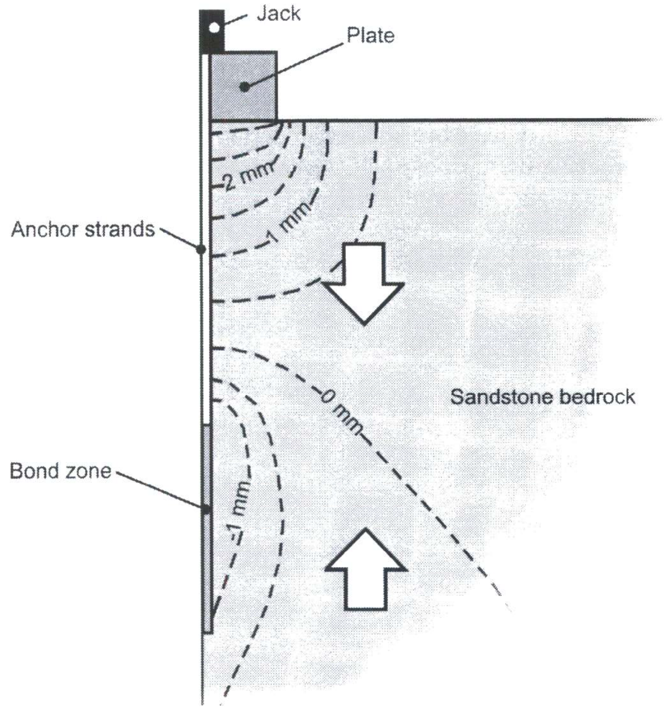

Figure 4. Axisymmetric FLAC model showing vertical movement for an assumed mass modulus of 900 MPa.

Interpreted modulus values based on the first cycle loading are summarised in Table 1. Where there is some non-linearity in the test data, the lower stress portions of the data have been used, as these are of more relevance to the actual loads proposed for the Neutron Hall.

Table 1. Interpreted Young's Modulus.

Position	**Young's Modulus** (MPa)
Plate	810
Surface (0.90 m radius)	990
Surface (1.75 m radius)	810
Surface (2.3 m radius)	700
Extensometer (1.15 m depth)	830
Extensometer (2.15 m depth)	910
Extensometer (8.15 m depth)	1050

The reload modulus was slightly higher than the initial loading moduli shown in Table 1. The increase was about 20% for the plate, and less for the other measuring points.

Assessment of the ground surface movement requires addition of the dial gauge movements and the reference beam movements. This approach has the limitation that the calculated absolute movement is only as accurate as the least accurate component, which is the survey levelling. The interpreted values for the extensometers are based on the differential measurements made by these instruments between rock surface and anchor point and are therefore considered to be the most reliable measurements.

Therefore it is concluded that the rock mass modulus at this location ranges from 800 MPa to 1000 MPa, with some indication of increasing stiffness with depth.

There is evidence from some of the extensometer readings that the modulus of the rock at low stress levels (<600 kPa) may be higher than the average values given above.

The test was located within the fault zone and it is likely that the results reflect poorer quality sandstone than elsewhere within the building footprint. Weathered seams were observed at several depths, as shown in Figure 1, and it is most probable that these seams are of extremely low strength and are contributing significantly to the overall relatively low mass modulus.

CONCLUSIONS

1. The test method presented is capable of measuring a mass modulus as high as 3000 MPa.
2. The elastic response of Hawkesbury Sandstone is remarkably linear.
3. Reload modulus was up to 20% higher than the initial modulus.
4. Creep is insignificant relative to elastic movements.
5. The test results are consistent with the mass modulus guidelines given in Pells et al (1998), with a mass modulus of 800 to 1000 MPa for borderline Class II/III Sandstone. This may be compared with an estimated substance modulus (Eqn. 1) of 3200 MPa to 4800 MPa.

ACKNOWLEDGEMENTS

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REFERENCES

Coffey Geosciences Pty Ltd (1999) "ANSTO Replacement Research Reactor, Lucas Heights, Geotechnical Investigations" *Report No. S20251/1-BA*

Coffey Geosciences Pty Ltd (2002) "ANSTO Replacement Research Reactor Project, Neutron Guide Hall, Additional Geotechnical Investigation", *Report No. S20251/3-AO*

Pells, P.J.N., and Mostyn, G., and Walker, B.F. (1998), "Foundations on Sandstone and Shale in the Sydney Region", *Australian Geomechanics*.

Pells Sullivan Meynink Pty Ltd (2003) "ANSTO Replacement Research Nuclear Reactor, Neutron Guide Hall, Lucas Heights, Sydney, Report on Rock Mass Modulus Test No. 1" *Report No. PSM650.R1*

Pells, P.J.N., (1983), "Plate Loading Tests on Soil and Rock", Chapter 6, *In-Situ Testing for Geotechnical Investigations*, ed. Ervin, M.C., Balkema, Rotterdam.