Fourth Australia - New Zealand
Conference on Geomechanics,
Perth, 14-18 May 1984

Installation of Earth Pressure Cells at a Surface Coal Mine

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SUMMARY Hydraulic earth pressure cells with a diameter of approximately 0.70 m were designed and constructed at the CSIRO Division of Geomechanics. A prediction of cell registration factor was made using results from a finite element model. In collaboration with the Utah Development Company, four cells were located in an area where a 30 m high spoil dump was scheduled for construction. Site investigation of the foundation materials included standard rock mechanics testing, geophysical logging, core sampling and the use of a Menard pressuremeter. Values of deformation modulus for the foundation material were estimated from field and laboratory tests for future finite element modelling of the dump's construction to give predictions of earth pressure for cell evaluation. The paper describes the design of the pressure cells and site investigation and installation of the cells at a strip coal mine in Queensland's Bowen Basin.

1 INTRODUCTION

The Goonyella Mine in Queensland's Bowen Basin has been a site for research into surface coal mine spoil slope stability for many years. The research has led to a clear definition of relevant slope failure mechanisms (e.g. Philp et al., 1981, and Dunbavan, 1981) and more reliable estimates of spoil shear strength values (e.g. Dunbavan, 1983). These results are being incorporated into current mine designs using existing methods of slope analysis, particularly the two-wedge limiting equilibrium method.

The understanding of spoil slope instability has reached a stage where the degree of sophistication of the stability analysis and the reliability of the available geotechnical data are comparable. Thus, new directions in research must be followed so that greater understanding of the two-wedge failure sequence and spoil material properties may be acquired. One aspect of continuing research at the CSIRO Division of Geomechanics is the determination of stress distributions at the base of a spoil pile during and after its construction. The identification of the mechanisms which cause the changes in stresses will have important implications for the possible use of more sophisticated numerical modelling methods (such as the finite element method) in the design of large multi-stage spoil dumps associated with deep strip and open cut mines in which soft rock is the predominant overburden material.

The purpose of this pressure cell installation is not to determine stress redistribution mechanisms at the base of a spoil pile, but is to evaluate the suitability of a large oil-filled earth pressure cell for measuring stresses in mine spoil material. Therefore, the interpretation of results at this stage would have no immediate practical application to spoil slope design. The results would provide a basis for a stress measuring study in an operational pit which would lead to greater understanding of the sequential development of the two-wedge slip mechanisms (see Dunbavan, 1981). Until this understanding is acquired, further improvements in mine spoil dump design will be a matter for experimentation with results based on trial and error.

This paper contains the details of the design of a 700 mm diameter circular hydraulic earth pressure cell. Four of these cells were installed at the Central Queensland Coal Associates' (CQCA) Goonyella Mine in an area away from the pits where a 30 m high dump of mine spoil material was scheduled for construction. Results from the field installation will be used to monitor spoil material stresses during and after dump construction, but the main reason for the installation is as a feasibility study for the installation of a group of cells in an operating pit. Elastic properties of spoil and dump foundation (i.e. undisturbed overburden) materials were measured as part of the site investigation so that field results could be compared with stress levels predicted using a simple finite element analysis. The prediction of earth pressures acting on the installed cells is outside the scope of this paper.

2 PRESSURE CELL DESIGN

2.1 Fundamental Design Concepts

The use of devices to measure earth pressures has its origins before the time when soil mechanics was recognized as an engineering science (see Hvorslev, 1976). Thus, considerable effort has been given to the design of different types of earth pressure cell and their response during field loading. Penman (1979) described the characteristics of the three basic types of cell (cell using electrical resistance strain gauges, vibrating wire cell, and oil-filled cell) and included notes on the practice of field stress measurement using earth pressure cells.

Recent attention to pressure cell design has concentrated on the vibrating wire and electrical resistance strain gauge types rather than the oil-filled type (e.g. Brown, 1977). However, there are several basic cell characteristics which should be considered in the design of all types of cell and Trianafilidis (1974) identified these as:

1) geometry and stiffness,
2) pressure sensitive and gross gauge areas,
3) unit weight,
4) frequency response,
5) calibration,

6) waterproofing,
7) temperature sensitivity,
8) signal-to-noise ratio, and
9) placement.

The first four points should be considered at an early stage in the cell's design, while the remaining points may be left until a later stage of detailed design work.

Optimal conditions for the first four characteristics are:

1) low thickness to diameter ratio and high cell stiffness, compared with surrounding soil stiffness,
2) stress sensing area being 14 to 45% of the total cell area,
3) unit weight as close as practicable to that of the surrounding soil, and
4) fast cell response time in relation to the rate of stress change to be measured.

Because of the wide particle size range for surface mine spoil material, the effect of single particle loading on measured stress levels had to be considered. Brown (1977) recommended that the cell diameter should be at least 50 times the diameter of the largest soil particle. To satisfy the above requirements, the type of earth pressure cell chosen was the oil-filled type with a diameter of about 700 mm. The cell comprised two parts: the load sensor, being a 480 mm diameter steel flat jack, and the base support being a 700 mm diameter reinforced concrete disc recessed to hold the flat jack. The oil-filled flatjack was sealed free from air inclusions and its pressure response was indicated by a strain gauge pressure transducer contained within the concrete base. This combination of flat jack and concrete base resulted in a pressure cell in the order of 1000 times stiffer than the surrounding spoil material, and the height to diameter ratio was 0.12. The unit weight of the cell was about 2300 kg/m^3 compared with about 2000 kg/m^3 for spoil material. The rate of loading would be essentially static so that the dynamic response of the cell was irrelevant for this study.

2.2 Detailed Design of Cell

The majority of published pressure cell design charts are relevant only for cells which rely on the deformation of a flexible metal diaphragm (electrical strain gauge and vibrating wire types) rather than an induced pressure in an oil-filled cavity. For individual cell designs, Hvorslev (1976) recommended the use of the finite element method for the prediction of cell response factor once the basic form of the cell had been determined. These numerical models are very useful for establishing the effects of variation of particular cell characteristics or soil parameters on cell response (e.g. Tory and Sparrow, 1967). Thus, the response factor for the large hydraulic cells used in this study was determined from the results of a finite element model of a cell placed in a block of soil.

The finite element program used was ADINA (Bathe, 1978), but the majority of the sophisticated types of solution available with this program were not used. The main reason for using the program was the ability to include fluid elements and thus model the oil-filled flat jack very closely. All solid materials were assumed to have isotropic linear elastic properties and the stress levels were assumed not to cause failure in any material. A total of 308 elements were used to model a sector of the cell and surrounding soil assuming axial symmetry existed. A detailed view of the finite element grid surrounding the cell region is shown in Figure 1. Two values for the thickness of the concrete base were used (25 mm and 50 mm) by changing the lower row of concrete material elements to soil elements. One material variable was investigated during modelling, that being the elastic modulus of the soil. Values of material properties used are given in Table 1. Stress applied to the soil block was 1 MPa, representing a surcharge spoil height of 50 m. Stresses due to self-weight were neglected.

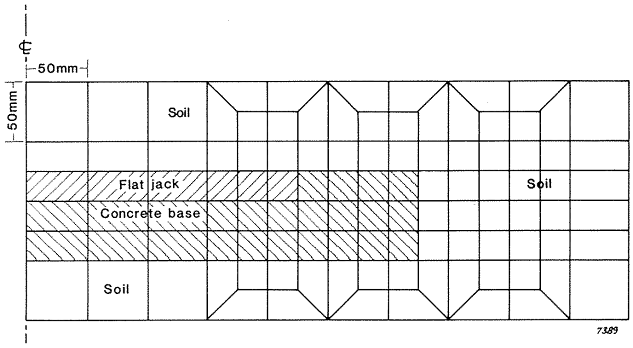

Figure 1 Detail of finite element model

TABLE I
VALUES OF MATERIAL PROPERTIES

Material	Young's Modulus E	Poisson's Ratio
Soil	20, 35, 50 MPa	0.35
Concrete	24 GPa	0.25
Oil (jack fluid)	38 GPa	-

Results from the finite element computations are shown in Figures 2 and 3, being fluid pressure variation along the cell radius and variation of cell factor for change in soil elastic modulus respectively. The cell factor was calculated as the average of the fluid element pressures excluding the outer-most element because of low pressures caused by edge effects. If this element was included in the cell factor calculation, the value of the factor would be 0.03 and 0.02 lower for cell base thicknesses of 25 and 50 mm respectively.

The final design of the cell was one with a 50 mm concrete base. Two reasons prompted this choice; the uniform cell factor for this base thickness (see Figure 3, and the improved strength of the base and protection of the light reinforcement included. It was anticipated that the cells would experience rough treatment in the mining environment so that the latter reason was important for the survival of the cells while they were being surcharged. Figure 4 shows a plan and elevation of the final cell design.

2.3 Cell Construction

Because the field installation site was more than 2000 km away from the Divsion's laboratories, the construction of the four cells was organized into two parts. The moulding of the concrete bases which were a large proportion of each cell's 75 kg mass, was to be done at the field site. The filling of the flat jacks with oil and the assembly of various electronic components needed for the cell were carried out at the Division.

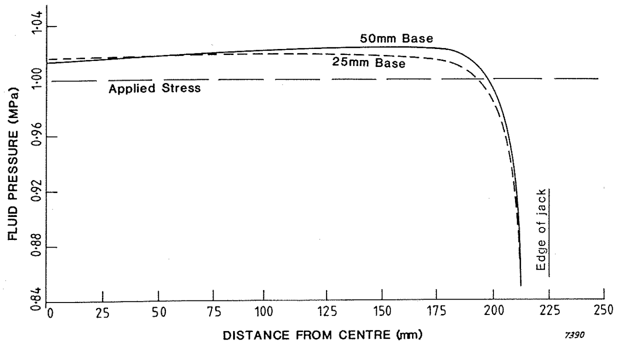

Figure 2 Fluid pressure variation along cell radius; E_{soil} = 35 MPa, ν=0.35

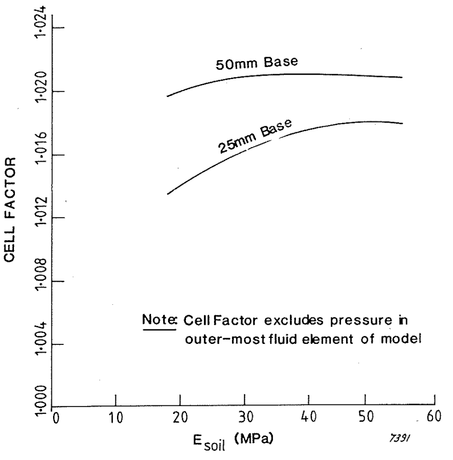

Figure 3 Variation of cell factor with soil elastic modulus, ν=0.35

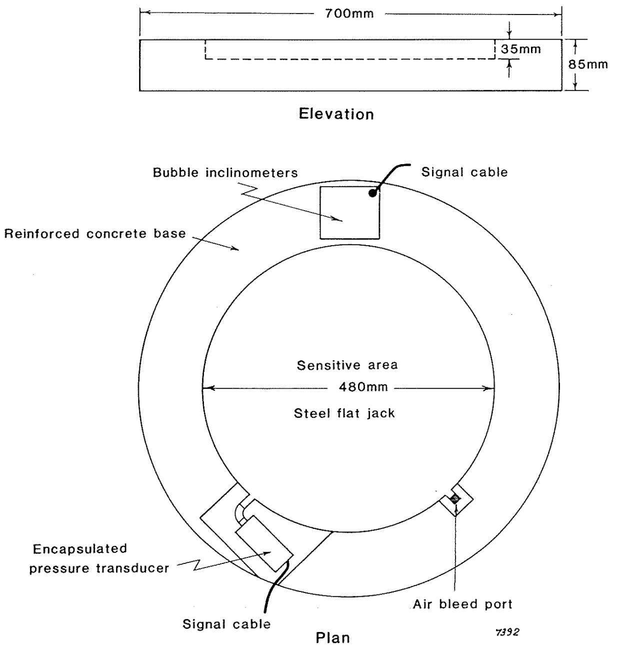

Figure 4 Large hydraulic earth pressure cell design

The moulding of the concrete bases was achieved by using a simple plywood form with the appropriate pieces attached to create recesses for the flat jack and electronic sensors. The base was cast upside-down to make reinforcement location simple and to minimize the time required for surface finishing. The bases were left to cure for a minimum of 28 days before further use.

The flat jacks (VSL Prestressing (Aust) Pty. Ltd., model 480C) were filled with machine oil with as much air as possible being removed from the enclosure. Each jack was placed in a universal compression machine and uniformly loaded to an equivalent surface stress of about 2 MPa while the internal oil pressure was being monitored through a strain gauge pressure transducer. When a non-linear response was given by the cell, a small enclosure of air was usually found and expelled. The loading process was repeated until all cells responded linearly.

Two types of electronic measuring device were included as parts of the cell; a strain gauge pressure transducer for monitoring cell fluid pressure, and electrolytic bubble inclinometers for determining the orientation of the stress measuring face. One bubble inclinometer was used in cells measuring horizontal stress and two when measuring vertical stress. All electronic components were encapsulated in epoxy resin for waterproofing. The flat jacks were fixed into the concrete bases with a flexible epoxy resin at the field site. The resin not only served as a bonding agent, but also provided a thin protective layer for the lower side of the flat jack against any point loads from aggregate in the concrete mix which may have punctured the flat jack under load. Details of cell placement are given in Section 4.2.

3 SITE INVESTIGATION

3.1 Geology

The Utah Development Company, operators of the CQCA Goonyella Mine, made an installation site available near the eastern boundary of the surface mine lease, approximately 7 594 350 m N, 602 650 m E (AMG). The area was allocated for the construction of a 30 m high spoil dump for material being trucked from another area of the mine where the spoil had been dumped previously.

A series of five holes with chip and geophysical logging was drilled in a square pattern centred on a possible site for the field installation. A change in dumping practice by the earthmoving contractor made the first site unsuitable and a further three holes in a triangular spread were drilled and logged to the north of the first series. Thus, stratigraphic information to a depth of about 30 m was available over an area of 220 m x 120 m with the installation site within 10 m of one of the holes.

Graphic logs of all holes were compiled by staff of Utah Development Company's Technical Services Section using information from both chip and geophysical logs. The data was presented in the form of a fence diagram from which the uniformity of sedimentary beds was obvious. The two major geological features of interest in this study were the Tertiary-Permian unconformity and the base of the weathered Permian sandstone which formed the first major geological unit below the unconformity.

Figure 6 contains a graphic log for Hole 21755, in which the first 5 m is Tertiary material and the next 15.5 m is weathered Permian sandstone (litharenite). The dip of the Tertiary-Permian unconformity is about 1° WNW and that of the base of the weathered sandstone is about 3.5° WNW. The site used for pressuremeter testing was 10 m north of Hole 21755. The average surface grade of the area drilled was about 1 in 250 to the southeast.

3.2 Pressuremeter Testing

In order to obtain some understanding of the deformation properties of the foundation material at the site of the pressure cell installation, in situ pressuremeter tests were performed at depths from 4 to 20.5 metres. In addition to moduli of deformation obtained from the pressuremeter results, Young's moduli were determined from uniaxial compressive strength tests performed on core samples recovered.

Pressuremeter testing involves the insertion of a cylindrical probe in a borehole, inflation of the probe's rubber membrane with water and recording the resulting change in volume with changing pressure. Volume change is due to the radial expansion of the borehole along the length of the probe. A volume versus pressure curve is obtained after corrections are made for pressure required to overcome the resistance of the rubber membrane and volume change resulting from expansion of tubing and compression of the membrane.

Tests performed were the stress-controlled type where equal increments of pressure are applied to the probe, with each level of stress being maintained for one minute.

The pressuremeter modulus, E_p, is given by

$$E_p = 2(1+\nu)\, V_m\, \Delta p/\Delta v \qquad (1)$$

V_m = volume of the cavity at the midpoint of the straight line portion of the pressure-volume curve
Δp = pressure change during the elastic phase
Δv = volume change during the elastic phase
ν = Poisson's ratio

Drilling with an NMLC size tungsten carbide bit produced the required diameter hole (76.2 mm) for executing the pressuremeter test. A 1.5 m triple tube soil coring barrel was used to obtain 50 mm diameter core for subsequent laboratory testing. Air circulation was necessary due to the swelling of the clay-rich rock on contact with water.

The pressuremeter used was the Menard GB which was designed for testing in soils. At the shallower depths of 4 and 5 m, where the hole had been enlarged by air and particle impingement during drilling, the volume of water available to the probe was exhausted before plastic deformation was reached. The onset of some plastic deformation was reached for tests at 6 and 7 m (see Figure 5). Plastic deformation could not be achieved at 8,19 and 20.5 m with the pressures available and as a consequence V_m, volume of the cavity at the midpoint of the elastic region of the volume-pressure curve, was understated.

The original intention was to perform cycled pressuremeter tests, however, difficulty was experienced in maintaining each of the three individual cells of the GB probe intact at the high pressures necessary for testing rock. Hence it was necessary to use the less demanding single cycle test, although ruptured membranes were still common.

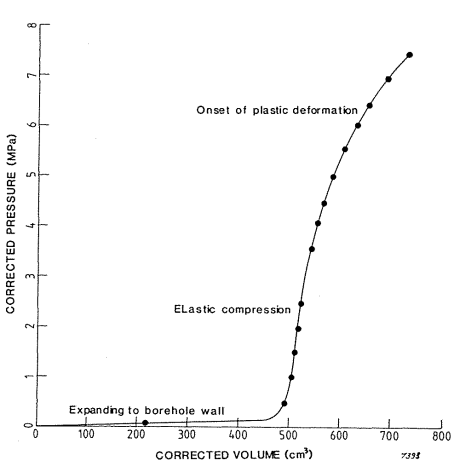

Figure 5 Corrected pressuremeter curve, 6m

3.3 Determination of Moduli

3.3.1 UCS tests

Uniaxial compressive strength (UCS) tests were made using 118 mm lengths of core recovered from the depths at which five of the pressuremeter tests were performed. Young's moduli were found from the linear regression analysis of that part of the axial stress-axial strain curve between 1/3 and 2/3 of the peak stress and are shown plotted against depth in Figure 6. Previous experience had shown poor bonding of strain gauges to this type of clay-rich sandstone, and displacement transducers were used in addition to strain gauges to measure axial strain. Strain gauge performance, however, was better than expected, giving more reliability for the values obtained for Poisson's ratio. Typically, Poisson's ratio was found to be approximately 0.35 (range of 0.33 to 0.37) and this was the value used with the formula for pressuremeter moduli.

3.3.2 Point load tests

As the pressuremeter is thought to measure the horizontal modulus of deformation (Shields and Bauer, 1977), the possible anisotropy of the material tested should be considered when viewing the disparity between the values of modulus determined by pressuremeter and UCS tests. To obtain an indication of vertical to horizontal anisotropy, the Strength Anisotropy Index, I_a (50), was calculated from point load index tests performed on some of the core recovered. I_a (50) is the ratio of strength indexes for tests where loading is perpendicular and parallel to the core axis. As the value of the index was found to be close to unity, the material may be assumed to be isotropic.

The ISRM have suggested that when determining the Point Load Strength Index: "Rocks to be classified are first divided into units, each of which is considered on the basis of a preliminary inspection to have uniform strength". With the limited core available from a single borehole this resulted in fewer samples than would be ideal.

The correlation between Point Load Index and UCS for 50 mm diameter core (Hoek and Bray, 1977) is stated as:

$$\sigma_c = 23\ I_s\ (50) \qquad (2)$$

This exercise resulted in the following uniaxial compressive strength values (for material from a depth of between 18 and 19 m).

σ_c (via eq. (2)) = 16.6 MPa (median of 7 tests)

σ_c (UCS) = 15.33 MPa (single test only)

3.3.3 Pressuremeter modulus

In Figure 6 both pressuremeter and Young's moduli values are plotted against depth, with the pressuremeter modulus being between 1/2 and 1/4 the value of Young's modulus.

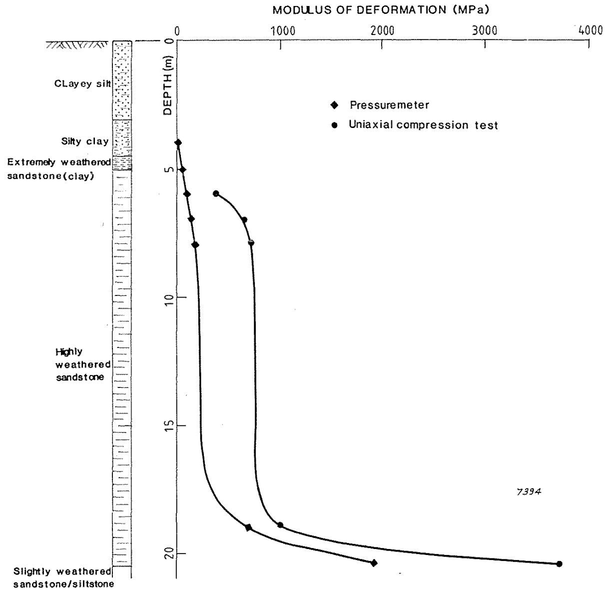

Figure 6 Young's and pressuremeter moduli with depth

Shield and Bauer (1975) found the pressuremeter modulus (single cycle test) to be 1/2 to 1/3 the value obtained from plate bearing and footing tests even though the moduli they measured horizontally and vertically by plate bearing tests were found to be in close agreement. Thus, they could not attribute the low value of pressuremeter modulus to the anisotropic properties of the test medium.

Baguelin et al., (1978) found that the pressuremeter modulus determined from a single cycle test varied between 1/2 to 1/4 the value of modulus determined from a multi-cycled test (the Menard reloading or compression modulus).

As seen in Figure 6 the ratios of pressuremeter to UCS determined moduli fell in this same range. The intact length of core used in a UCS test may be likened to the recompacted material surrounding the probe in a multi-cycled pressuremeter test, where the closing of fractures opened by the disturbance of drilling takes place before subsequent deformation.

4 PRESSURE CELL INSTALLATION

4.1 Site Preparation and Instrument Location

The installation site was cleared of all vegetation by bulldozer which left some larger tree roots in the ground close to the surface. The area selected for placement of the cells was checked thoroughly and any remaining tree roots were removed. Loose surface soil was pushed aside by grader which also made a V-shaped slot from the installation site to the edge of the proposed dump for signal cable placement.

Figure 7 shows the positions of the four pressure cells and eight soil moisture blocks. The distance between pressure cells was a minimum of 3 m, which is double that recommended by Penman (1979) as the extent of cell influence. The horizontal cells were roughly levelled using a spirit bubble and the vertical cells were positioned using a surveyor's staff level. The exposed face of each flat jack was covered by two layers of marine grease and 3 mm Neoprene rubber. The grease and rubber served to minimize any surface tractions applied across the face of the cell and to protect the face from point loading by spoil particles and chemical attack by the slightly saline spoil pore water.

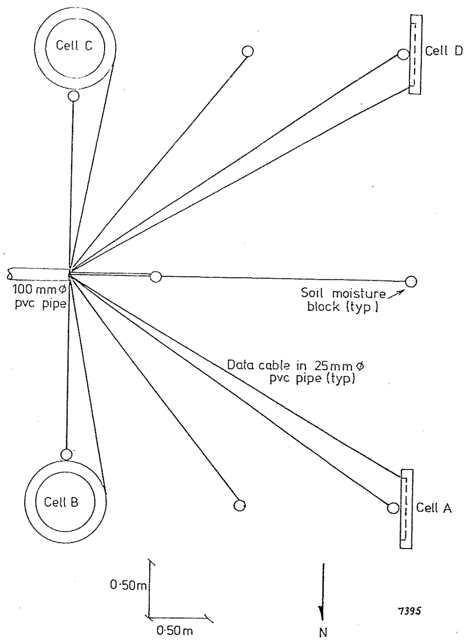

Figure 7 Location of instruments at installation site

After the necessary electrical connections were made and the soil moisture blocks were positioned, the group of instruments was covered to a depth of about 1 m with spoil material from the same source as the proposed dump material. The spoil material was placed using a combination of small front end loader and manual shovelling. Care was taken to maintain correct positioning of the instruments during the operation and correct alignment was confirmed by inclinometer output when the task was completed.

4.2 Additional Instruments

The highly weathered to fresh Tertiary and Permian coal measure sediments which constitute the spoil material at the Goonyella Mine often show significant reduction in shear resistance and load-deformation properties with increasing moisture content because of the swelling and dispersion of the clay-rich rocks (e.g. Seedsman and Emerson, 1981). There is no evidence for the existence of a groundwater mound at the base of spoil dumps at Goonyella and this may be attributed to the low rainfall and deep regional groundwater table. However, when rain occurs, water infiltrates the spoil material forming perched water tables and localized moist zones (Philp et al., 1981). To determine spoil moisture content changes in the immediate vicinity of the pressure cells, eight gypsum soil moisture blocks (Aitchison and Richards, 1965) were placed around the installation area. The soil moisture blocks were chosen for their simplicity and robust design as well as their capacity to continue functioning while drying after a period of saturation. Many other devices which give a better measurement of pore suction do not continue functioning once they are saturated.

4.3 Data Collection

All instruments installed were able to be electrically monitored from a remote station. The pressure cells were located about 250 m from the edge of the dump which had a face gradient of 15%, so that the horizontal shear stresses caused by the slope face would be minimal at the installation site.

The signal cables from the instruments were located inside 100 mm diameter PVC pressure conduit which was laid in the V-shaped slot and covered over with earth. Splices between lengths of cable were encapsulated in epoxy resin and all cables were tested thoroughly before earthfill was placed over them. A mobile hut was situated at the edge of the dump where the cables ended so that monitoring equipment could be safely stored while data was collected.

The dump construction is scheduled to start in the second half of 1983 and material is likely to be placed in six layers of approximately 5 m thickness. The changes in stress at the installation site would be in six increments with some stress redistribution likely between increments. Thus, it will not be necessary to continually monitor signals as would have been the case for the construction of the dump by end tipping from a full-height crest. The signals will probably be recorded manually once each week during construction and occasionally afterwards, provided the instruments remain operative.

5 INTERPRETATION OF FIELD DATA

5.1 Earth Pressure Cell Readings

The cell fluid pressure can be simply calculated from the calibration constants for the pressure transducer. The vertical and horizontal stresses can then be gained from the cell pressure corrected for the tilt of the sensing plane which is known from the output of the inclinometers in the cell.

During the field installation, samples of spoil material from the dump source were collected and brought back to the laboratory. A series of triaxial tests is planned for some of that material so that its elastic parameters may be evaluated. By combining those values with similar property values for the foundation material (i.e. the intact overburden), a finite element model can be used to predict stress levels at the installation site. The width and length of the dump are large compared with the dump height and the foundation material may be approximated as a series of horizontal layers, so that a two-dimensional representation of the dump for numerical modelling would be adequate. Stress predictions from analytical models (e.g. Davis and Taylor, 1962, and Trollope, 1968) would also be compared with field measurements.

5.2 Soil Moisture Block Readings

The soil moisture block gives only an indirect reading of the pore fluid conditions in the soil. The relationship between block reading and soil moisture content or pore fluid suction must be determined in the laboratory for the particular soil under study. The moisture suction characteristic of a soil is hysteretic and needs to be established for conditions when the soil is wetting up and drying out. Samples of spoil material collected during the field installation will be used to determine the moisture-suction characteristic for the dump material.

Changes in spoil stresses will be correlated with changes in moisture condition to determine the influence of changes in pore fluid suction on soil stress distribution. The moisture blocks may also provide information on rainfall infiltration of the spoil dump, provided they remain operational for a sufficient period.

6 CONCLUSIONS

The design and construction of a robust oil-filled earth pressure cell of large diameter was achieved. Numerical modelling studies showed that the cell is likely to have a response factor very close to unity. The installation of four pressure cells at a remote field location presented no major difficulties. The assessment of the cell's suitability for placement in an operating open strip pit will be made after the surcharging of the cells presently installed is completed.

The combination of a number of chip log boreholes and one cored hole proved to be an effective approach for site characterization. The uniform horizontal stratigraphy at the site makes the future use of finite element modelling for stress prediction a relatively straight-forward task. The use of a Menard GB pressuremeter did not appear to be a particular advantage in the study mainly because of the materials encountered (i.e. rock compared with soil). Results from simple unconfined compressive strength and point load tests led to the same results as those inferred from the pressuremeter tests when results were adjusted to those expected from multi-cycled testing (i.e. x 2-4). The use of a pressuremeter designed for testing rock may have given improved results.

7 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial contribution from the assistance of staff of the Utah Development Company's Technical Services Section and Goonyella Mine operations. Special thanks goes to Mr. Alan Davies who supplied the graphic borehole log interpretations.

Assistance for laboratory and field testing and for the field installation was provided by technical staff of the CSIRO Division of Geomechanics.

8 REFERENCES

AITCHISON, G.D. and RICHARDS, G.B. (1965). A broadscale study of moisture conditions in pavement subgrades throughout Australia. 2-Techniques adopted for the measurement of moisture variables. In: "Moisture Equilibria and Moisture Changes in Soils Beneath Covered Areas", G.D. Aitchison, ed., Butterworth and Co. (Australia). Ltd.

BAGUELIN, F., JEGEQUEL, J.F. and SHIELDS, D.H. (1978). *The pressuremeter and foundation engineering*. Trans. Tech. Publications.

BATHE, K-J. (1978). ADINA - A finite element program for automatic dynamic incremental nonlinear analysis. Massachusetts Institute of Technology, *Report 82448-1 revised*.

BROWN, S.F. (1977). State-of-the-art report on field instrumentation for pavement experiments. Transportation Research Board, *Transportation Research Record 640*, pp. 13-28.

DAVIS, E.H. and TAYLOR, H. (1962). The movement of bridge approaches and abutments on soft foundation soils. *Proc. 1st. Conf. Australian Road Research Board*. Vol. 1, pp. 740-764.

DUNBAVAN, M. (1981). Spoil pile instability with reference to the Goonyella Mine, Queensland. *Proc. Symp. Strip Mining - 45 metres and beyond*. Australasian Inst. Mining and Metallurgy, Symposium Series No. 28, pp. 119-130.

DUNBAVAN, M. (1983). Engineering properties of an opencast spoil material associated with pit instability. Submitted to *2nd Int. Symp. on Surface Mining and Quarrying, Bristol U.K.*, October 1983.

HOEK, E. and BRAY, J.W. (1977). *Rock slope engineering, 2nd ed.* Institution of Mining and Metallurgy, London.

HVORSLEV, M.J. (1976). The changeable interaction between soils and pressure cells; tests and reviews at the Waterways Experiment Station. U.S. Army Engineer Waterways Experiment Station, *Technical Report S-76-7*.

PENMAN, A.D.M. (1979). Measuring earth pressures in embankment dams. *Water Power and Dam Construction*, Vol. 31(6), pp. 29-34.

PHILP, M.G., BOYD, G. and ECKERSLEY, J. (1981). Stabilisation of large scale spoil piles in deep open strip coal mines. *Proc. Symp. Strip Mining - 45 Metres and Beyond*. Australasian Inst. Mining and Metallurgy, Symposia Series No. 28, pp. 131-144.

SEEDSMAN, R.W. and EMERSON, W.W. (1981). Dispersion tests and their application to problems of mine stability. CSIRO Aust. Inst. Energy and Earth Resources, Division of Geomechanics, *Geomechanics of Coal Mining Report* No. 33.

SHIELDS, D.H. and BAUER, G.E. (1975). Determination of the modulus of deformation of a sensitive clay using laboratory and *in situ* tests. *Proc. Conf. In Situ Measurement of Soil Properties*, Vol. 1, pp. 395-421.

TORY, A.C. and SPARROW, R.W. (1967). The influence of diaphragm flexibility on the performance of an earth pressure cell. *Jl. Sci. Instruments*, Vol. 44(9), pp. 781-785.

TRIANDAFILIDIS, G.E. (1974). Soil-stress gauge design and evaluation. *Jl. Testing and Evaluation, JTEVA*, Vol. 2(3), pp. 146-158.

TROLLOPE, D.H. (1968). The mechanics of discontinua or clastic mechanics in rock problems. Ch. 9 in "*Rock Mechanics in Engineering Practice*". K.G. Stagg and O.C. Zienkiewicz eds., John Wiley and Sons, London.