A COMPARISON OF INFERRED CBR TEST RESULTS ON 'PERTH SANDS'

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ABSTRACT

This paper presents a comparison of inferred California Bearing Ratio (CBR) results obtained from a 4.5 kg Clegg Hammer, 20 kg Clegg Hammer, Perth Sand Penetrometer (PSP) and Dynamic Cone Penetrometer (DCP). Fieldwork was undertaken on four occasions at three locations within the Perth metropolitan area, namely at Preston Beach (Safety Bay Sand), Muchea (Colluvial Sand), and twice at Cockburn (engineered fill and Tamala Sand, the name of the sand derived from the Tamala Limestone). CBR values were inferred and the results from the different pieces of field equipment compared. Overall, at the locations tested, the 4.5 kg Clegg Hammer gave results that produced higher inferred CBR values, whilst the PSP inferred lower CBR values, with the CBR values inferred from the DCP and 20 kg Clegg Hammer in between.

1 INTRODUCTION

The California Bearing Ratio (CBR) test is a penetration test used in pavement design that evaluates the mechanical strength of road and airfield runway subgrades and basecourses. The test can be conducted in the field using a portable jack, loading plunger and reaction load such as an excavator or backhoe to jack against. The plunger is jacked into the subgrade at a constant rate and the load measured at regular depths of penetration. From this data the CBR may be obtained. However, it is common to rely on quicker and cheaper field methods to obtain design data and what is in fact an inferred CBR value.

The field equipment used to obtain an inferred CBR value includes the Dynamic Cone Penetrometer (DCP), 4.5 kg and 20 kg Clegg Hammers as well as the Perth Sand Penetrometer (PSP). The PSP was developed by Glick and Clegg in the 1960s, originally as a means of checking earthworks compaction of sand, as is commonly found in Perth. It is the authors' understanding there is no direct correlation from PSP to CBR, rather PSP results need to be converted first to an equivalent Young's Modulus and then to a CBR.

CBR testing can also be undertaken in a laboratory. However, from the outset it was not envisaged the testing would be undertaken in controlled laboratory conditions, rather it would reflect conditions that might be encountered on site.

2 THE SWAN COASTAL PLAIN

Perth is located on a coastal plain broadly comprising unconsolidated sediments or dune limestone, with the eastern suburbs on weathered Precambrian crystalline rocks. The coastal plain is underlain by between 30 m and 70 m of Quaternary superficial sands ('Perth Sands'), limestone and clay. As noted by McInnes (2003) 'Perth Sands' is a generic description, and they comprise a group of dunal soils that include the Bassendean, Spearwood and Quindalup Dune Systems. In turn these systems are sub-divided, with the Jandakot Sand being part of the Bassendean System, the Cottesloe and Karrakata soils lying within the Spearwood System, and the Safety Bay Sand a sub-system of the Quindalup Dune System.

The dune systems run parallel with the coast and increase in age from west to east. The sands are calcareous in nature, with the older (more easterly) leached to a greater extent to the point where after 200,000 years the Bassendean Sands are essentially siliceous. Silt and clay fractions vary and together with cementation (related to iron content) and density result in variable geotechnical properties that typically are inconsistent with depth and location (McInnes, 2003).

3 PERTH SANDS

Sands tested as part of this study included Safety Bay Sand, colluvial sand and sand derived from the Tamala Limestone, both *in situ* and engineered. The following summaries, except for that of colluvial sands, are taken from Commander (2003). The summary of colluvial sand is taken from the Geological Survey of Western Australia (GSWA) 1:50,000 Environmental Geology Series 'Muchea' sheet. Figure 1 illustrates the generalised surface geology of the Perth Basin, and the stratigraphic column of the Perth Basin sediments that follows (Table 1) is based on a similar table that appears in Commander (2003).

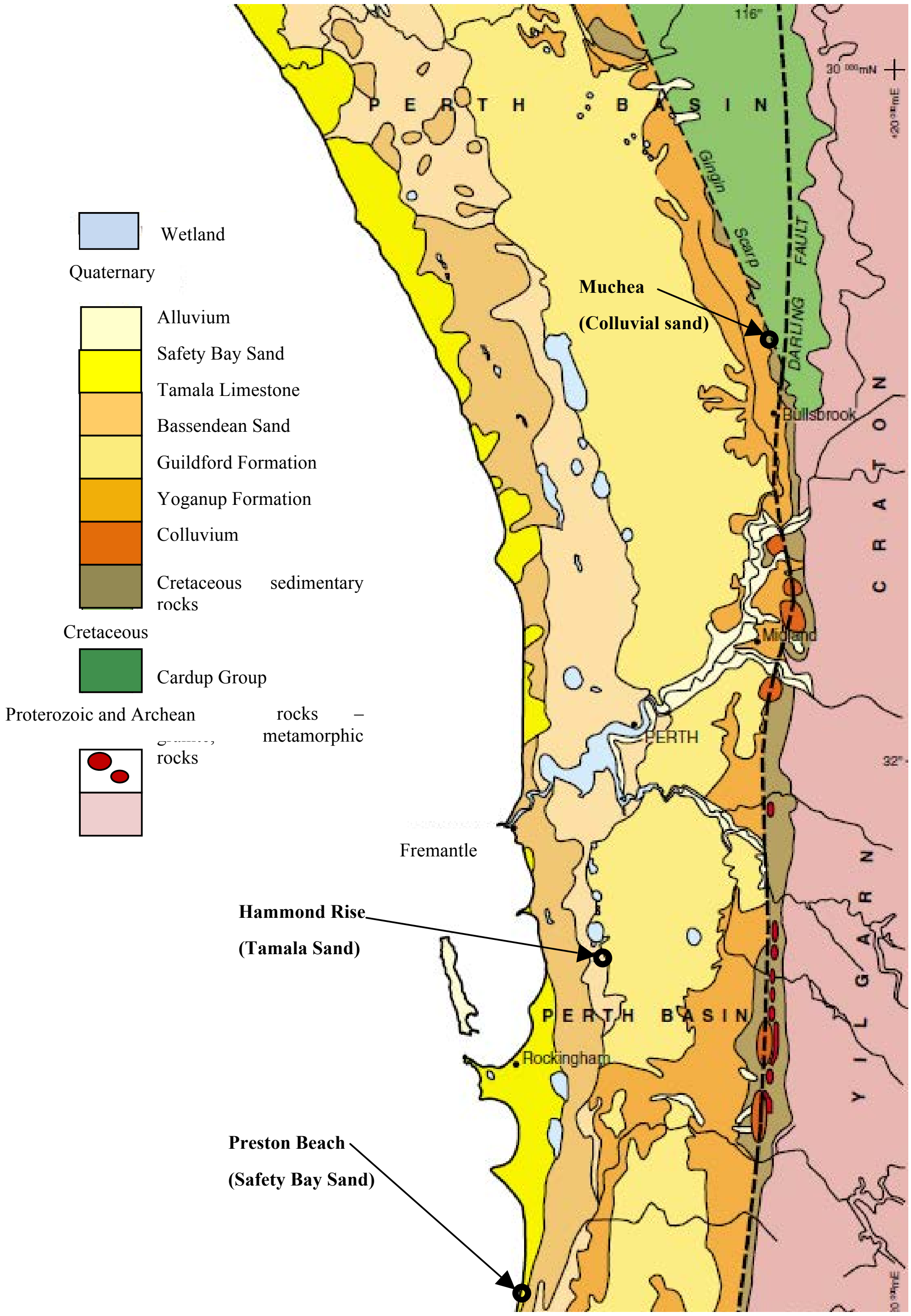

Figure 1: Simplified Geology of the Perth Region (Source: Gozzard, 2007)

Table 1: Stratigraphic column of the Perth Basin – Tertiary and younger (after Commander, 2003)

Age		Formation
Quaternary	Holocene	Alluvial, colluvial, estuarine and swamp deposits
		Muchea Limestone
		Safety Bay Sand
		Becher Sand
	Pleistocene	Tamala Limestone
		Bassendean Sand
		Gnangara Sand
		Guildford Clay
Tertiary	Pliocene	Ascot Formation
		Yoganup Formation
Major unconformity		
Tertiary	Pliocene	Rockingham Sand
	Palaeocene	Kings Park Formation
		Mullaloo Sandstone Member
		Como Sandstone Member

3.1 BASSENDEAN SAND (NOT TESTED)

Bassendean Sand is present over much of the Perth metropolitan area and is up to 80 m thick. A general description of the unit is light grey to white, yellow limonite-coated, fine to coarse-grained (predominantly medium-grained), moderately sorted, sub-rounded to rounded quartz sand. Fine-grained heavy minerals occur throughout the formation. The depositional mechanism for this unit is unclear; however, it was likely deposited in fluvial, estuarine and shallow-marine environments.

The Bassendean Sand provides building sand for mortars, concrete and construction fill.

3.2 TAMALA LIMESTONE

The Tamala Limestone extends along the coastal strip of the Perth region. The limestone consists of creamy-white to yellow or light grey cemented calcarenite and is likely to be up to 150 m thick. The lithology is highly variable, ranging from limestone through calcarenite to sand, with minor calcareous siltstone or marl. The sand derived from weathering of the limestone is fine to coarse-grained (predominantly medium-grained), moderately sorted, sub-rounded to rounded, quartz and commonly stained with limonite. For the purposes of brevity, sand derived from the Tamala Limestone is referred to as "Tamala Sand" within this paper. The depositional mechanism for this unit is coastal dunes.

The Tamala Limestone has been used for building stone and armour blocks. Parts of the formation with high lime content have also been used for cement manufacture.

3.3 SAFETY BAY SAND

The Safety Bay Sand was defined by Playford *et al.* (1976) to include Holocene age littoral sands (beach ridges) of the Rockingham area and the coastal aeolian sands of the Quindalup Sands and may be up to 100 m thick. A general description of Safety Bay Sand is: white, unlithified, calcareous (>50% $CaCO_3$), fine to medium-grained quartz sand and shell fragments with traces of fine-grained, black, heavy minerals. The sand is weakly lithified in places below the dunes.

3.4 COLLUVIAL SAND

Whilst technically not a Perth Sand, the colluvial sand, as encountered near Muchea, is typically light grey, fine to coarse-grained, moderately sorted, angular to sub-rounded quartz sand with some feldspar. The depositional mechanism for this unit is colluvial having been derived from the residual soils on the nearby slopes.

3.5 PARTICLE SIZE DISTRIBUTION TESTING

In addition to the field testing of the sands, two representative samples of each of the subsoils were taken for Particle Size Distribution (PSD) testing at a NATA accredited laboratory. The results are illustrated below in Figure 2. The PSD results largely confirm the similarity of the sands, with the Safety Bay Sand having a slightly higher proportion of fine-grained sand and the colluvial sands having higher coarse-grained sand content.

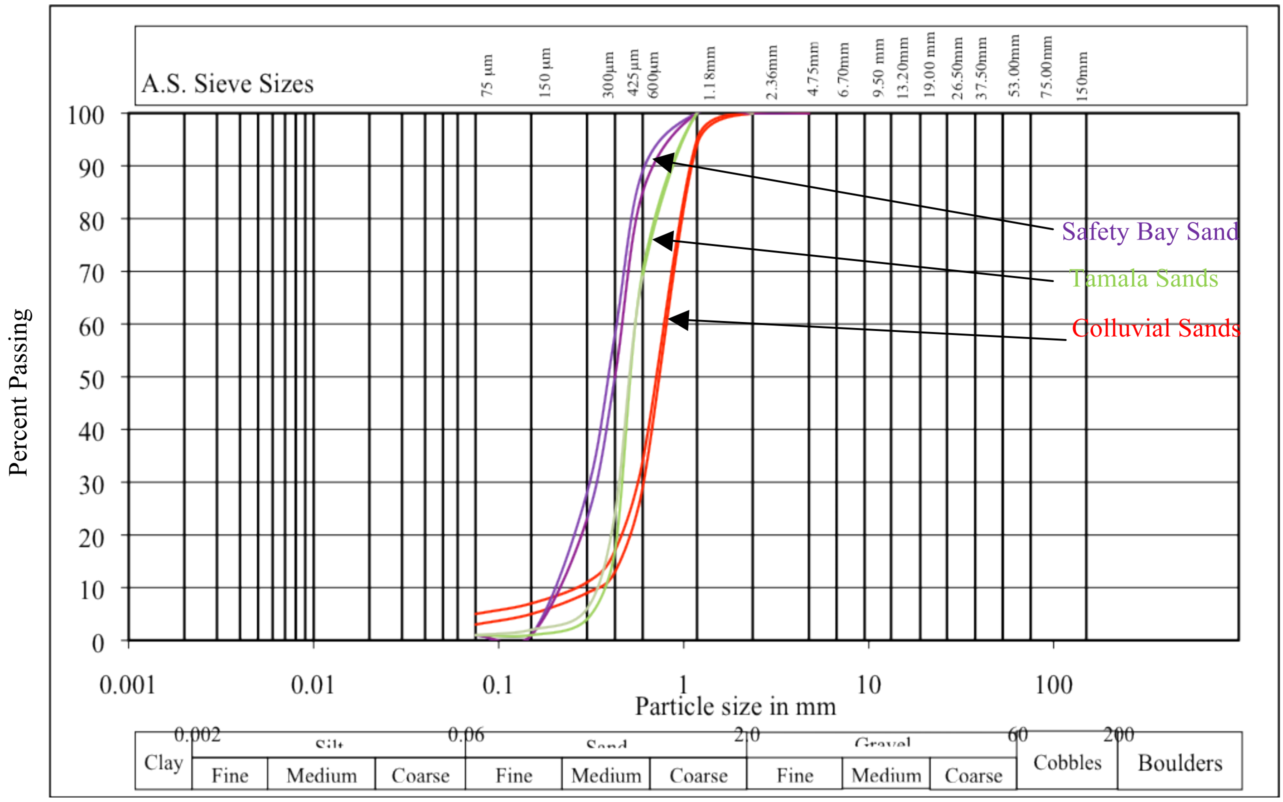

Figure 2: Particle Size Distribution results

4 FIELD EQUIPMENT

A brief description of the field equipment used in this study is presented below.

4.1 DYNAMIC CONE PENETROMETER (DCP)

The DCP is described in detail in Australian Standard AS 1289.6.3.2. It comprises a sliding 9 kg weight which delivers a known quantum of energy by falling through a height of 510 mm onto an anvil. The impact energy is used to drive a 30° angled, 20 mm diameter, pointed tip steel rod into the ground. Penetration resistance, N_p, is calculated by totalling the number of blows required to produce 300 mm of penetration over the selected test interval and from that an inferred CBR may be calculated.

4.2 PERTH SAND PENETROMETER (PSP)

The PSP was specifically developed for use on 'Perth Sands' and is described in detail in Australian Standard AS 1289.6.3.3. It comprises a sliding 9 kg weight which delivers a known quantum of energy by falling through a height of 600 mm onto an anvil. The impact energy is used to drive a 16 mm diameter, blunt tipped, steel rod into the ground. Penetration resistance, N_p, is calculated by totalling the number of blows required to produce 300 mm further penetration after the initial penetration of 150 mm (referred to as the 'set'). From the penetration between 150 mm and 450 mm an inferred CBR may be calculated.

4.3 4.5 KG CLEGG HAMMER

The 4.5 kg Clegg Hammer is described in Australian Standard AS 1289.6.9.1. It comprises a 4.5 kg, 50 mm diameter, blunt, compaction hammer operating within a vertical guide. When the hammer is released from the top of the guide it falls a fixed distance (455 mm) and strikes the surface being tested, and then decelerates at a rate determined by the stiffness of the material within the region of the impact. An accelerometer mounted on the hammer generates an electrical charge which is fed by a cable to a hand-held digital readout unit. The value recorded is termed the impact value; the test is then repeated to give a total of six impact values. From those six values the third, fourth and fifth values are used to determine a mean; if the range of the three values is less than 25% of their mean then the mean is accepted as the Clegg Impact value for that site. Typically a Clegg Hammer will give an indication of soil strength over a depth equivalent to at least twice the hammer diameter (Clegg Impact Soil Tester Newsletter No. 15, 1995), which in the case of the 4.5 kg hammer corresponds to a depth of approximately 100 mm.

4.4 20 KG CLEGG HAMMER

The 20 kg Clegg Hammer is described in ASTM Standard D5874. It comprises a 20 kg, 130 mm diameter, blunt compaction hammer operating within a vertical guide of lesser height (300 mm) than the 4.5 kg Clegg but otherwise is identical to that described above. In this case the soil strength to a depth of around 260 mm can be assessed.

5 FIELDWORK

Fieldwork was performed between April 2010 and June 2010. A test area comprising a 40 m long section of exposed sand was selected at each site. The four tests were conducted side by side along the 40 m section, at 2 m intervals. Each test was separated from adjacent tests by at least 0.50 m to reduce interference.

The initial 150 mm for a PSP test comprises the set and does not form part of the final blow count, hence a test section from 0.15 m to 0.45 m was chosen for both the PSP and DCP. In order to compare the PSP and DCP results with the Clegg Hammer results, the test locations for both the 4.5 kg and 20 kg Clegg Hammers were excavated to a depth of 0.15 m below the existing ground level prior to testing. In all, 80 separate tests were undertaken at each site, giving a total of 320 data points. No other preparation of the test sites, other than that described above, was undertaken.

Preston Beach (April 2010, in situ Safety Bay Sand) – The site was located on approximately level ground on the leeward side of the dunes behind the beach at Preston, some 125 km south of Perth CBD. The test section was located adjacent to the main path to the beach and is likely to have been traversed by pedestrians but not by vehicular traffic.

Cockburn (May 2010, Tamala Sand) - The site was located on approximately level ground close to a subdivision that was in the earthworks phase of construction in the Cockburn area some 25 km south of Perth CBD. With the assistance of the earthworks subcontractor the upper 250 mm of sand was removed and the test locations set out, as described above, on the newly exposed surface.

Cockburn (May 2010, Engineered Tamala Sand) - The site was located on level ground within a new subdivision in Cockburn some 25 km south of Perth CBD. As the site was currently part of a developing subdivision, it had undergone stripping of topsoil and proof-rolling.

Muchea (June 2010, in situ Colluvial Sand) - The site was located on broadly level ground within a larger parcel of land, that has been investigated as a potential sand resource, some 65 km north-east of Perth CBD. The test section was located well away from the area being investigated but is likely to have been traversed by both vehicular and pedestrian traffic, although probably only very occasionally in each case.

Figure 3: Test sections: clockwise from top left: Safety Bay Sand (Preston Beach), Tamala Sand (Cockburn), Colluvial Sand (Muchea) and Engineered Tamala Sand (Cockburn).

Upon completion of the testing, a representative bulk disturbed sample of sand was collected from each site for PSD testing at a NATA accredited laboratory. Descriptions, along with illustrative photographs, of each of the test sites are presented in Figure 3.

6 DATA INTERPRETATION

Following completion of the fieldwork the results were collated and CBR values calculated from the field results as summarized below.

6.1 DYNAMIC CONE PENETROMETER (DCP)

DCP blow counts were converted to inferred CBR values in accordance the method detailed in Scala (1956), as illustrated in Figure 4.

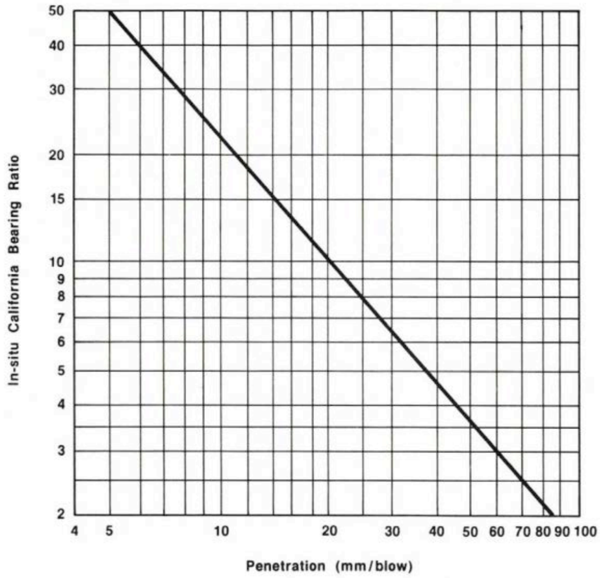

Figure 4: DCP penetration (mm/blow) versus CBR

6.2 PERTH SAND PENETROMETER (PSP)

At the time of writing there appeared to be no direct correlation between PSP blow count, N_p, and CBR. Therefore, based on Clegg (1979), PSP blow counts were converted to an equivalent Young's Modulus (E_s) from the correlation:

$$E_s = 0.8N_p + 2.5$$

The equivalent Young's Modulus values were then converted to CBR in accordance with Figure 3.1 from Austroads (2009) which provides an average correlation of Modulus (E) = 10 x CBR (range reported from 5 to 20 x CBR).

6.3 4.5 KG CLEGG HAMMER

The Clegg Impact Values (CIV) recorded on site were converted to CBR values in accordance with the correlation detailed in the July 1986 Clegg Impact Soil Tester Newsletter and reproduced below:

$$CBR = 0.06\,(CIV)^2 + 0.52\,(CIV) + 1$$

6.4 20 KG CLEGG HAMMER

The Clegg Impact Values (CIV) obtained from the 20 kg Clegg Hammer were converted to CBR values in accordance with the correlation detailed in the July 1986 Clegg Impact Soil Tester Newsletter and reproduced below:

$$CBR = 0.18\,(CIV)^2$$

7 RESULTS

Following calculation of inferred CBR values, the results were plotted as line graphs for each item of equipment at each location.

7.1 PRESTON BEACH (SAFETY BAY SAND)

Figure 5 illustrates the findings from Preston Beach (Safety Bay Sand).

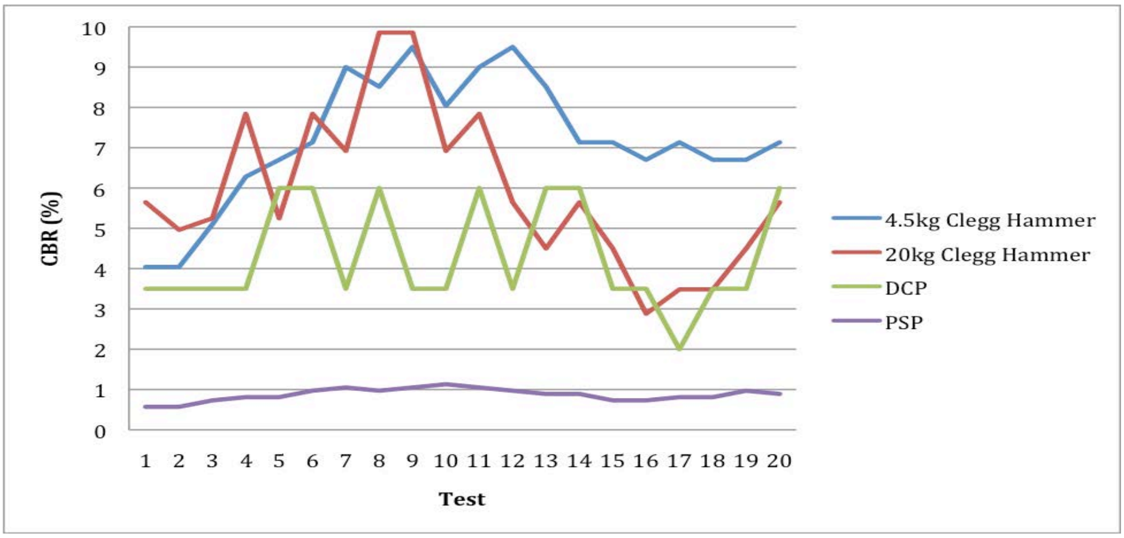

Figure 5: Inferred CBR of Safety Bay Sands

The CBR values derived from the PSP are consistently lower along the entire test section. The CBR values derived from the Clegg Hammers and DCP are noted to be variable along the test section. It is noticeable that the inconsistent results broadly mirror each other. The inferred CBR results for the tests on Safety Bay Sand are as tabulated below.

Table 2: Average CBR values for Safety Bay Sand

	PSP	DCP	4.5 kg Clegg Hammer	20 kg Clegg Hammer
Average CBR (%)	0.9	4.3	7.2	5.9
Minimum (%)	0.6	2.0	4.0	2.9
Maximum (%)	1.2	6.0	9.5	9.9
Standard Deviation	0.2	1.3	1.6	2.0

7.2 COCKBURN (“TAMALA SAND”)

The results of the testing conducted on the *in situ* “Tamala Sand” are illustrated in Figure 6.

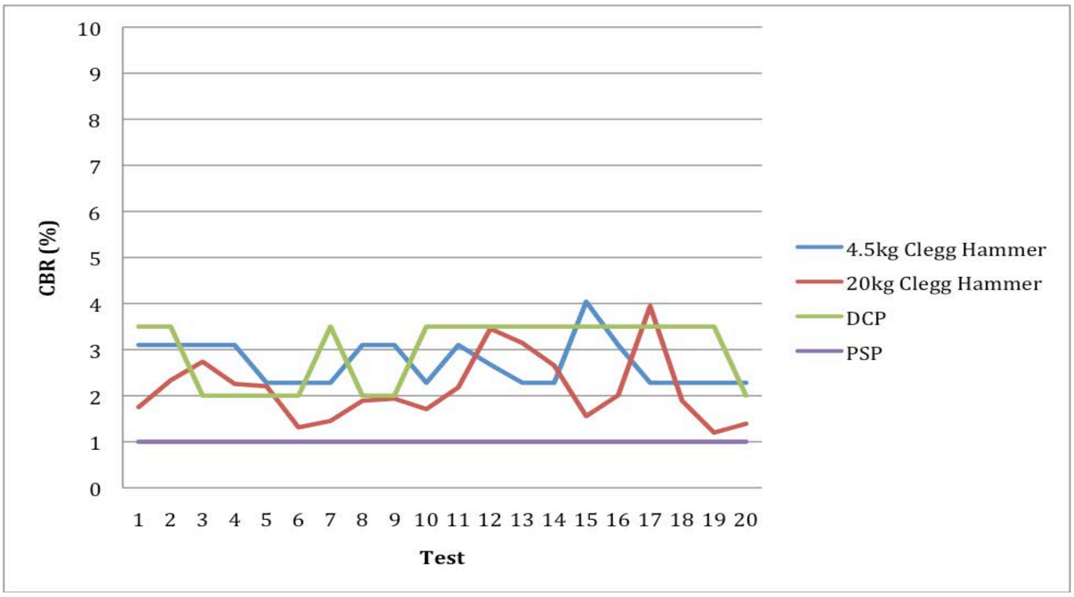

Figure 6: Inferred CBR of “Tamala Sand”

Again the CBR values derived from the PSP gave the lowest average results. The CBR values derived from the DCP and 4.5 kg Clegg Hammer gave the highest average values. The Clegg Hammer results appear to broadly mirror each other. The inferred CBR results for the tests on *in situ* "Tamala Sand" are tabulated below.

Table 3: Average inferred CBR values for *in situ* Tamala Limestone Sand

	PSP	DCP	4.5 kg Clegg Hammer	20 kg Clegg Hammer
Average CBR (%)	0.7	3.0	3.0	2.2
Minimum (%)	0.5	2.0	2.3	1.2
Maximum (%)	0.8	3.6	4.7	3.9
Standard Deviation	0.1	0.7	0.7	0.8

On returning to the site later in May 2010 testing was undertaken on a stretch of engineered sand (different to the section tested prior to earthworks earlier in May 2010) that was to form part of a new subdivision in the Cockburn suburb of Perth; the results of the testing are illustrated in Figure 7.

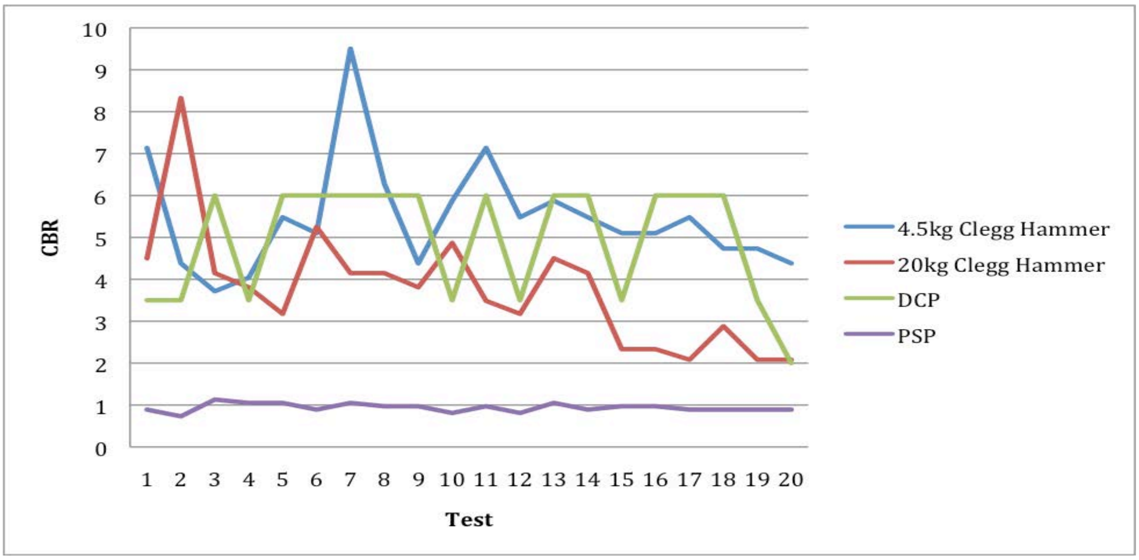

Figure 7: Inferred CBR of Engineered "Tamala Sand"

The PSP gave consistently lower CBR results, with the 4.5 kg Clegg Hammer giving the highest average result. The CBR values derived from the Clegg Hammers and DCP are noted to be variable along the test section. It is noticeable that the inconsistent results broadly mirror each other. The inferred CBR results for the tests on engineered Tamala Limestone Sand are as tabulated below.

Table 4: Average inferred CBR values for Engineered Tamala Limestone Sands

	PSP	DCP	4.5 kg Clegg Hammer	20 kg Clegg Hammer
Average CBR (%)	0.9	4.9	5.5	3.8
Minimum (%)	0.7	2.0	3.7	2.1
Maximum (%)	1.1	6.0	9.5	8.3
Standard Deviation	0.1	4.9	1.3	1.5

7.3 MUCHEA (COLLUVIAL SAND)

The final test section was in colluvial sands from near Muchea to the north of Perth. The results of the testing are illustrated in Figure 8.

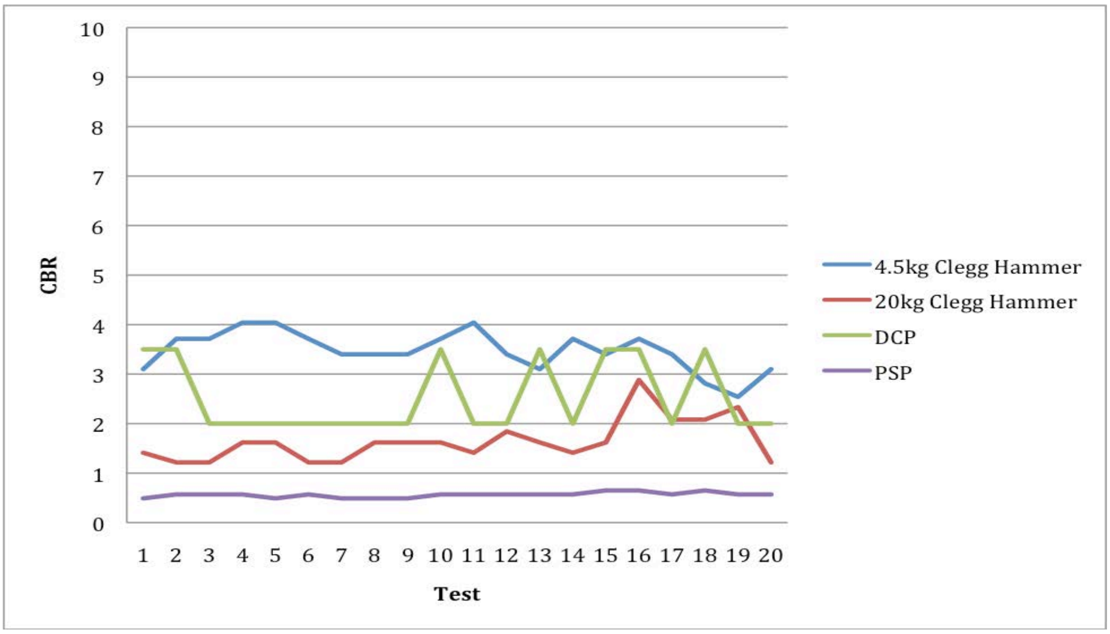

Figure 8: Inferred CBR of Colluvial Sands

As with the other sites the PSP gave consistently lower results when compared to the other items of equipment. The 4.5 kg Clegg Hammer gave the highest average inferred CBRs. The CBR values derived from the Clegg Hammers and DCP are noted to be variable along the test section, although the Clegg Hammer results broadly mirror each other. The inferred CBR results for the tests on Colluvial Sand are tabulated below.

Table 5: Average CBR values for Colluvial Sands

	PSP	DCP	4.5 kg Clegg	20 kg Clegg
Average CBR (%)	0.6	2.5	3.5	1.7
Minimum (%)	0.5	2.0	3.0	1.0
Maximum (%)	0.7	3.5	4.0	3.0
Standard Deviation	0.1	0.7	0.5	0.6

7.4 ALL SITES

When all of the CBR results are pooled and an average obtained for each of the four pieces of equipment then the following is indicated.

Table 6: Average CBR values all sand types

	PSP	DCP	4.5 kg Clegg	20 kg Clegg
Overall Average CBR (%)	0.8	3.7	4.7	3.4

8 DISCUSSION

This technical paper was born out of curiosity to see how four pieces of field equipment compared when tested on reasonably uniform soils. Analysis of the results was limited to simple graphing and averaging of results. No in depth statistical analysis has been undertaken or was envisaged.

The results are interesting in that the PSP, which was specifically developed for compaction control of Perth Sands, consistently gave significantly lower results than the other pieces of equipment. The obvious question is "why?." To the author's knowledge the PSP was not developed with the intent that it be used to infer CBR values. However the similarities between the pieces of equipment and the use of both the DCP and PSP in earthworks compaction control suggest it would not be unreasonable to expect the results to be similar. Whilst they are not an order of magnitude apart, the difference is sufficient to warrant further investigation. There would appear to be five possible reasons:

- Operator error,
- Heterogeneity of subsoils,
- It is not appropriate to use the PSP to investigate CBR values,

- The correlation used to convert PSP blow count to equivalent Young's Modulus is incorrect and
- The correlation to convert equivalent Young's Modulus to CBR is incorrect.

The first of these can be eliminated, given the simplicity of the equipment used and the fact that all the CBR values inferred from the PSP results were consistently low. Similarly, the second can be eliminated as it is expected that the top 0.45 m of the sand deposits that were tested with all four pieces of equipment are very similar.

The question of whether the PSP is appropriate to use for inferring CBR values was investigated by examining the trends noticed on the graphs. This was done by enlarging the scale of the PSP graphs to see whether they exhibited similar peaks and troughs to the results from the other pieces of equipment. At the scales shown in Figures 5 to 8, the PSP lines tend to be near horizontal and difficult to compare. However, Figure 9 shows the results for Safety Bay Sand using the 4.5 kg Clegg Hammer and the PSP with the scales manipulated. As can be seen, the PSP reflects similar peaks and troughs to the 4.5 kg Clegg Hammer.

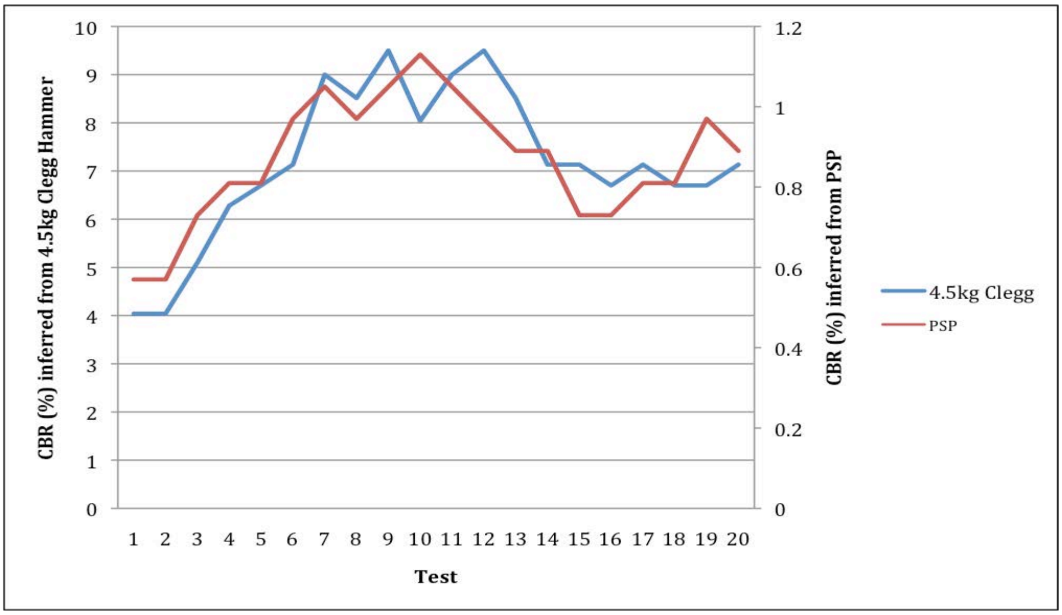

Figure 9: Inferred CBR for Safety Bay Sand using 4.5kg Clegg Hammer and PSP

When compared it can be seen the peaks and troughs for both the 4.5 kg Clegg Hammer and PSP correspond fairly well. This suggests that the PSP measures variations in the subgrade similar to the other pieces of equipment.

The correlations used to convert PSP blow counts to CBR values are shown in Section 6.2. It should be noted that the correlation of E = 10 x CBR is a mean of the correlations that have been established over the years. The reported accuracy of the correlation lies between E = 5 to 20 x CBR; in addition a number of other correlations have also been reported, with some subdivided into correlations for low CBR (<5%) and high CBR (>15%) (Austroads, 2009). However, the PSP results are still well below the averages of the three other pieces of equipment even if converted from Young's Modulus to CBR with a multiple of 20.

9 CONCLUSIONS

Unfortunately time and budget did not permit the use of field CBR equipment or laboratory determination of CBR values. Therefore, it was not possible to determine whether the actual CBR values of the sands should be closer to the CBR values inferred from the PSP or the DCP/Clegg Hammer test results. CBR values of >5% are typical for sands, in which case the CBR values should be closer to those inferred by the DCP and Clegg Hammer tests.

It is likely that the discrepancy in results is due to the correlations used for inferring CBR values from DCP and Clegg Hammer test results or else the fact a double correlation is required to convert PSP blow count to equivalent Young's Modulus and then to CBR. What is evident is that without further work to establish a direct correlation between PSP blow count and CBR, the use of the PSP to infer CBR values is not recommended.

Furthermore, it is evident there is variation between the other pieces of equipment used in the study. Therefore, without laboratory test results to compare, it is not advised to rely solely on the DCP or Clegg Hammer data for design purposes.

10 ACKNOWLEDGEMENTS

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A special thanks to Mark Drechsler for his review, comments and encouragement.

11 BIBLIOGRAPHY

ASTM D5874 (1995), *'Standard Test Method for Determination of the Impact Value (IV) of a Soil'* American Society for Testing and Materials

AS1289.6.3.2 (1997), *'Soil strength and consolidation tests – Determination of the penetration resistance of a soil – 9 kg dynamic cone penetrometer test',* Standards Australia

AS1289.6.3.3 (1997), *'Soil strength and consolidation tests – Determination of the penetration resistance of a soil – Perth sand penetrometer test',* Standards Australia

AS1289.6.9.1 (2000), *'Soil strength and consolidation test – Determination of stiffness of soil – Clegg impact value (CIV)',* Standards Australia

Austroads (2009), *'Review of relationship to predict subgrade modulus from CBR (California Bearing Ratio'*

Clegg, B (1979), *'Penetrometer Application, Sands, Perth',* Proceedings of the Jubilee Conference, Institute of Engineers Australia, Perth 1979

Clegg Impact Soil Tester Newsletter July 1986 *'Correlation with California Bearing Ratio'*

Clegg Impact Soil Tester Newsletter February 1995

Commander, P (2003). *Outline of the geology of the Perth region*, Australian Geomechanics Society Volume 38 Issue 3, September 2003

Environmental Geology Series, 1:50,000 scale, *Muchea*, Geological Survey of Western Australia

Gozzard, J R (2007), *SGeology and landforms of the Perth Region*, Western Australia Geological Survey

Gozzard, J R (2010), *Sea to scarp – geology, landscape, and land use planning in the southern Swan Coastal Plain*, Geological Survey of Western Australia

McInnes, D B (2003), *Perth Sands*, Australian Geomechanics Society Volume 38 Issue 4, December 2003

Playford, P E et al (1976) *'Geology of the Perth Basin in Western Australia',* Geological Society of Western Australia, Bulletin 124

Scala, A J (1956), *'Simple Methods of Flexible Pavements Design Using Cone Penetrometers'* Proceedings of Second Australia-New Zealand Conference on Soil