Geotechnical Testing for Leigh Creek Coalfield

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SUMMARY This paper presents the results of some of the field and laboratory testing undertaken in providing geotechnical mine planning constraints at the Leigh Creek Coalfield, South Australia. The approach adopted to systematically test large amounts of drill core is described. Correlations developed between the basic classification test, the Point Load Strength Index, and other more sophisticated tests used in geotechnical analysis are presented. In particular the difficulties of testing material transitional between strong "soils" and weak "hard rocks", the characteristics of rock defects with very low residual strengths; and the simplification of a test used in assessing diggability of bucketwheel excavators are described.

1 INTRODUCTION

The Leigh Creek Coalfield is situated in the northern Flinders Ranges of South Australia some 600 km north of the capital Adelaide. The mine provides sub bituminous coal for use in generating the State's electricity supply in power stations located at Port Augusta about midway between Leigh Creek and Adelaide. Coal was first mined underground at Leigh Creek in the 1890's. Since 1943 coal has been mined by open cut methods to depths of about 30 m. Planning studies are now under way to extend the life of the mine into the twenty-first century with maximum depths increasing to 150 m. Mining is relatively difficult due to both the geometry of the deposit and low rock substance and defect strengths.

Between 1975 and 1978 three major geotechnical drilling programmes have been carried out as an adjunct to mine exploration drilling with some 9700 m of HQ size core being recovered for geotechnical purposes. The programme was instigated in order to:

1 Further define the geology and stratigraphy of the basin
2 Define regimes with similar geotechnical characteristics
3 Quantify through laboratory testing both substance and defect properties
4 Carry out analysis and make recommendations for mine planning
5 Monitor trial sections of the mine to confirm and upgrade predictions based on drilling and testing of laboratory samples

Items 1 to 4 have largely been completed whilst item 5 is just commencing. This paper describes the approach used and results of some of the laboratory testing undertaken and illustrates how they were incorporated into the analyses.

2 COALFIELD GEOLOGY

2.1 Stratigraphy

The Leigh Creek Coalfield consists of four separate deposits as shown on Fig. 1. The largest of these Lobe B has been the subject of the geotechnical studies undertaken to date. Lobe B is a remnant, asymmetric saucer-shaped basin of Triassic and Jurassic coal measures unconformably overlying Precambrian basement rocks of siltstone and limestone. Three separate sequences of coal have been identified (Coffey & Partners Pty. Ltd. 1975, 1979) and named the Lower Series, Main Series, and Upper Series, as shown on Fig. 1. The intervening overburden strata have been named after the coal seams which they cover. The units, their composition and typical strength range are given in Table 1. Strength ranges have been defined using the Point Load Strength Index (Broch & Franklin 1972).

Thin bands of rock of high to extremely high strength called "hardbars", are also encountered in some units. Hardbar thicknesses are often less than 100 mm although a significant number with thicknesses up to 500 mm have been encountered. They appear to be continuous over distances of one to several kilometres.

2.2 Defects

Defects in the rock mass include joints, sheared and crushed zones clay seams, and faults. Their distribution is however quite variable. In the Upper Series and to a lesser extent in the Main Series Overburden there are large volumes of rock where joints are often spaced greater than 10 m. In contrast the Lower Series Overburden and Main Series Coal have substantial zones where spacings are under 1 m and the remainder in the 3 to 10 m range. There is a concentration of defects sub-parallel to the bedding plus two other, steeply dipping concentrations which strike parallel and perpendicular to the bedding dip. Many of the joints in all units are polished and slickensided, showing evidence of past movements along them.

In addition to joints a number of clay seams exist. The seams are of medium to high plasticity ($w_L \approx 40$ to 60%) and vary from about 5 to in excess of 200 mm thick. Samples from clay seams had residual angles of friction down to 8°. The clay seams are believed to be the product of extensive shearing of the rocks along planes of extreme movement and thus low residual shear strengths were anticipated.

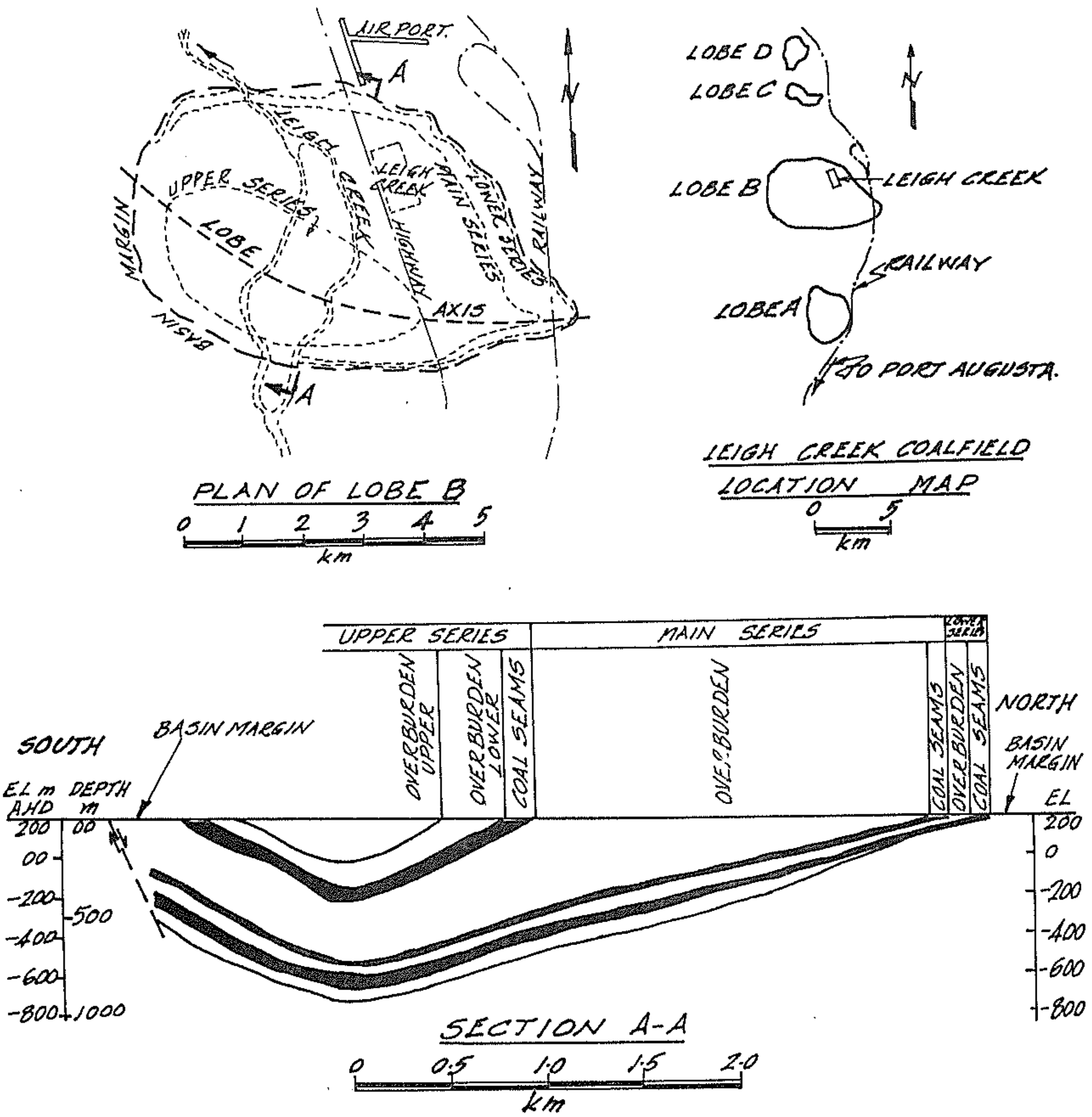

Figure 1 Plan and Section of Leigh Creek Coalfield

TABLE 1

Lobe B - Stratigraphic Sequence

Unit	Principal Composition	Strength Range
Upper Series Overburden		
Upper	Mudstone and Siltstone	EL-L
Lower	Weakly cemented sand and Sandstone	EL & VL-L
Upper Series Coal	Coal with siltstone partings	L-M
Main Series Overburden	Mudstone	L-M
Main Series Coal	Two thick coal seams minor partings	L
Lower Series Overburden	Mudstone some siltstone	L-M
Lower Series Coal	Thin coal seams and siltstone partings	L-M
EL = Extremely Low VL = Very Low L = Low M = Medium Strength		

They have also been observed to be continuous over very large areas beneath and parallel to the mine low wall. A number of low wall failures have been attributed to sliding along clay seams, particularly when associated with groundwater seepage.

3 APPROACH TO TESTING

The extended nature of the project and the large amount of core which had to be assessed for geotechnical properties required that a systemmatic approach to testing be developed. Further difficulties were evident due to the remoteness of the site limited transportation facilities to an established geotechnical laboratory and the harsh semi-arid climate. The approach adopted was:

1. Establishment in Leigh Creek of a fully equipped geotechnical testing laboratory capable of conducting both classification and some strength tests
2. Logging and classification testing all core on site within 24 to 48 hours of drilling
3. Carry out both on site and, for more sophisticated tests, on samples returned to Adelaide a more limited testing programme to determine strength and other required properties
4. Correlate the classification and other tests so that the latter could be applied to the entire deposit.

4 CLASSIFICATION TESTS

4.1 The Point Load Strength Index - $I_s(50)$

The Point Load Strength test shown on Fig. 2 was selected as the basic classification test and all drill core was tested progressively as it was recovered during the drilling. The Point Load Strength which is a measure of tensile strength and was developed at the Imperial College, London (Broch & Franklin 1972) and subsequently adopted by the International Society for Rock Mechanics (ISRM 1972) was selected as the standard test because it is a simple and rapid one which is readily carried out using portable testing equipment thus making it suitable for field use. Further since a large number of tests can be carried out a much more statistically significant interpretation of rock strengths may be obtained. Tests were carried out on a systemmatic basis every 5 to 10 m along all core plus on the remains of other test samples e.g. unconfined compression tests. Fig. 3 presents the correlation obtained between Point Load Strength Index and Unconfined Compressive Strength.

5 SHEAR STRENGTH OF DEFECTS

5.1 Testing Equipment

The Leigh Creek rocks whilst not unique, are difficult to test in that their strengths are often in the transition range between strong "soils" and weak "hard rocks". Thus tests conducted with equipment designed along classical "soil mechanics" or "rock mechanics" lines may be either inappropriate or susceptible to inaccuracies. Shear strength tests were carried out using two types of equipment:

a) A Hoek shear box designed for testing defects in hard rock and

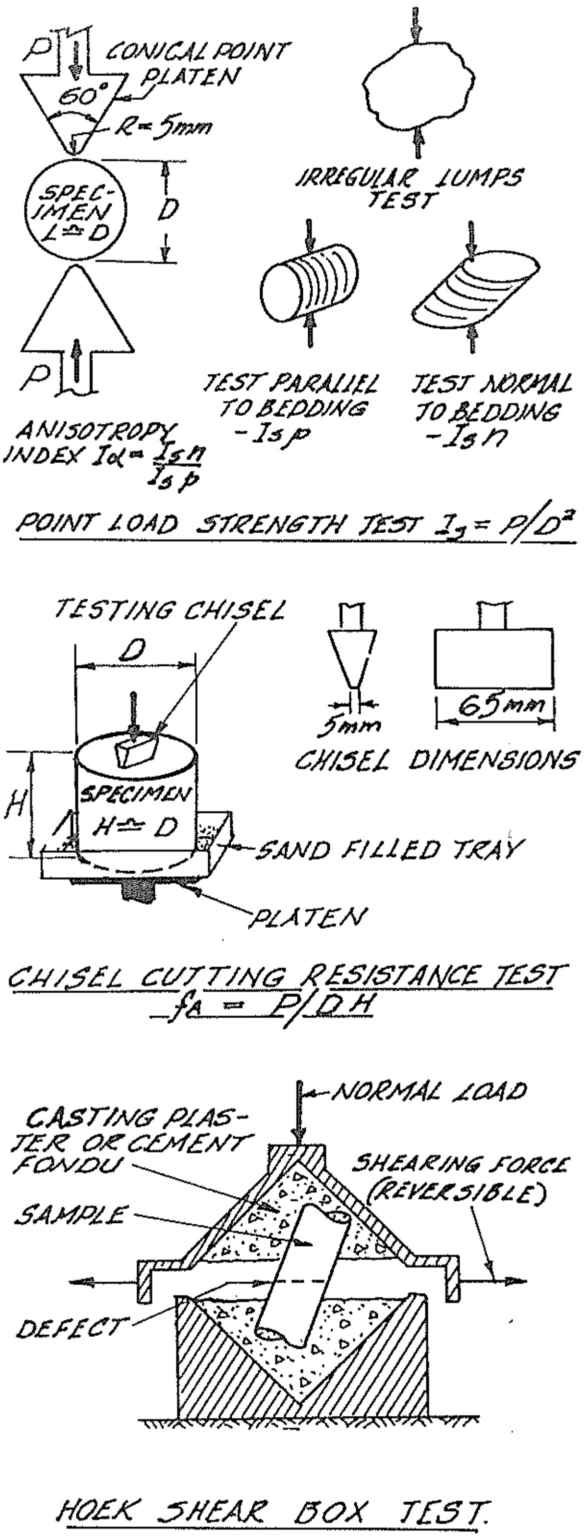

Figure 2 Description of Rock Strength tests

b) A conventional soil shear box

The two machines differ greatly in characteristics. The Hoek Shear Box (Hoek & Bray 1974) is designed to test defects in very strong rock and is very rigid and stiff in operation. Loading is by hand pumped hydraulic jacks which are difficult to operate accurately at very low strain rates; Accurate measurement of low shearing forces,

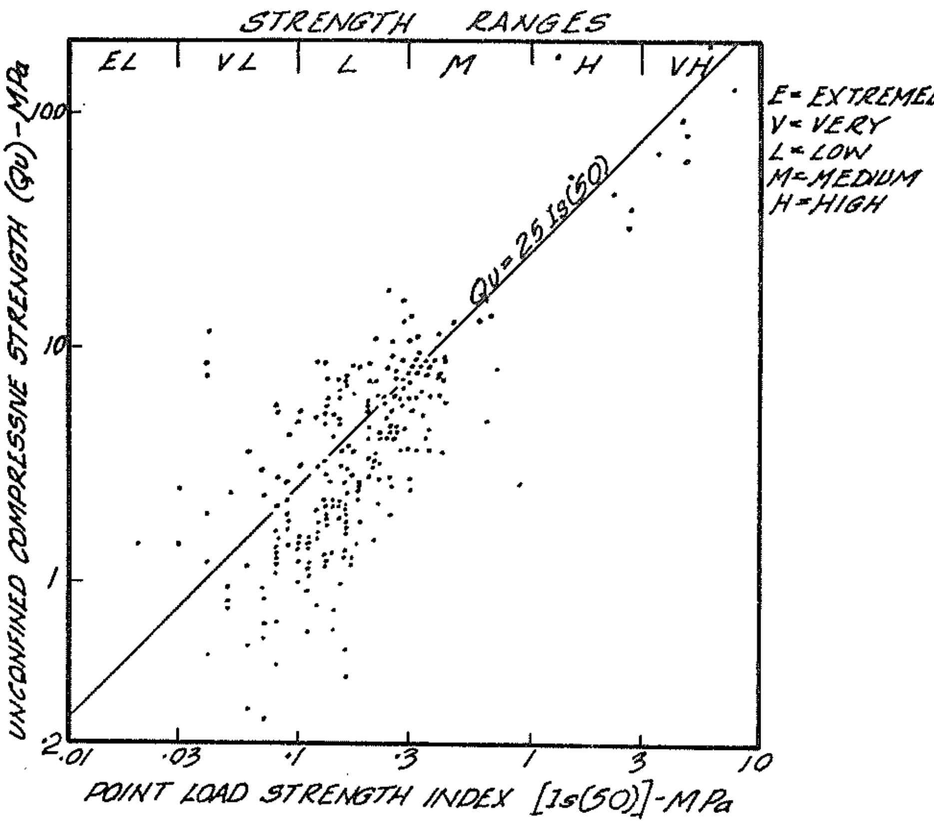

Figure 3 Unconfined Compressive Strength vs Point Load Strength Index

particularly when coupled with low normal loads is difficult and requires careful and detailed calibration of individual jacks. The sample (a length of core containing the defect) is first cast in a diamond shape mould and then sheared across the diagonal as shown on Fig. 2.

The soil shear box was a conventional Farnell constant strain type box with automatic mechanical feed . By use of a lever system normal pressures up to the equivalent of 30 m overburden could be applied. Preparation was by trimming into the box in the usual manner.

The strain rate used in the soil shear box was 10 mm/h. The Hoek shear box strain rate was between about 100 to 150 mm/h it being extremely difficult to hold steady normal and shearing loads at lower loading rates. Both boxes were capable of having the shearing force direction reversed so that repeated shearing cycles could be carried out in order to obtain residual strength parameters. Between 4 and 6 shearing operations were required at each normal pressure to obtain a repeatable minimum value.

5.2 Clay Seam Strengths

Typical shearing force-displacement curves for successive shearing cycles at the same normal pressure are presented in Fig. 4. The peak shear strength obtained in the first cycle is only slightly higher than the residual value after six cycles. This characteristic of peak strengths being little higher than residual values was common for most of the Leigh Creek defects and suggests that sufficient displacement and shearing has already occurred along the defects for their strengths to have approached residual values.

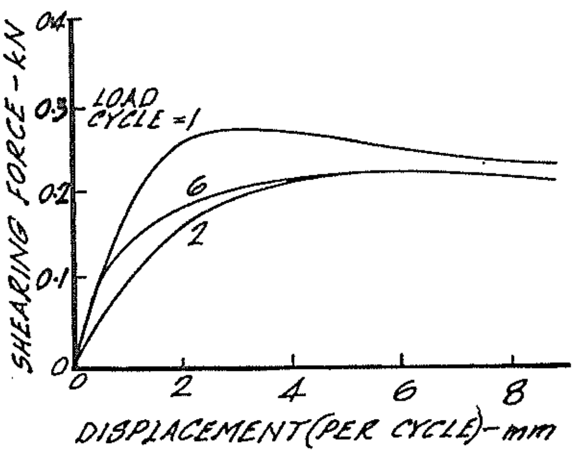

Figure 4 Typical load displacement curves on clay seam

The clay seams represent the weakest defects tested with residual friction angles down to 8 degrees and most values under 15 degrees. Residual angles of friction and apparent cohesion are summarised in the upper portion of Fig. 5. It is clear that the Hoek shear box gives significantly higher apparent residual cohesion values than the soil shear box for similar friction angles. It is considered that the apparent high cohesions are due to an excessive rate of shearing which does not allow sufficient time for pore pressure dissipation in the high plasticity, low permeability clays.

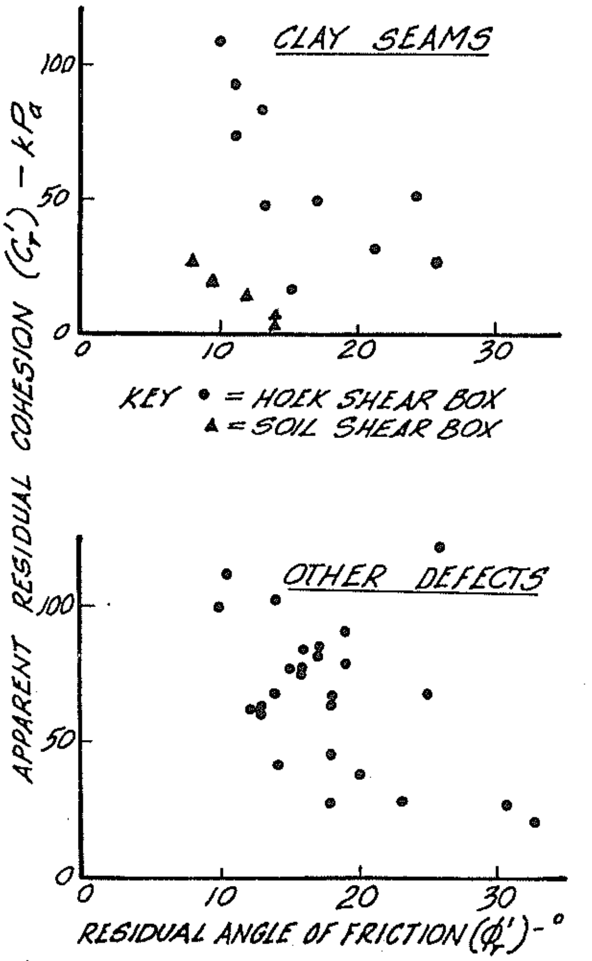

Figure 5 Summary residual shear strength tests

5.3 Other defects

Other defects which were strength tested included mainly slickensided and polished joints and sheared zones in mudstone and siltstone with some cemented sand/sandstone, and intact shale and coal also being tested. As shown on the lower portion of Fig. 5 the residual angles are higher than for the clay seams but still relatively low with most being under 20°. Apparent residual cohesion values are similar to the Hoek shear box results for clay seams. They should however be viewed with caution since most of the defects tested were in fine grained rocks where it is still possible for pore pressures to develop on the failure surface during shearing. Examination of the samples after completion of the tests often revealed the development of a layer of silt or clay material on the failure surface.

5.4 Application of Results

Low wall dips typically vary between about 10 and 30° which is considerably greater than the residual angle of friction of the clay seam. The effect of cohesion is relatively minor both because of the low values and the size of the failure mass. Clay seams have been found to be generally parallel to the bedding and to extend over considerable areas, thus as shown on Fig. 6 the bottom of the low wall contains a "plug" of rock which is placed in compression. A limiting depth is reached when failure occurs by crushing or buckling of the plug. The major constraints to mine planning identified to date have thus been:

a) that the dumping of overburden spoil on the low wall, thereby placing additional load on the plug, is not feasible except in limited cases without seriously reducing the allowable depth of mining, and

b) that there is a limiting depth to which mining may proceed before further flattening of the low wall is required.

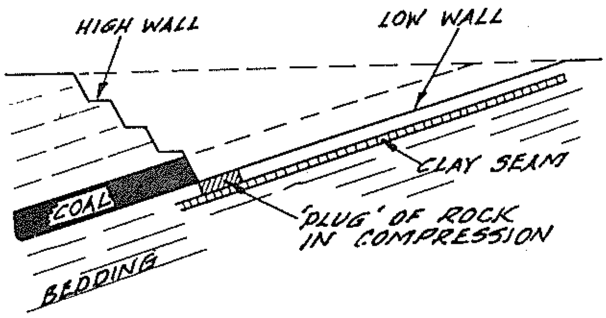

Figure 6 Low wall failure mechanism

6 DIGGABILITY

Part of the planning at Leigh Creek included a review of the most suitable type of excavation equipment for future use as the economic limit of mining with existing draglines was being approached. One alternative is the use of large bucketwheel excavators for overburden and coal removal. One of many tests developed by bucket-wheel manufacturers is the chisel cutting resistance (Rasper 1975) which consists of loading a 150 mm cube to failure with a chisel as shown on Fig. 2. Obtaining such large size samples at depth is both difficult and expensive. Samples were obtained at shallow depths by diamond coring in existing mine pits with right circular cylinders being judged sufficiently similar to cubes to not adversely affect results. Considerable care must be exercised in trimming the ends of the cylinders to be smooth and parallel.

It has been recognised (Coleman & Fitzhardinge 1979) that from the geotechnical viewpoint there is considerable similarity between the chisel cutting test and the top half of the point load test as may be seen from Figure 2.

Figure 7 presents a comparison of chisel cutting resistance and Point Load Strength Index. Also shown in the figure are the theoretical correlation obtained between the chisel and point load tests assuming different load conditions applied by the bottom platen in the chisel test. It may be seen that assuming the platen in the chisel test acts as the point of symmetry (applies UDL) of a point load test given a reasonable upper bound for cutting resistance by use of the much simpler and more economical point load strength index which may be carried out on core recovered at any depth.

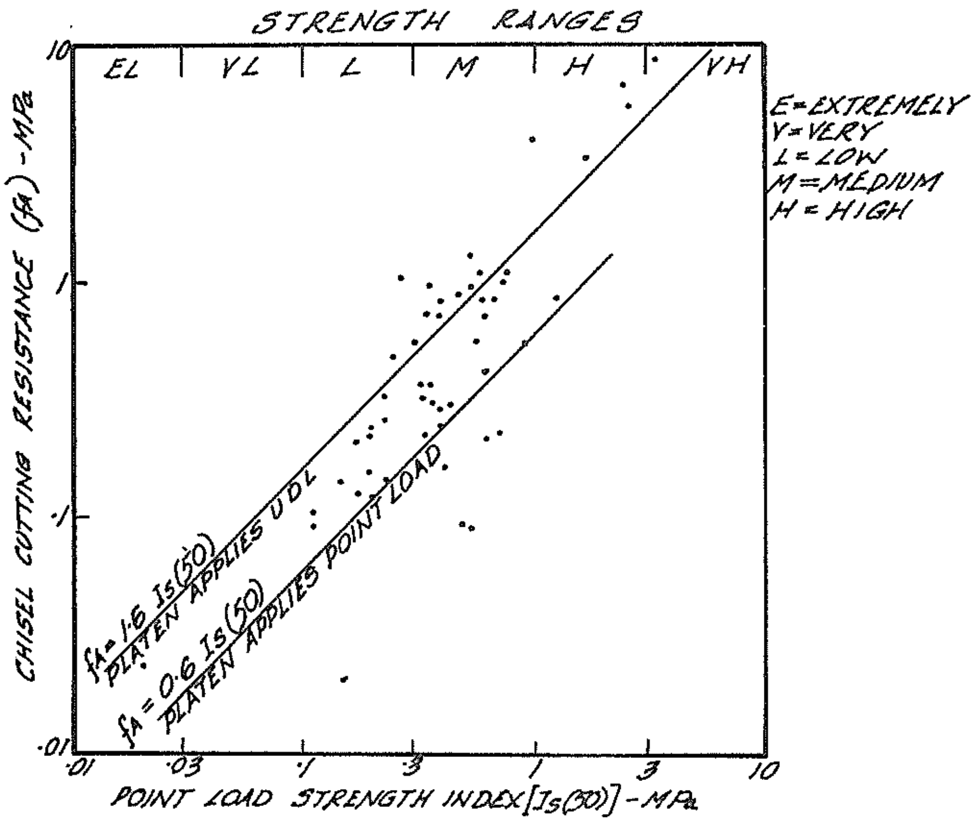

Figure 7 Chisel cutting resistance vs Point Load Strength Index

7 CONCLUSIONS

1. For a large and extended programme such as was carried out at Leigh Creek it is essential to systematically and progressively test all core with a simple and economical classification test which is capable of being correlated with more sophisticated, and usually expensive, tests for use in geotechnical analysis. The Point Load Strength Index has been found to be suitable as such a classification test. It may be readily carried out with portable equipment.

2. Many of the rocks at Leigh Creek are transitional in strength between strong clays and weak rocks and conventional shear boxes designed for soft soils or hard rocks are not ideally suited for determination of residual shear strength parameters. In particular the effect of strain rates needs to be carefully considered.

3. Sufficient movement has occurred along most defects at Leigh Creek to reduce their shear strength value to very close to residual strength and the latter are considered appropriate for use in stability analyses.

4. Correlations between Point Load Strength Index versus Unconfined Compressive Strength and chisel cutting resistance are presented.

8 ACKNOWLEDGEMENT

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9 REFERENCES

BROCH E. & FRANKLIN J.A. (1972). The Point Load Strength Test. Int. J. Rock Mech. Min. Sci. Vol. 9 pp 669-697

COFFEY & PARTNERS PTY. LTD. (1975). South-eastern margin - Report on Geotechnical Studies for Slope Design, Report No. A183/1-1 to Electricity Trust of South Australia. Unpublished.

COFFEY & PARTNERS PTY. LTD. (1979). Results of Geotechnical Investigations (1978), Report No. A183/4E to Electricity Trust of South Australia. Unpublished.

COLEMAN, J.R. and FITZHARDINGE, C.F.R. (1979) The Geotechnology of Excavation Equipment Selection with Particular Emphasis on Bucket Wheel Excavators. Int. Conf. Min. Mach., Brisbane. pp 139-146

HOEK E. & BRAY W. (1974). "Rock Slope Engineering", The Institution of Mining & Metallurgy. London.

I.S.R.M. (1972). International Society for Rock Mechanics Commission on Standardisation of Laboratory and Field Tests suggested methods for determining the Uniaxial Compressive Strength of Rock Material and the Point Load Strength Index - Committee on Laboratory Tests Document No. 1.

RASPER, L. (1975). "The Bucket Wheel Excavator". Trans. Tech. Publications.