Determination of the Structural Number of Pavements on Volcanic Subgrades

Transfund New Zealand Research Report No. 213
Determination of the Structural Number of Pavements on Volcanic Subgrades

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Executive Summary

Pavements constructed on volcanic subgrades typically have higher deflections under load than similarly performing pavements constructed on other subgrades. This has created a difficulty in determining the structural strength of these types of pavements based on their deflection response when determined by instruments such as the falling weight deflectometer (FWD). The anomalous behaviour of volcanic subgrades means the standard methods used for assigning strength based on FWD readings cannot be used. The relationship between the in situ CBR (California bearing ratio) and FWD modulus of volcanic soils was investigated.

Past work was reviewed together with geological maps regarding the engineering properties and distribution of the volcanic soils within the North Island.

An attempt to class the volcanic soils into three main soil types was carried out. The location of 15 in situ test sites was then obtained. Site location was based on the amount of past work and the classification.

The performance of the 15 sites was investigated using the FWD, test pits, in situ CBR and other standards tests; and the Allophane content was also obtained.

From the results of the testing it was found that three correlations between the in situ CBR and the isotropic modulus were apparent.

These relationships were then used to derive a robust method to assess the structural number of pavements constructed on volcanic subgrades. Factors were presented based on the relationships and the process to enable the structural number to be calculated.

Factors for the use in Austroads pavement design were also presented.

To enable the Tonkin & Taylor method of indirect measurement of the structural number (SN) to be calculated on volcanic soils the addition of a constant was suggested (SNC), which should allow for the main differences between volcanic soils.

It is recommended that on volcanic soils a possible correlation between the FWD modulus and in situ CBR for volcanic soils on a network basis maybe:

- Isotropic Modulus = 1 × CBR, typically for pumice/sandy soils,
- Isotropic Modulus = 3 × CBR, mixture of Silty soils and Brown ash, (however, the relationship not well defined)
- Isotropic Modulus = 10 × CBR, typically includes clayey ash soils,
- That the above correlations be used to determine the CBR, which can be then used to calculate the SNC.
- That within the above relationship the modulus should be multiplied by 1.5 to obtain the vertical anisotropic modulus for use in Austroads design.
- That the T&T method for network surveys should be modified by the addition of 1.5, when using on pumiceous subgrades.
- That further research be performed to define the relationship between the FWD modulus and in situ CBR for volcanic silty soils.
Abstract

Pavements constructed on volcanic soils behave differently to non-volcanic soils and have higher deflections when dynamically loaded. Past relationships between CBR and modulus may therefore not be applicable. Fast non-destructive methods currently being used rely on these relationships and therefore relationship(s) between the CBR and modulus need to be obtained for volcanic soils. The project investigated the various volcanic soils within the North Island and attempted to classify the various types into three groups, initially based on the geological description and past work. In situ testing of the volcanic subgrades was conducted using the falling weight deflectometer (FWD) test and in situ CBR (California bearing ratio) together with other standard tests. From the in situ testing three correlations were identified for volcanic soils, however the third was not well defined. The volcanic soil types represented by the correlations were, clayey, pumiceous and silty/brown ash. To enable the structural number of pavements on volcanic soils to be determined, factors were presented, based on the identified relationships and the procedure for determining the structural number of pavement from the FWD modulus suggested. A modification of the Tonkin & Taylor method of determining the structural number was included which allowed for the use on volcanic subgrades. Also included were factors that allowed the volcanic relationships to be used in Austroads pavement design.
1 Introduction

1.1 Background

Pavements constructed on volcanic subgrades typically have higher deflections under load than similarly performing pavements constructed on other subgrades. This has created a difficulty in determining the structural strength of these types of pavements based on their deflection response when determined by instruments such as the falling weight deflectometer (FWD). The FWD is being used to obtain a measure of the pavement strength for use in pavement deterioration modelling as this is a rapid relatively inexpensive method suitable for network surveys. The anomalous behaviour of volcanic subgrades means the standard methods used for assigning strength based on FWD readings cannot be used.

As a large area in the Central North Island has volcanic subgrades and many of these areas are experiencing significant traffic growth, the application of pavement deterioration models in these areas will be constrained until an appropriate method is derived to determine their structural performance.

The concept of describing the strength of a pavement in terms of one number, called the structural number (SN), was developed from the AASHO road test published in 1962. The modified structural number (SNC) was developed to incorporate the contribution to the strength from the subgrade. The original definition of the SNC was based on the determination of the California bearing ratio (CBR) of the various pavement layers including the subgrade. The CBR test gives an indication of the shear strength of a material. Each pavement layer is then given a weighting based on its strength and thickness. The summation of these factors for each layer and the subgrade gives the SNC. The method for calculating the input into the modified structural number equation can be carried out either directly (CBR) or non-directly, using non-destructive methods.

The in situ determination of the CBR requires the digging of test pits and thus it is an expensive exercise. In order to obtain a faster and cheaper method the FWD has been used to calculate the modulus of the pavement layers and subgrade and then use a standard relationship between modulus and CBR to assign a strength factor to each layer. The FWD technique therefore, relies on the relationship between CBR and modulus.

Previous research performed by Central Laboratories on Taranaki brown ash demonstrated that the relationship between the CBR and modulus does not correspond to the standard relationship, which may lead to pavements being over-designed and the above non-destructive method to determine the SNC not applicable to volcanic soils. This has also been recognised by the RIMS group in their dTIMS implementation document “Establishing Pavement Strength for use with dTIMS” where the anomalous behaviour of volcanic subgrades has been highlighted. Therefore, for volcanic subgrades, the CBR FWD modulus relationship – to enable non-destructive methods to be used – needs to be determined.
The research project's aim was to develop a relationship between the subgrade CBR and FWD determined modulus so that this technique can be used for network surveys of pavement strength, the *structural number*.

Various studies have investigated different ways to determine the modified structural number. Salt and Stevens (2001) carried out a study to investigate the validity of the different methods, to determine which were applicable to New Zealand roads and developed an equation to determine the structural number from FWD non-destructive testing. This relationship however, was also derived from the standard CBR modulus relationship, and therefore to enable the equation to be used on volcanic subgrades an investigation to assess if the difference is significant must be carried out.

The results of this research will also be of benefit to pavement designers who at present accept that the performance of pavements on volcanic subgrades does not conform to the Austroads Pavement Design Guide. Although previous research reported in Transfund NZ Research Report No. 128 has given pavement designers information for areas on brown ash, for other volcanic subgrades the information is lacking. This research project will allow the expansion of the analysis performed in the previous research to be applied to other types of volcanic subgrades.

### 1.2 Objectives Of the Research

The objectives of this research were:

- To develop a relationship between the CBR and modulus derived from the FWD of volcanic soils;
- To use this relationship to derive a robust method to assess the structural number of pavements constructed on volcanic subgrades.
2 Background on Volcanic Soils

Volcanic ash showers have coated large areas of the North Island of New Zealand during the last 100,000 years Gibbs (1968). Some of the deposits have been removed by the elements or buried, but the ash deposits remaining are the principal soil-forming materials of the North Island. These deposits of volcanic ash have had a far-reaching effect, especially on soils and land use in the North Island. Slopes are generally smoother, and the soils more permeable, more friable, and more responsive to human management, than they would have been on land formed from the underlying rocks.

The principle centres of soil-forming ash showers in New Zealand are Mt. Egmont, Mt. Ruapehu, Mt. Ngauruhoe, Mt. Tongariro, Mt. Tarawera, and craters near Taupo, Rotorua, and the Bay of Plenty.

Two broad types of ash beds are recognised (Taylor 1933):

1. Intermittent type, in which materials are ejected on numerous occasions over a period of years. The materials are generally andesitic or basaltic and gradually build up a cone around the vent.

2. Paroxysmal type, in which materials are belched out in sudden explosions at long intervals. These materials are generally rhyolitic and are ejected from craters or rifts.

Most volcanic soils are best described as silty clays or clayey silts, despite the fact that they plot well below the Casagrande A-line on the plasticity chart (i.e. are clearly in the silt zone).

Gibbs (1968) grouped New Zealand volcanic soils into five representative soil types. These were: recent soils from volcanic ash, yellow-brown pumice soils, yellow-brown loams, brown granular loams, and red loams and brown loams. These soil types were useful as a base to begin to determine the classification of volcanic soils discussed in the next section.

Some volcanic ashes have been named to collectively describe the Andesitic tephas which were deposited during the Taranaki eruptions, e.g. the Taranaki brown Ash, which frequently occurs in thick weak to strongly weathered beds. This weathering process produces a succession of ‘clay minerals’ with initially allophane being formed, which in time (say 20,000 years) changes to halloysites and finally kaolin. Other groups include the Hamilton ashes and the Taupo pumice. The ashes are given their name from either the locality of the vent or the locality of where the ash is extensively exposed at the surface.
3 Classification of Volcanic Soil Types

3.1 General
To try and define possible areas of similar volcanic soil that could then be tested in their various groups, previous OPUS research and projects were reviewed, and other work was also taken into consideration. The engineering properties were collated and used to develop a broad classification for the various volcanic soils. A number of tests were used to develop the classification: a few of these were the geological description, the particle size distribution, atterburg limits and the CBR test. A summary of the findings regarding the engineering properties of volcanic soils is detailed below.

3.2 Engineering Properties of Volcanic Soils
It has been found from previous studies [Fullarton, (1978), Jacquet, (1987),(1988), Miller, (undated), Parton, and Olsen, (1980) Sutherland, et al. (1997) White, (1982), Pender, (1996), Wesley and Chan, (1991), Wesley, I.D. (1999)], that volcanic soils engineering properties are wide ranging. Some volcanic soils, for example the brown ashes, tend to be sensitive to remoulding, and some volcanic soils can also physically change their properties when remoulded and/or dried, the soil altering its particle size distribution (psd).

It has been reported that the clay mineral ‘allophane’ and to a lesser extent halloysite are in a large part responsible for the unusual psd changing properties. Allophane contributes to the greasy feel of the soil. The change in the psd occurs due to the effect of the water being expelled from the molecular particle structure by bond-breakdown analogous to the way ice becomes water. The gel-like structure of the clay minerals collapse and form aggregations, which in turn makes the soils ‘gritty’. These new aggregates are reported to have a relatively high stability.

The sensitivity to remoulding of these soils may be due to the oxidation of iron in the ash. Iron oxide has been reported to form a ‘structure’ between the particles, which is broken-down when remoulded.

Most undisturbed volcanic soils tend to have high bearing capacities, as high pre-consolidation pressures have been measured on undisturbed volcanic ash, accompanied by irregular variations with depth. As there is no geological evidence as to why these soils have a high over-consolidation ratio, it is thought that this is due to the oxidation of iron forming a type of structure within the soil matrix. Once this pre-consolidation pressure is reached the soils rapidly lose strength and are highly compressible, i.e. the structure has broken-down.

Apparent pre-consolidation pressures can vary markedly. It was reported by Miller (undated) that a brown ash material (grey in its reduced state) effectively exhibited no pre-consolidation and was recovered from within a local poorly drained area. Jacquet (1987) reported that the pre-consolidation pressure was directly proportional to the shear strength. The strength characteristics of the ash were also reported to vary depending on the degree of weathering, oxidation (drainage conditions) and saturation, Miller (undated). Therefore an oxidised ash, with the iron structural
matrix developed may be stronger up to the pre-consolidation pressure than an ash in its reduced state.

Pumice soils however, tend to be less sensitive to remoulding. This may be due to the kind of deposition and then cementation of the pumice grains, although some pumice soils still exhibit fairly high sensitivities, possibly due to larger amounts of iron present in some areas. Pumice soils also tend to be sandy and contain smaller amounts of the Allophane clay mineral; and therefore after remoulding, any change within the Allophane will be small and less likely to change the overall particle size distribution compared to such soils as clays.

In general, volcanic materials have been reported as having; a high particle density, due to the presence of heavy minerals, and a low dry density due to the high volume of voids. These voids have been found to be discrete internal voids within the particles themselves, and the particle shapes are angular, together with the rough microtexture which causes a high shear strength/friction angle. The soils also usually exhibit some cohesion. The natural moisture content of many of the soils, especially the brown ash soils, tends to be high, and in some case have been higher then the liquid limit. The liquid limit of the soils is also high compared to non-volcanic soils.

Care has to be taken in the interpretation of laboratory test results, as it has been found in New Zealand ashes that four different moisture/density relationships can be obtained, depending on whether a wet or dry soil is the starting point, and whether the same soil is used throughout or a fresh sample is taken for each compaction. Jacquet (1987). The clay mineral Allophane may be responsible for these relationships. However, for pumice soils their particle size distribution may change under compaction activities due to their soft (low crushing resistance) character and the presence of Allophane.

3.3 Broad Groupings

During the review of the existing data, it was found that the test results were wide ranging with overlapping of results making the defining of the volcanic soils difficult. In general a broad grouping of the pumice soils/sands and the brown ashes could be considered reasonable due to their difference in behaviour and engineering properties as discussed above.

An investigation into whether a possible relationship between the shear strength and the modulus of the volcanic soils already tested in the existing studies was conducted. The existing data was gathered together and a graph of modulus versus shear strength (equivalent CBR) was developed. It was found that two relationships were possibly forming, as shown in Figure 3.1.

Some correlation was observed in this figure, i.e.,

- Modulus = 6 × CBR \hspace{1cm} (3.1)
- Modulus = 3 × CBR \hspace{1cm} (3.2)

It can be seen that these relationships are different from the AUSTROADS relationship of ten times the CBR value. It was decided however, for purposes of the site selection, to group the various volcanic soils by their main geological description
i.e., Hamilton ashes, Taranaki brown ash and Taupo pumice. This was due to the previous data on volcanic soils in some cases shown in Fig 3.1 being incomplete and variable, and therefore inconclusive. By initially grouping the volcanic soils into their geological grouping it helped to make a base for the site testing and made the location of the site testing simpler. However, after the site testing we were open to other correlations which may develop, which was found to be the case as reported in section 6.5.

Figure 3.1 Graph of Modulus versus Equivalent CBR value from past work.

In order to obtain results from locations spread throughout the North Island, (so that a broad set of test results, and therefore relationship, could be obtained) the location of the testing from the existing reports were plotted on a map of the North Island. This allowed areas where relatively little information was available, to be identified. These areas were considered a priority to achieve more information so a potentially broad relationship could be obtained for volcanic soils, if there was one. The site selection covered the main volcanic soils in the central North Island.
4 Site Selection

4.1 General

As discussed in section 3, the volcanic ashes grouping was based on their geological description and from the geological map (Rijkse and Hewitt, 1995). The three groupings were the pumiceous soils, the Taranaki brown ashes and the Hamilton ashes. The existing data was plotted on the geological map. So that areas where little information existed could then be identified easily. Sites were selected so that together with the existing data the results would enable a wide spread of sites within the broad groupings to be obtained and so that the testing was not duplicated.

It was found that a relatively large amount of information existed for the Taranaki brown ashes. Little information on the modulus and shear strength of the pumice soils was available for areas tested at the same site. Areas in the Hamilton ashes were shown to have been tested fairly extensively but were wide ranging. It was decided therefore, to select more sites in the pumice soils to achieve a spread of results, to test a few sites on the brown ashes to verify previous data, and to obtain a spread of data throughout the Hamilton ash to identify a possible relationship in their variability.

A detailed site inspection ensured that the sites were not located on fill and were representative of the surrounding area. Fifteen sites in total were selected.

4.2 Site locations

Due to the lack of existing information in the pumice soils, five sites were selected. The location of sites 1 to 5 are shown in Figure 4.1 and a more detailed description of each site is included in Table 1, with a site location plan for each site in appendix A. A relatively large amount of existing test results was available for Taranaki brown ash so it was decided to select only two sites in this area to confirm the existing data, sites 6 and 7. An additional site was also selected on 'brown soil', (Hewitt 1998 classification) site 8. This site was selected to determine the soil’s properties and to investigate whether they are similar to the volcanics, due to the sites close proximity to the brown ash and allophanic soils.

Previous testing around the Hamilton area has provided information on volcanic ash within the area, but because of the variability of the ash falls three sites were chosen to try and determine if a pattern to the variability could be found (sites 9, 10 and 11). Two non-volcanic soils were also tested within this area to try and assess their difference between volcanic soils (sites 14 and 15). These sites were also used as a control. South of Auckland low-strength soils can be found, but the main volcanic material is from weathered Basaltic and pyroclastic deposits. One site was located on this ‘granular material’ (site 12), together with a site located between Hamilton and Pukekohe (site 13).
Description of selected sites; (A detailed site location plan for each site can be found in appendix A)

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Soil Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>Okere Falls, Okere Road</td>
<td>Pumiceous</td>
</tr>
<tr>
<td>Site 2</td>
<td>Lichfield, Vospers Road</td>
<td>Pumiceous</td>
</tr>
<tr>
<td>Site 3</td>
<td>Murupara, Golf Road</td>
<td>Pumiceous</td>
</tr>
<tr>
<td>Site 4</td>
<td>Waiotapu, Jay Road</td>
<td>Pumiceous</td>
</tr>
<tr>
<td>Site 5</td>
<td>Bennydale, SH30</td>
<td>Pumiceous</td>
</tr>
<tr>
<td>Site 6</td>
<td>Stratford-Inglewood, Tariki Road</td>
<td>Brown ash</td>
</tr>
<tr>
<td>Site 7</td>
<td>Waitara-Urenui, Upper Epiha Road</td>
<td>Brown ash</td>
</tr>
<tr>
<td>Site 8</td>
<td>Whangamomona, SH43</td>
<td>Brown soil</td>
</tr>
<tr>
<td>Site 9</td>
<td>Pio Pio, Mairoa Road</td>
<td>Hamilton ash (south)</td>
</tr>
<tr>
<td>Site 10</td>
<td>Hamilton-Cambridge, Day Road</td>
<td>Hamilton ash</td>
</tr>
<tr>
<td>Site 11</td>
<td>Te Poi, Stopfords Road</td>
<td>Hamilton ash (east)/pumice</td>
</tr>
<tr>
<td>Site 12</td>
<td>Pukekohe, Coles Road</td>
<td>Granular material</td>
</tr>
<tr>
<td>Site 13</td>
<td>Taupiri, Jew Road</td>
<td>Hamilton ash (north, granular)</td>
</tr>
<tr>
<td>Site 14</td>
<td>Te Awamuta, Bowman Road</td>
<td>Non-volcanic</td>
</tr>
<tr>
<td>Site 15</td>
<td>Cambridge, Peake Road</td>
<td>Non-volcanic</td>
</tr>
</tbody>
</table>

Table 4.1 Sites selected for testing
Figure 4.1 Location of the test sites in volcanic soils
5 Testing

5.1 Testing Conducted

After each specific site had been located, ensuring that the sites were not located on fill and were representative of the surrounding area, on-site testing was carried out. Testing at each of the 15 sites included;

- two logged/photographed test pits, for the identification of the pavement layers, the subgrade and the depth;
- *in situ* CBR tests were performed on the subgrade, together with dynamic cone penetrometer tests, moisture contents. Allophane contents were also determined and the subgrade density. Atterburg tests were conducted at the laboratory.

Testing was carried out to NZS 4402 (refer to appendix B for the test results).

Falling weight deflectometer (FWD) tests were also carried out to determine the modulus of the subgrade. FWD tests were conducted and marked out before the test pits were dug so that the two could be located on the same part of pavement. The FWD testing involved testing the section of roadway in one direction at 20m intervals for a length between 100 to 200m. At least two loading levels were used to give a measure of the stress dependency of the subgrade. The modulus results from the FWD testing are included in the summary in Appendix B.
6 Results and Analysis

6.1 General

The results from the on-site and laboratory testing, and the FWD were analysed and relationships between the CBR and the FWD derived modulus determined for volcanic soils.

This relationship was then used to determine factors for the determination of the CBR from the FWD modulus so that the structural number (SN) for pavements could be obtained and also the determination of the vertical modulus from the CBR for use in Austroads pavement design.

The indirect method of determining the SNP (the SNC for thin pavements) from the deflection results without knowledge of the pavement structure [developed by Tonkin & Taylor (Salt and Stevens, 2001)] was also examined, and a factor for modifying the relationship for the different subgrade types determined.

6.2 Results from the Trial Pits

Two test pits were dug at each site with measurements of in situ CBR and scala penetrometer values obtained. Laboratory testing of samples was also conducted.

Results from the Allophane testing showed variable amounts of the clay mineral Allophane throughout the sites tested. In general the highest concentrations were found to be located south of Hamilton. Medium levels were obtained near Tauranga and Taranaki. The soils near Taranaki and Tauranga have been historically sensitive to remoulding and able to change their psd (Jacquet 1987), initially reported to be due to the Allophane mineral present: however from the testing, this may not be the only reason. As suggested in section 3, the sensitivity may also be due to the breakdown of the soil matrix due to the oxidation of iron within the soil.

The Allophane test results are summarised in Table 6.1 with the test pit results summarised and presented at the beginning of appendix B.

6.3 FWD Analysis

6.3.1 General

Transfund Research Report No. 117 describes the procedure for the detailed structural analysis of the pavement from the shape of the deflection bowl. Basically, the outer deflections define the stiffness of the subgrade while the bowl shape close to the loading plate allows analysis of the stiffness of the near-surface layers. A broad bowl with little curvature indicates that the upper layers of the pavement are stiff in relation to the subgrade. A bowl with the same maximum deflection but high curvature around the loading plate indicates that the upper layers are weak in relation to the subgrade.

A back-analysis procedure is generally adopted to find moduli from an observed deflection bowl. Once the pavement profile model is established, a forward-analysis can be carried out to determine the strains for say, a modelled rehabilitation treatment such as overlay.
<table>
<thead>
<tr>
<th>Site Number</th>
<th>Location</th>
<th>Allophane &gt;7% (High)</th>
<th>Allophane 5-7% (Medium)</th>
<th>Allophane &lt;5% (Low)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Okere Falls</td>
<td>PP1,PP2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Lichfield</td>
<td>PP1,PP2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Murupara</td>
<td></td>
<td></td>
<td>PP1,PP2</td>
</tr>
<tr>
<td>4</td>
<td>Waiotapu</td>
<td></td>
<td></td>
<td>PP1,PP2</td>
</tr>
<tr>
<td>5</td>
<td>Bennydale</td>
<td>PP2</td>
<td></td>
<td>PP1</td>
</tr>
<tr>
<td>6</td>
<td>Stratford - Ingle</td>
<td></td>
<td></td>
<td>PP1,PP2</td>
</tr>
<tr>
<td>7</td>
<td>Waitara - Urenui</td>
<td></td>
<td></td>
<td>PP1,PP2</td>
</tr>
<tr>
<td>8</td>
<td>Whangamonoma</td>
<td></td>
<td></td>
<td>PP1,PP2</td>
</tr>
<tr>
<td>9</td>
<td>Pio Pio</td>
<td>PP1,PP2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Hamilton - Cam</td>
<td>PP1</td>
<td></td>
<td>PP2</td>
</tr>
<tr>
<td>11</td>
<td>Te Poi</td>
<td></td>
<td></td>
<td>PP1,PP2</td>
</tr>
<tr>
<td>12</td>
<td>Pukekohe</td>
<td></td>
<td></td>
<td>PP1,PP2</td>
</tr>
<tr>
<td>13</td>
<td>Taupiri</td>
<td></td>
<td></td>
<td>PP1</td>
</tr>
<tr>
<td>14</td>
<td>Te Awamutu</td>
<td></td>
<td></td>
<td>PP1</td>
</tr>
<tr>
<td>15</td>
<td>Cambridge</td>
<td></td>
<td></td>
<td>PP1,PP2</td>
</tr>
</tbody>
</table>

$PP1 = test pit 1, PP2 = test pit 2$

Table 6.1 Results from the Allophane testing

6.4 ELMOD

Back-analysis to determine the subgrade modulus from the FWD data was carried out using the ELMOD (Evaluation of Layer Moduli and Overlay Design) programme. ELMOD (Dynatest 1989) is based on the Odemark-Boussinesq transformed section approach (Ullidtz 1987), and can combine both the back and forward analysis.

ELMOD has the capacity to analyse non-linear subgrade moduli as stress dependent (rather then depth dependent from sublayering). It will only analyse isotropic materials. The package only requires one subgrade layer because it uses the deflections to calculate C and n in the non-linear subgrade modulus relationship:

$$E = C \left(\frac{\sigma_z}{\sigma^*}\right)^n$$

(6.1)

where:
- $E$ modulus of elasticity,
- $C$ and $n$ are constants,
- $\sigma_z$ is the vertical stress and,
- $\sigma^*$ is a reference stress.
The reference stress is introduced to make the equation dimensionally correct, with E and C then both having the dimensions of stress. The exponent ‘n’ is a measure of the non-linearity of the subgrade modulus. If ‘n’ is zero the material is linear elastic. Soft cohesive soils may have an ‘n’ value between −0.3 and −1, indicating the amount of non-linearity in the soil.

ELMOD analysis can be carried out either with or without knowing the thickness of the pavement; in this case the depth of the pavement to the subgrade was found from the test pits and inputted into the analysis.

ELMOD calculates the isotropic modulus of the pavement materials. The Tonkin and Taylor (1998) report infers that, if the calculated FWD ELMOD subgrade moduli are to be used in CIRCLY for Austroads pavement design (for anisotropic granular materials), then the moduli would have to be multiplied by 1.5 to model the vertical modulus for the subgrade with an anisotropic modulus, \( E_v = E_h \) of 2. The horizontal modulus would then be calculated from \( 0.5 \times E_v \).

Relevant results for this project found from the FWD analysis include the modulus of the subgrade and basecourse, C, subgrade modulus exponent ‘n’, deflection and stress level.

The results for the subgrade modulus show some variations in value at each site, but in general are small, so it can be assumed that they are a natural variation along the length of the pavement. These variations may also be due to volcanic soils within the basecourse layer clouding the indicated modulus for the subgrade.

Results of the subgrade modulus are plotted in Figure 6.1 together with the results of the in situ CBR.

6.5 FWD Modulus CBR Relationship

It has been documented (Tonkin & Taylor 1998) that the modulus CBR relationship may vary by a factor of two. Austroads pavement design for granular roads have suggested using 10 times the CBR for all soils to obtain the vertical anisotropic modulus, and 6.7 times the CBR value for isotropic modulus. It has been found from previous reports, Sutherland et al. (1997), that this may not be the case for volcanic soils.

Traditional pavement design charts and the structural number have been determined from the measured CBR value. Because of time and money constraints, non-destructive testing to obtain the modulus of the pavement is now used. However, the basis of the CBR value is still used to obtain the design and life of the pavement. Therefore the relationship \( 10 \times \text{CBR} \), and thus the pavement design, may be correct for tested CBR values: however, the determination of the CBR from the measured in situ modulus may not be correct, especially for volcanic soils.

The results from the in situ testing are shown in Figure 6.1. Both the FWD subgrade modulus and in situ CBR of the subgrade have been plotted. It is apparent that two relationships can be seen, with a possible third in between.
It was found that, in general, the sandy pumiceous soils lay near the bottom of the graph, with the clayey volcanic materials forming the steeper relationship. A linear regression was carried out and the following correlations found:

\[
\text{Isotropic modulus} = 10 \times \text{CBR}, \quad \text{for clayey volcanic soils} \quad (6.2) \\
\text{Isotropic modulus} = 1 \times \text{CBR}, \quad \text{for pumiceous sandy soils} \quad (6.3)
\]

These relationships are very different from each other and may account for the reason for the many discrepancies occur in the testing of volcanic soils.

![Graph of FWD Isotropic Modulus versus in situ CBR for tests.](image)

**Figure 6.1** Graph of FWD Isotropic Modulus versus *in situ* CBR for tests.

The $R^2$ for the correlations shown on Fig 6.1 are reasonable for a network study. However for localised areas the relationships may vary somewhat, and therefore the use in project level tools requires some caution, Patrick and Dongol (2001).

The data obtained from previous projects was also added and plotted on the same graph, Fig 6.2.

The possible third relationship can now also be seen although not well defined. Variations with the test data made it difficult to make precise judgements regarding the relationship. Largely the two main constituents of soil type that could be found producing this relationship were Silty soil and Brown ash.

Therefore an additional relationship, which will need additional data to define, for volcanic Brown ash and silty soils is:

\[
\text{Isotropic modulus} = 3 \times \text{CBR} \quad (6.4)
\]

Transfund Research Report No. 128 also recommended a relationship of $3 \times \text{CBR}$ for brown ashes.
Figure 6.2 Graph of Isotropic Modulus versus CBR for current data and previous data.

A possible reason why this relationship may not be well defined, is that when remoulded the clayey materials containing the Allophane mineral tend to alter their particle size distribution into more like a silt, and may therefore lie below the $10 \times \text{CBR}$, and obscures the third relationship.

The possible explanation for relationships in Fig 6.2, may lie in the structure and grain shape of the volcanic soils. Pumice soils tend to be sandy and have sharp angular grains which would indicate a high CBR value; however, due to their structure, under the FWD loading the pumice soils exhibit a high elastic deformation and therefore low modulus when back-analysis of the FWD results are carried out. This type of behaviour can be seen in Fig. 6.2. The clayey soils on the other hand are finer grained and usually exhibit higher water contents, which may lead to lower CBR values and higher modulus values when dynamically loaded by the FWD. This relationship can also be seen in Fig 6.2.

Consequently silty soils tend to lie in-between the two relationships owing to being neither clays or sandy, as would be expected. The brown ash is slightly different in that is shows a low modulus and a low CBR value. This maybe due to: the Allophane content, as discussed above, the in situ structure of the soils as pumice, and the fined grained nature of the soil producing a low CBR. The degree of saturation, an unknown variable in the in situ CBR test, may affect the results slightly.

The above correlations are not dissimilar to the groups used to select the various site locations for testing (section 3.3). The pumiceous were mainly sandy soils, and the Hamilton ashes mostly clayey soils. The Taranaki soils however, which were also classified in the test pits as clayey, lay closer to the middle correlation together with the silty soils. Again, this may be due to the behaviour of Allophane, as suggested above.

The above relationships are also similar to those presented on Figure 3.1, with the brown ash largely forming the 3 times relationship. However, the 6 times CBR
relationship (equation 3.1), is different – this may be due to the presence of the Allophane changing the psd of the soil as discussed above. In general the presence of the Allophane material tended to affect the results, in that some variation was found which affected the correlations – but the content of the mineral did not seem to affect the results too much.

6.5.1 Summary of the FWD, in situ CBR relationship

The relationships discussed above can be summarised into three subgrades types A, B, and C:

A: Typically pumice/sandy soils, isotropic modulus = 1 \times CBR \hspace{1cm} (eqn. 6.3)
B: Mixture of silty soils and brown ash, isotropic modulus = 3 \times CBR
(However, the relationship is not well defined.) \hspace{1cm} (eqn. 6.4)
C: Typically includes clayey ash soils, isotropic modulus = 10 \times CBR (eqn.6.2)

6.6 Calculation of Modified Structural Number (SNC)

The modified structural number (SNC) is an indication of the pavement strength and has been adopted in a number of empirically based pavement design and deterioration models of organisations such as AASHTO (1986), the Transport and Road Research Laboratory (1977), and the World Bank (Paterson, 1987).

Structural numbers can be determined using direct or indirect methods. Direct methods use measurements of the strengths of each of the layers in a pavement and indirect methods are generally based on deflections of the entire pavement (Patrick and Dongol 2001).

A number of different ways have been developed, to calculate the structural number. Some indirect methods however, are based on correlations obtained from back-calculations (against more direct methods); and have limitations that need to be understood (Patrick and Dongol 2001).

To determine the SNC using non-destructive methods an indication of the relationship between CBR and modulus needs to be known.

During a FWD test the deflection of the pavement is back-analysed to obtain a measurement of modulus of the various pavement layers. The calculated modulus of the basecourse and subsequent layers can be inputted into the structural number equation directly, but the subgrade contribution to the strength of the pavement cannot as it is based on the CBR. The calculated modulus therefore requires to be converted into a CBR value. As discussed in section 6.5 this relationship for volcanic soils indicates that it is different to the standard modulus = 10 \times CBR usually used for soils. Factors presented below allow the structural number to be determined for volcanic subgrades, based on the relationships indicated in section 6.5.
The structural number, including the additional variable for subgrade strength, is defined as follows:

\[ SNC = \left(\frac{1}{25.4}\right) \sum_{i=1}^{n} a_i h_i + SN_{sg} \]  \hspace{1cm} (6.5)

where  
\[ a_i = \text{layer coefficient} \]
\[ h_i = \text{thickness of layer, mm} \]
\[ SN_{sg} = \text{structural number contribution from the subgrade} \]

\[ a_i = a_g (E_i/E_g)^{1/3} \]  \hspace{1cm} (6.6)

where  
\[ a_g = \text{layer coefficient of standard materials (AASHTO road test as listed in Table 6.2)} \]
\[ E_i = \text{layer modulus (in this case, from FWD)} \]
\[ E_g = \text{modulus of standard materials (AASHTO road test as listed in Table 6.2)} \]

<table>
<thead>
<tr>
<th>LAYER TYPE</th>
<th>LAYER Coe ( a_g )</th>
<th>RESILIENT MODULUS ( E_g ) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt concrete surface coarse</td>
<td>0.44</td>
<td>3100</td>
</tr>
<tr>
<td>Untreated and stabilised base course</td>
<td>0.14</td>
<td>207</td>
</tr>
<tr>
<td>Granular Subbase</td>
<td>0.11</td>
<td>104</td>
</tr>
</tbody>
</table>

Table 6.2 Layer coefficients and resilient modulus of standard materials in AASHTO road test.

The contribution to the structural number from the subgrade was derived by Hodges et al. (1975).

\[ SN_{sg} = -0.85 (\log \text{CBR})^2 + 3.51 (\log \text{CBR}) - 1.43 \]  \hspace{1cm} (6.7)

where CBR = California Bearing Ratio of the subgrade (percent).

Traditionally, when determining the structural number of pavements, the CBR for the subgrade has been obtained from the in situ CBR testing. However, faster non-destructive testing is now being used, such as the FWD test. As the FWD only gives the modulus of the pavement materials, a relationship between the CBR and FWD modulus must be obtained to allow equation 6.7 to be calculated. But while \( 10 \times \text{CBR} \) has been used by Austroads, for some volcanic soils this is not applicable. Patrick and Dongal (2001) also state that care must also be taken when determining the structural number on volcanic subgrades, in that due to the ‘bouncy’ nature of the soils cracking may be an issue. They suggest that a second SNP [SNC for thin pavements] should be derived which may give a better prediction of cracking.
6.6.1 Factors which the isotropic modulus should be divided by to obtain CBR for determination of SNC

From the FWD, *in situ* CBR relationship, summarised in section 6.5.1., the table below gives a factor which the FWD isotropic modulus should be divided by to obtain a value for CBR which can then be inputted into eqn 6.7.

<table>
<thead>
<tr>
<th>Volcanic Soil Type</th>
<th>A (pumice)</th>
<th>B (mixture Silty)</th>
<th>C (Clayey)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>1</td>
<td>≈ 3</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 6.3 Factor for the determination of CBR for SNC calculations

These factors should only be used for the determination of the SNC, as the isotropic modulus is used.

6.6.2 Steps to obtain the SNC from FWD measurements

Once the FWD testing has been carried out by the back-analysis of the deflection bowl, the isotropic modulus for each layer can be calculated and subsequently the CBR of the subgrade can be obtained. Depending on the subgrade type, the factor from Table 6.3 can be used to obtain the CBR value from the isotropic FWD modulus. An example is shown in Table 6.4.

<table>
<thead>
<tr>
<th>Volcanic Soil Type, section 6.5.1</th>
<th>FWD isotropic Modulus MPa (<em>obtained from testing</em>)</th>
<th>Factor from Table 6.3 (Modulus divided by)</th>
<th>CBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
<td>3</td>
<td>16.7</td>
</tr>
<tr>
<td>C</td>
<td>50</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 6.4 Example of using factors in Table 6.3

Using equation 6.7 the contribution to the pavement strength from the subgrade can be obtained. Inputting the modulus of the pavement layers into equation 6.6 together with Table 6.2 the contribution to the strength of the pavement obtained from the pavement layers can be obtained. The various contributions to the strength are then summed (equation 6.5) which gives the SNC for that particular pavement.

6.7 Determination of the Anisotropic and Isotropic Modulus for input into Austroads Pavement Design

For the Austroads pavement design on granular pavements; traditionally the anisotropic vertical modulus is calculated from $10 \times \text{CBR}$. The isotropic modulus is calculated from $6.7 \times \text{CBR}$. If these relationships were to be used for pavement design on volcanic subgrades, due to the ‘bouncy’ nature of volcanic soils that leads to low FWD modulus, a low CBR would be obtained, and the road may therefore be over designed. For volcanic soils the following is recommended: that the factor in
Table 6.5, be multiplied by the CBR to obtain the vertical modulus and isotropic modulus respectively, which can then be inputted into Austroads pavement design.

<table>
<thead>
<tr>
<th>Volcanic Soil Type</th>
<th>A (pumice)</th>
<th>B (mixture Silty)</th>
<th>C (Clayey)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor Vertical Modulus</td>
<td>1.5</td>
<td>≦ 4.5</td>
<td>15</td>
</tr>
<tr>
<td>Factor for Isotropic Modulus</td>
<td>1</td>
<td>≦ 3</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 6.5 Factor to be applied to the CBR to determine the vertical/isotropic modulus for input into Austroads pavement design.

6.7.1 Example using Factors for Pavement Design

An example of using the factors in Table 6.5 is presented below for determination of the vertical modulus for the input into Austroads design.

<table>
<thead>
<tr>
<th>Volcanic Soil Type, section 6.5.1</th>
<th>CBR</th>
<th>Factor from Table 6.5 (CBR multiplied by)</th>
<th>Anisotropic vertical modulus MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50</td>
<td>1.5</td>
<td>75</td>
</tr>
<tr>
<td>B</td>
<td>16.7</td>
<td>4.5</td>
<td>75</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>15</td>
<td>75</td>
</tr>
</tbody>
</table>

Table 6.6 Example of using the factors in Table 6.5 to determine the anisotropic vertical modulus.

6.8 Modification to T&T deflection based assessment of structural number

To estimate indirectly the SNC or (SNP for thin pavements) Patrick and Dongal (2001) recommended that the T&T method (Salt and Stevens, 2001) be used for network surveys, as it was derived using typical New Zealand pavements. The method requires no information regarding the thickness of the pavement or the soils properties; only the deflection bowl measurements. The equation used is

\[
SNP = 112(D_0)^{0.5} + 47(D_0-D_{950})^{0.5} - 56(D_0-D_{1500})^{0.5} - 0.4 \quad (6.8)
\]

However, to derive this equation equation 6.7 was used together with the standard relationship for the Modulus CBR, defined by Emery and used in the AASHTO method 1 (1986) where equation 6.9 was used which may not be applicable to volcanic soils.

\[
E_{sg} = 41.19\ CBR^{0.385} \quad (6.9)
\]
The different relationships for the CBR modulus presented for the different volcanic subgrade types will affect the CBR calculated for equation 6.7, and therefore will also affect the T&T equation 6.8.

To try and obtain an approximate solution to this problem so that equation 6.8 could be used on volcanic soils, the SNs [calculated from equation 6.7] difference between using Emery's equation (6.9), and the relationships for volcanic soils, was plotted, Fig.6.3.

![Graph showing SNs difference vs Modulus MPa](image)

**Fig 6.3 Comparison with the T&T method**

Fig 6.3 shows two relationships for volcanic soils (the third was not used as it was not well defined). The difference between the CBR = Mod × 0.1 (clayey) and Emery (equation 6.9) is small, and with the T&T equation (6.8) the error is of a similar magnitude and therefore within its limits.

However, for the CBR = Mod × 1 relationship (pumice) the difference is larger, between 1 and 2. To enable equation 6.8 to be used on pumiceous soils on a network level this difference will have to be taken into account. It is proposed to use the average 1.5 difference and add this to equation 6.8, giving equation 6.10:

\[
\text{SNP} = 112(D_0)^{-0.5} + 47(D_0-D_{900})^{-0.5} - 56(D_0-D_{1500})^{-0.5} + 1.1
\]  

(6.10)

This relationship is not an exact fit but should be sufficient for network surveys. If a more exact fit is required the fundamental equations should be used, using *in situ* CBR.
7 Summary and Conclusions

Volcanic soils tend to produce larger elastic deformations when a dynamic load is applied compared to non-volcanic soils. At present the CBR is calculated from the vertical modulus by dividing by ten, or 6.7 in the case of isotropic modulus or using Emery's equation. However, past studies have indicated that this may not be applicable to volcanic soils. By using the relationship above, a low value for subgrade CBR is produced, giving a low structural number resulting in an under-prediction of the life of the pavement in dTIMS. Conversely, if that low subgrade CBR were used for pavement design, the pavement would be over-designed. In order to determine a relationship for volcanic soils, between the FWD modulus and in situ CBR, 15 test sites were located and tested.

It has been found that deposits of volcanic soils are extensive over the North Island. Past work has indicated that some volcanic soils are sensitive to remoulding due to the oxidation of iron, which forms a matrix within the soil. During remoulding this matrix breaks down causing a drop in strength of the soil. Volcanic soils containing the mineral Allophane also expel water when remoulded and the soil particles form aggregations, and effectively change the psd of the soil to one more silty.

The different behaviour of volcanic soils to non-volcanic soils therefore depends largely on the minerals present within the soil.

The engineering properties of volcanic soils are variable due to their amount of weathering, minerals and remoulding. A classification of volcanic soils based on their geological description was presented and 15 sites were selected based on the location of past work. Testing at each site included two test pits with measurements of scala and in situ CBR. FWD testing was also carried out.

The subgrade modulus, obtained from the FWD tests (via ELMOD), was plotted on a graph with in situ CBR. The following relationships were obtained for volcanic soils.

A: Typically pumice/sandy soils, Isotropic Modulus = 1 x CBR
B: Mixture of silty soils and brown ashes, Isotropic Modulus = 3 x CBR
(However the relationship is not well defined)
C: Typically includes clayey ash soils, Isotropic Modulus = 10 x CBR

These relationships can then be to be used in pavement deterioration modelling and pavement design. Factors were presented which related the modulus to CBR for structural number modelling, and CBR to vertical modulus for pavement design, Table 6.3 and 6.5.

The procedure for determining the Structural Number of pavements on volcanic subgrades using the presented CBR, modulus relationships was presented. A modification to the deflection bowl based on the T&T method was also proposed, (equation 6.10), which allowed the structural number to be estimated on pumice volcanic subgrades.
8 Recommendations

It is recommended that on volcanic soils a possible correlation between the FWD modulus and in situ CBR for volcanic soils on a network basis maybe:

- Isotropic Modulus = 1 x CBR, typically for pumice/sandy soils,
- Isotropic Modulus = 3 x CBR, mixture of silty soils and brown ash, (However, the relationship is not well defined)
- Isotropic Modulus = 10 x CBR, typically includes clayey ash soils,
- That the above correlations be used to determine the CBR, which can be then used to calculate the SNC.
- That within the above relationship the modulus should be multiplied by 1.5 to obtain the vertical anisotropic modulus for use in Austroads design.
- That the T&T method for network surveys should be modified by the addition of 1.5, when using on pumice subgrades.
- That further research be performed to define the relationship between the FWD modulus and in situ CBR for volcanic silty soils.
References and Bibliography


dTIMS implementation document “Establishing Pavement Strength for use with dTIMS”.


Appendix A
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 1 OKERE FALLS
(Okere Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 2 LICHFIELD
(Vospers Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 3 MURUPARA
(Golf Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 4 WAIOTAPU
(Jay Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 5 BENNYDALE
(SH 30)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 6 STRATFORD-INGLEWOOD
(Tariki Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 7 WAITARA-URENUI
(Upper Epiha Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 9 PIO PIO
(Mairoa Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 10 HAMILTON-CAMBRIDGE
(Day Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 11 TE POI
(Stopfords Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 13 TAUPIRI
(Jew Road)
VOLCANIC SOILS PROJECT
LOCATION MAP
SITE: 15 CAMBRIDGE
(Peake Road)
<table>
<thead>
<tr>
<th>Site Number</th>
<th>Location</th>
<th>Subgrade Description</th>
<th>In-Situ CBR</th>
<th>CBR (from Scala)</th>
<th>Modulus from the FWD</th>
<th>Water Content %</th>
<th>Dry Density t/m3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Okere Falls</td>
<td>Pumice SAND</td>
<td>35</td>
<td>45</td>
<td>2</td>
<td>2</td>
<td>17.5</td>
</tr>
<tr>
<td>2</td>
<td>Lichfield</td>
<td>SILT/fine SAND</td>
<td>16</td>
<td>10</td>
<td>4</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>Murupara</td>
<td>Pumice SAND</td>
<td>50</td>
<td>40</td>
<td>8</td>
<td>7</td>
<td>29</td>
</tr>
<tr>
<td>4</td>
<td>Waipatipu</td>
<td>Pumice SAND</td>
<td>60</td>
<td>55</td>
<td>18</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>Bennydale</td>
<td>1SILT, rare CLAY2Pum SAND</td>
<td>3</td>
<td>19</td>
<td>2</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Stratford Ingle</td>
<td>CLAY</td>
<td>5</td>
<td>11</td>
<td>2</td>
<td>2</td>
<td>27</td>
</tr>
<tr>
<td>7</td>
<td>Waitara - Urenui</td>
<td>CLAY</td>
<td>30</td>
<td>18</td>
<td>16</td>
<td>5</td>
<td>77</td>
</tr>
<tr>
<td>8</td>
<td>Whangamonona</td>
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<td>19</td>
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<tr>
<td>9</td>
<td>Pio Pio</td>
<td>SILT</td>
<td>9</td>
<td>6</td>
<td>5</td>
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<td>30</td>
</tr>
<tr>
<td>10</td>
<td>Hamilton - Cami</td>
<td>SILT</td>
<td>8</td>
<td>9</td>
<td>4</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>Te Poi</td>
<td>SILT, rare CLAY</td>
<td>9</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>19</td>
</tr>
<tr>
<td>12</td>
<td>Puketokoko</td>
<td>CLAY, some silt</td>
<td>10</td>
<td>15</td>
<td>7</td>
<td>5</td>
<td>55</td>
</tr>
<tr>
<td>13</td>
<td>Taupiri</td>
<td>CLAY</td>
<td>11</td>
<td>20</td>
<td>10</td>
<td>12</td>
<td>106</td>
</tr>
<tr>
<td>14</td>
<td>Te Awamutu</td>
<td>SAND</td>
<td>80</td>
<td>100</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>15</td>
<td>Cambridge</td>
<td>SILT, rare CLAY</td>
<td>9</td>
<td>12</td>
<td>5</td>
<td>5</td>
<td>25</td>
</tr>
</tbody>
</table>

Appendix B Summary of in-situ test results
## Test Results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Location: Okere Road</td>
<td>Voppers Road</td>
<td>Golf Road</td>
<td>Jay Road</td>
</tr>
<tr>
<td>Sample ID: PP1</td>
<td>PP2</td>
<td>PP1</td>
<td>PP2</td>
</tr>
<tr>
<td>Liquid Limit: Non</td>
<td>Non</td>
<td>84</td>
<td>88</td>
</tr>
<tr>
<td>Plastic Limit: (Sand)</td>
<td>(Sand)</td>
<td>See Note 1</td>
<td>See Note 1</td>
</tr>
<tr>
<td>Plasticity Index: NP</td>
<td>NP</td>
<td>PP1</td>
<td>PP2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Location: Tariki Road</td>
<td>Upper Eruhia Road</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample ID: PP1</td>
<td>PP2</td>
<td>PP1</td>
<td>PP2</td>
</tr>
<tr>
<td>Liquid Limit: 109</td>
<td>Non</td>
<td>Non</td>
<td>48</td>
</tr>
<tr>
<td>Plastic Limit: 56</td>
<td>Plastic</td>
<td>55</td>
<td>31</td>
</tr>
<tr>
<td>Plasticity Index: 53</td>
<td>(Sand)</td>
<td>See Note 1</td>
<td>SH43</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Location:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample ID: PP1</td>
<td>PP2</td>
<td>PP1</td>
<td>PP2</td>
</tr>
<tr>
<td>Liquid Limit: 182</td>
<td>129</td>
<td>92</td>
<td>82</td>
</tr>
<tr>
<td>Plastic Limit: 107</td>
<td>98</td>
<td>67</td>
<td>60</td>
</tr>
<tr>
<td>Plasticity Index: 75</td>
<td>31</td>
<td>25</td>
<td>22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site: 13. Taupiri Jew Road</th>
<th>14. Te Awamutu Bowman Road</th>
<th>15. Cambridge Peake Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample ID: PP1</td>
<td>PP2</td>
<td>PP1</td>
</tr>
<tr>
<td>Liquid Limit: 72</td>
<td>48</td>
<td>Non</td>
</tr>
<tr>
<td>Plastic Limit: 35</td>
<td>23</td>
<td>Plastic</td>
</tr>
<tr>
<td>Plasticity Index: 37</td>
<td>25</td>
<td>(Sand)</td>
</tr>
</tbody>
</table>

### Test Methods
- Liquid Limit, NZS 4402:1986, Test 2.2
- Plastic Limit, NZS 4402:1986, Test 2.3
- Plasticity Index, NZS 4402:1986, Test 2.4

### Notes
1. Unable to roll to specified dimensions.
2. NP=Non Plastic

### Date Tested:
June 2001

### Date Reported:
05/07/01

---

IANZ Approved Signatory

Designation: Senior Civil Engineering Technician

Date: 05/07/01

---

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---

Page 1 of 1
PAVEMENT INVESTIGATION LOG
TEST REPORT

Project: Volcanic Soils Project (Site 1, Okere)
Location: Okere Rd @ 60m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: A Ingoe. (Opus Laboratory, Hamilton)
Date Sampled: 23/04/01
Sampling method: NZS 4407 : 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 3. Worn, slightly flushed.</td>
</tr>
<tr>
<td>50</td>
<td>BASECOARSE Greyish brown Gravely fine to medium grained pumice SAND, gravels subrounded/fine to medium grained, dense, moist, non plastic.</td>
</tr>
<tr>
<td>300</td>
<td>SUBGRADE Brown Silty fine to medium SAND, quartz/pumice intermixed, loose, moist, non plastic.</td>
</tr>
<tr>
<td>450</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

Insitu CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>350mm</td>
<td>35</td>
<td>2.5mm</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at : 350 - 450mm.
Depth at scale penetrometer started : 350mm.

Test Methods

Determination of Penetration Resistance of a Soil, NZS 4402 : 1988, Test 6.5.2
Insitu Density, sampling tube method, NZS 4402 : 1986, Test 5.1.3
California Bearing Ratio (insitu), NZS 4402 : 1988, Test 6.1.3
Inferred CBR values taken from Austroads pavement design manual 1992

Date tested: 23/04/01
Date reported: 27/04/01

IANZ Approved Signatory

Designation: Laboratory Manager

IANZ Accreditation does not apply to inferred CBR values or pavement descriptions

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Project No: 5-22480.00
Lab Ref No: 01/310/001/0
Client Ref No: Okere PPI

Subgrade Density

<table>
<thead>
<tr>
<th>Push tube results at :</th>
<th>350mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet density (t/m³) :</td>
<td>1.40</td>
</tr>
<tr>
<td>Dry density (t/m³) :</td>
<td>1.27</td>
</tr>
<tr>
<td>W / C % :</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Tests indicated as not accredited are outside the scope of the laboratory's accreditation
**PAVEMENT INVESTIGATION LOG**

**TEST REPORT**

**Project:** Volcanic Soils Project (Site 1, Okere)

**Location:** Okere Rd @ 180mbLHS OWT

**Client:** Opus International Consultants Ltd

**Contractor:** N/A

**Sampled by:** A Ingoe. (Opus Laboratory, Hamilton)

**Date Sampled:** 23/04/01

**Sampling method:** NZS 4407 : 1991 Test 2.4.8.2

**Sample condition:** Natural

**Pavement pit number:** 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL</td>
</tr>
<tr>
<td></td>
<td>Grade 3. Worn, slightly flushed.</td>
</tr>
<tr>
<td>55</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td></td>
<td>Greyish brown Gravelly fine to medium grained</td>
</tr>
<tr>
<td></td>
<td>pumice SAND, gravels surrounded/fine to medium</td>
</tr>
<tr>
<td></td>
<td>grained, some class of brown Silty Sand intermixed,</td>
</tr>
<tr>
<td></td>
<td>dense, moist, non plastic.</td>
</tr>
<tr>
<td>400</td>
<td>SUBGRADE</td>
</tr>
<tr>
<td></td>
<td>Brown Gravelly fine to medium pumice SAND,</td>
</tr>
<tr>
<td></td>
<td>abundant fine rounded pumice gravels, loose,</td>
</tr>
<tr>
<td></td>
<td>moist, non plastic</td>
</tr>
<tr>
<td>550</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

---

### In situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>440mm</td>
<td>45</td>
<td>2.5mm</td>
<td>20.9</td>
</tr>
</tbody>
</table>

**Test Methods**

- Determination of Penetration Resistance of a Soil. NZS 4402 : 1988, Test 6.3.2
- In-situ Density, sampling tube method, NZS 4402 : 1986, Test 5.1.3
- California Bearing Ratio (in-situ), NZS 4402: 1988, Test 6.1.3
- Inferred CBR values taken from Augrades pavement design manual 1992

**Notes**

- IANZ Accreditation does not apply to inferred CBR values or pavement descriptions

**Inferred CBR %**

<table>
<thead>
<tr>
<th>Push Tube result at:</th>
<th>440mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet density (t/m³):</td>
<td>1.41</td>
</tr>
<tr>
<td>Dry density (t/m³):</td>
<td>1.16</td>
</tr>
<tr>
<td>W / C %:</td>
<td>20.9</td>
</tr>
</tbody>
</table>

---

**IAZNZ Approved Signatory**

**Designation:** Laboratory Manager

**Date:** 27/04/01

---

**Scale Penetrometer**

---

**Subgrade Density**

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**CSF 3067 (2001)**

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**Telephone +64 7 856 2670  
Facsimile +64 7 856 2673  
Website www.opus.co.nz**
Volcanic Soil Project Site 1: Okere Falls

Project No: 5-22480.00
Lab Ref No: 01/310/001/1

Okere Road
Pavement Pit 1
@ 60m LHS, OWT

Okere Road
Pavement Pit 2
@ 180m LHS, OWT
**PAVEMENT INVESTIGATION LOG TEST REPORT**

Project: Volcanic Soils Project (Site 2, Lichfield)  
Location: V有不少 Rd @ 60m LHS OWT  
Client: Opus International Consultants Ltd  
Contractor: N/A  
Sampled by: A Ingoe, (Opus Laboratory, Hamilton)  
Date Sampled: 24/04/01  
Sampling method: NZS 4407: 1991 Test 2.4.8.2  
Sample condition: Natural  
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 4. Sound.</td>
</tr>
<tr>
<td>25</td>
<td>BASECOURSE I AP 40. Fresh to slightly weathered angular GREYWACKE, well graded, medium dense, moist, non plastic.</td>
</tr>
<tr>
<td>100</td>
<td>SUBBASE Light greyish brown Gravelly fine SAND, some Silt, Gravels sub-rounded/fine to medium grained, medium dense, dry, non plastic.</td>
</tr>
<tr>
<td>220</td>
<td>OLD CHIPSEAL LAYER</td>
</tr>
<tr>
<td>250</td>
<td>BASECOURSE II GAP 40. Moderately to highly weathered GREYWACKE/Silty SAND conglomerate, medium dense, moist, slightly plastic.</td>
</tr>
<tr>
<td>390</td>
<td>SUBGRADE Light brown Silt/Fine SAND mixture, some black organic Silt intermixed in top 100mm, soft, slightly moist, non plastic.</td>
</tr>
<tr>
<td>600</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

**In-situ CBR Test Results**

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>440mm</td>
<td>16</td>
<td>6.9</td>
</tr>
<tr>
<td>16</td>
<td>2.5</td>
<td>66.9</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.  
Subbase sample not recovered.  
Subgrade sample recovered at: 440 - 600mm.  
Depth at which scale penetrometer started: 440mm.

**Test Methods**

- Determination of Penetration Resistance of a Soil, NZS 4402: 1988, Test 6.5.2
- In-situ Density, sampling tube method, NZS 4402: 1986, Test 5.1.3
- California Bearing Ratio (In-situ), NZS 4402: 1988, Test 6.1.3

**Subgrade Density**

<table>
<thead>
<tr>
<th>Push Tube result at: 440mm</th>
<th>Wet density (t/m³):</th>
<th>Dry density (t/m³):</th>
<th>W / C %:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.50</td>
<td>0.78</td>
<td>66.9</td>
<td></td>
</tr>
</tbody>
</table>

**Notes**

IANZ Accreditation does not apply to inferred CBR values or pavement descriptions

Sampling and testing is covered by IANZ Accreditation

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**IANZ Approved Signatory**

Designation: Laboratory Manager  
Date: 27/04/01

*Opus International Consultants Limited  
Hamilton Laboratory  
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Fox Street Private Bag 3057  
Hamilton, New Zealand  
Telephones +64 7 856 2670  
Facsimile +64 7 858 2973  
Website www.opus.co.nz*
**Project:** Volcanic Soils Project (Site 2, Lichfield)  
**Location:** Vospers Rd @ 120m LHS OWT  
**Client:** Opus International Consultants Ltd  
**Contractor:** N/A  
**Sampled by:** A Ingeo. (Opus Laboratory, Hamilton)  
**Date Sampled:** 24/04/01  
**Sampling method:** NZS 4407:1991 Test 2.4.8.2  
**Sample condition:** Natural  
**Pavement pit number:** 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 4. Sound.</td>
</tr>
<tr>
<td>30</td>
<td>BASECOURSE AP 40. Fresh to slightly weathered angular</td>
</tr>
<tr>
<td></td>
<td>GREYWACKE, well graded, medium dense, moist, non plastic.</td>
</tr>
<tr>
<td>90</td>
<td>SUBBASE Light pinkish greyish Gravelly fine SAND, some Silt, Gravels sub-rounded/fine to medium grained, chipped intermixed from 140mm, medium dense, dry, non plastic.</td>
</tr>
<tr>
<td>390</td>
<td>SUBGRADE Yellow brown homogeniuous fine Sandy Silt, firm, moist, non plastic.</td>
</tr>
<tr>
<td>490</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

---

**Insitu CBR Test Results**

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration (mm)</th>
<th>Water Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>340mm</td>
<td>10</td>
<td>2.5mm</td>
<td>61.5</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.  
Subbase sample not recovered.  
Subgrade sample recovered at: 340 - 490mm.  
Depth at which scale penetrometer started: 340mm.

**Test Methods**

- Determination of Penetration Resistance of a Soil, NZS 4402:1988, Test 6.5.2  
- Insitu Density, sampling tube method, NZS 4402:1988, Test 5.1.3  
- California Bearing Ratio (insitu), NZS 4402:1988, Test 6.1.3  
- Inferred CBR values taken from Austroads pavement design manual 1992

**Date tested:** 24/04/01  
**Date reported:** 27/04/01

---

**IANZ Accredited Signatory**

**Designation:** Laboratory Manager

---

**Scale Penetrometer**

- Blown / 100mm
- Depth measured (m):
- Inferred CBR %

**Subgrade Density**

- Push tube result at: 340mm  
- Wet density (t/m³): 1.38  
- DRY density (t/m³): 0.85  
- W/C %: 61.5

**Notes**

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---

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Website www.opus.co.nz
Volcanic Soil Project Site 2: Lichfield

Vospers Road
Pavement Pit 1
@ 60m LHS, OWT

Vospers Road
Pavement Pit 2
@ 120m LHS, OWT
PAVEMENT INVESTIGATION LOG
TEST REPORT

Project: Volcanic Soils Project (Site 3, Murupara)
Location: Golf Rd @ 20m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: B. Lorcet (Opus Laboratory, Rotorua)
Date Sampled: 10/04/01
Sampling method: NZS 4407: 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPS SEAL</td>
</tr>
<tr>
<td></td>
<td>Grade 3, flushed</td>
</tr>
<tr>
<td>40</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td></td>
<td>AP 40, Rounded, poorly graded, excess SAND, some Gravel, moderately dense, dry, non plastic.</td>
</tr>
<tr>
<td>150</td>
<td>SUBGRADE</td>
</tr>
<tr>
<td></td>
<td>Light brown fine to medium pumice SAND, loose, moist, non plastic.</td>
</tr>
<tr>
<td>350</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In situ CBR Test Results</th>
<th>150mm</th>
<th>2.5mm</th>
<th>56</th>
<th>18.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBR %</td>
<td></td>
<td></td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Penetration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Content %</td>
<td></td>
<td></td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 350 - 450mm.
Depth at scale penetrometer tested: 350mm.

Test Methods
- Determination of Penetration Resistance of a Soil, NZS 4402: 1988, Test 6.3.2
- In situ Density, sampling tube method, NZS 4402: 1986, Test 5.1.3
- California Bearing Ratio (in situ), NZS 4402: 1988, Test 6.1.3
- Inferred CBR values taken from Austroads pavement design manual 1992

Date tested: 10/04/01
Date reported: 01/05/01

IANZ Approved Signatory

Designation: Laboratory Manager
Date: 01/05/01

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PAVEMENT INVESTIGATION LOG
TEST REPORT

Project: Volcanic Soils Project (Site 3, Murupara)
Location: Golf Rd @ 160m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: B. Lorcrct (Opus Laboratory, Rotorua)
Date Sampled: 10/04/01
Sampling method: NZS 4407: 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL</td>
</tr>
<tr>
<td></td>
<td>Grade 3, flushed</td>
</tr>
<tr>
<td>40</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td></td>
<td>AP 40. Rounded, poorly graded, excess SAND, some gravel, moderately dense, dry, non plastic.</td>
</tr>
<tr>
<td>190</td>
<td>SUBBASE</td>
</tr>
<tr>
<td></td>
<td>Dark grey medium to fine Silty SAND, moderately dense, moist, non plastic.</td>
</tr>
<tr>
<td>230</td>
<td>SUBGRADE</td>
</tr>
<tr>
<td></td>
<td>Light brown fine to medium pumice SAND, loose, moist, non plastic.</td>
</tr>
<tr>
<td>320</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In Situ CBR Test Results</th>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>230mm</td>
<td>40</td>
<td>2.5mm</td>
<td>15.2</td>
</tr>
</tbody>
</table>

Baseline sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 230 - 320mm.
Depth at which scale sonotrodes started: 230mm.

Test Methods:
- Determination of Penetration Resistance of a Soil, NZS 4402: 1986, Test 6.5.2
- In situ Density, sampling tube method, NZS 4402: 1986, Test 5.1.3
- California Bearing Ratio (In situ), NZS 4402: 1988, Test 6.1.3
- Inferred CBR values taken from Austroads pavement design manual 1992

Date tested: 10/04/01
Date reported: 01/05/01

IA NZ Accredited Signatory: Laboratory Manager

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Subgrade Density
- Push tube result at: 230mm
- Wet density (t/m³): 1.29
- Dry density (t/m³): 1.09
- W/C %: 15.2

Notes: IANZ Accreditation does not apply to inferred CBR values or pavement descriptions
PAVEMENT INVESTIGATION LOG
TEST REPORT

Project: Volcanic Soils Project (Site 4, Waiotapu)
Location: Jay Road @ 60m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: A Iagoe. (Opus Laboratory, Hamilton)
Date Sampled: 23/04/01
Sampling method: NZS 4407:1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL&lt;br&gt;Grade 4/5. Slightly flushed, generally sound.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE&lt;br&gt;AP 40. Slightly weathered, subrounded river run&lt;br&gt;GREY WACKE, excess Silty SAND, medium dense, moist, non plastic.</td>
</tr>
<tr>
<td>200</td>
<td>SUBGRADE&lt;br&gt;Light brown Gravelly fine pumice SAND, Gravels rounded/fine to medium grained, dense, dry, non plastic.</td>
</tr>
<tr>
<td>350</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In situ CBR Test Results</th>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200mm</td>
<td>60</td>
<td>2.5mm</td>
<td>42.8</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at 200 - 300mm.
Depth at which scale penetrometer started: 200mm.

Test Methods
Determination of Penetration Resistance of a Soil, NZS 4402: 1988, Test 6.5.2
In situ Density, sampling tubs method, NZS 4402: 1986, Test 5.1.3
California Bearing Ratio (situ), NZS 4402: 1988, Test 6.1.3
Inferred CBR values taken from Austroads pavement design manual 1992.

Date tested: 23/04/01
Date reported: 27/04/01

IANZ Accredited Laboratory

Designation: Laboratory Manager
Date: 22/04/01

Note: IANZ Accreditation does not apply to inferred CBR values or pavement descriptions

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---

Project No: 5-22480.00
Lab Ref No: 01/310/0014
Client Ref No: Waiotapu PP1

---

Subgrade Density

---

Tests included as not accredited are outside the scope of the laboratory's accreditation.

---

Opus International Consultants Limited
Hamilton Laboratory
Quality Management Systems accredited to ISO 9001
PAVEMENT INVESTIGATION LOG
TEST REPORT

Project: Volcanic Soils Project (Site 4, Waitapu)
Location: Jay Road @ 160m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: A Ingoe (Opus Laboratory, Hamilton)
Date Sampled: 23/04/01
Sampling method: NZS 4407 : 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL</td>
</tr>
<tr>
<td></td>
<td>Grade 4/5. Slightly flushed, generally sound.</td>
</tr>
<tr>
<td>25</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td></td>
<td>AP 40. Slightly weathered, subrounded river run</td>
</tr>
<tr>
<td></td>
<td>GREY WACKE, excess Silty SAND, medium dense, moist, non plastic.</td>
</tr>
<tr>
<td>170</td>
<td>SUBGRADE</td>
</tr>
<tr>
<td></td>
<td>Dark brown grading to light brown Gravelly fine pumice SAND, Gravels rounded/random to medium grained, dense, dry, non plastic.</td>
</tr>
<tr>
<td>390</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

In situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>175mm</td>
<td>55</td>
<td>2.5mm</td>
<td>38.9</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at : 175 - 390mm.
Depth at which scale penetrometer started : 175mm.

Test Methods
Determination of Penetration Resistance of a Soil, NZS 4402 : 1988, Test 6.3.2
In situ Density, sampling tube method, NZS 4402 : 1986, Test 5.1.3
California Bearing Ratio (in situ), NZS 4402: 1988, Test 6.1.3
Inferred CBR values taken from Ausroads pavement design manual 1992

Date tested: 23/04/01
Date reported: 27/04/01

IANZ Accredited Signatory: Laboratory Manager

Subgrade Density

<table>
<thead>
<tr>
<th>Subgrade CBR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
</tr>
</tbody>
</table>

INFERRED CBR

<table>
<thead>
<tr>
<th>Depth below end of pit (m)</th>
<th>Inferred CBR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>55</td>
</tr>
<tr>
<td>0.10</td>
<td>45</td>
</tr>
<tr>
<td>0.20</td>
<td>40</td>
</tr>
<tr>
<td>0.30</td>
<td>35</td>
</tr>
<tr>
<td>0.40</td>
<td>30</td>
</tr>
<tr>
<td>0.50</td>
<td>25</td>
</tr>
<tr>
<td>0.60</td>
<td>20</td>
</tr>
<tr>
<td>0.70</td>
<td>15</td>
</tr>
<tr>
<td>0.80</td>
<td>10</td>
</tr>
<tr>
<td>0.90</td>
<td>5</td>
</tr>
<tr>
<td>1.00</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes
IANZ Accreditation does not apply to inferred CBR values or pavement descriptions
Sampling and testing is covered by IANZ Accreditation
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Hamilton Laboratory
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Facsimile: +64 7 856 2673
Website: www.opus.co.nz
Volcanic Soil Project Site 4: Waiotapu

Project No: 5-22480.00
Lab Ref No: 01/310/001/4

Jay Road
Pavement Pit 1
@ 60m LHS, OWT

Jay Road
Pavement Pit 2
@ 160m LHS, OWT
PAVEMENT INVESTIGATION LOG
TEST REPORT

Project: Volcanic Soils Project (Site 5, Bennymade)
Location: SH30 @ 60m RHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: A Ingec. (Opus Laboratory, Hamilton)
Date Sampled: 26/04/01
Sampling method: NZS 4407:1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
</table>
| 0         | CHIPSEAL
Grade 3/A. Worn, flushed, some rutting. |
| 30        | BASECOARSE
GAP 40. Slightly weathered angular GREYWACKE. Excess Sandy SILT, some Clay & old chipseal intermixed, medium dense, moist, slightly plastic. |
| 300       | SUBBASE
Brown Clayey SILT, stiff, moist, slightly plastic. |
| 360       | SUBGRADE
Yellow brown homogeneous SILT, rare Clay, soft, wet, very slightly plastic. |
| 630       | END OF PIT |

In situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>490mm</td>
<td>3</td>
<td>5.0%</td>
<td>93.4</td>
</tr>
</tbody>
</table>

Gravel course sample not recovered.
Subbase sample not returned.
Subgrade sample recovered at: 490 - 630mm.
Depth at which scale penetrometer started: 490mm.

Test Methods

- Determination of Penetration Resistance of a Soil, NZS 4402:1988, Test 6.5.2
- Sand Density, sampling tube method, NZS 4402:1986, Test 5.1.3
- California Bearing Ratio (in situ), NZS 4402:1988, Test 6.1.3
- Inferred CBR values taken from Austroads pavement design manual 1992

Date tested: 26/04/01
Date reported: 27/04/01

IANZ Approved Signatory

Designation: Laboratory Manager
Date: 27/04/01

Notes

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Sampling and testing is covered by IANZ Accreditation
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Project No: 5-22480.00
Lab Ref No: 01/310/004/S
Client Ref No: Bennymade PPI

Subgrade Density

<table>
<thead>
<tr>
<th>Depth below end of pit (m)</th>
<th>Inferred CBR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>1.20</td>
<td></td>
</tr>
<tr>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td>1.60</td>
<td></td>
</tr>
<tr>
<td>1.80</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>18</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>24</td>
</tr>
<tr>
<td>26</td>
</tr>
<tr>
<td>28</td>
</tr>
<tr>
<td>30</td>
</tr>
</tbody>
</table>

Test results are not accredited and are outside the scope of the laboratory's accreditation

Page 1 of 1

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Facsimile +64 7 856 2873
Website www.opus.co.nz
**PAVEMENT INVESTIGATION LOG**
**TEST REPORT**

**Project:** Volcanic Soils Project (Site 5, Bennydale)

**Location:** SH30 @ 140m RHS OWT

**Client:** Opus International Consultants Ltd

**Contractor:** N/A

**Sampled by:** A Ingoe. (Opus Laboratory, Hamilton)

**Date Sampled:** 26/04/01

**Sampling method:** NZS 4407 : 1991 Test 2.4.8.2

**Sample condition:** Natural

**Pavement pit number:** 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL&lt;br&gt;Grade 3/4. Worn, flushed, some rutting.</td>
</tr>
<tr>
<td>35</td>
<td>BASECOURSE&lt;br&gt;GAP 40. Slightly weathered angular GREYWACKE, excess Sandy SILT, some clay &amp; old chipseal intermixed, medium dense, moist, slightly plastic.</td>
</tr>
<tr>
<td>180</td>
<td>SUBBASE I&lt;br&gt;Dark Yellow brown Silty CLAY, some aggregates intermixed, stiff, dry, highly plastic.</td>
</tr>
<tr>
<td>260</td>
<td>SUBBASE II&lt;br&gt;Brown / black Gravely SILT, Gravels angular/medium grained, stiff, moist, non plastic.</td>
</tr>
<tr>
<td>410</td>
<td>SUBGRADE&lt;br&gt;Light brown Gravely fine to medium pumice SAND loose, dry, non plastic.</td>
</tr>
<tr>
<td>590</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

### In-situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>420mm</td>
<td>19</td>
<td>2.5mm</td>
<td>60.4</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 420 - 590mm.
Depth at which scena penetrometer started: 420mm.

### Test Methods

- Determination of Penetration Resistance of a Soil, NZS 4402 : 1988, Test 6.3.2
- In-situ Density, Sampling tube method, NZS 4402 : 1986, Test 5.1.3
- California Bearing Ratio (In situ), NZS 4402: 1988, Test 6.1.3

Inferred CBR values taken from Ausroads pavement design manual 1992.

### Subgrade Density

<table>
<thead>
<tr>
<th>Push Tube result at</th>
<th>420mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet density (t/m³)</td>
<td>1.05</td>
</tr>
<tr>
<td>Dry density (t/m³)</td>
<td>0.66</td>
</tr>
<tr>
<td>W / C %</td>
<td>60.4</td>
</tr>
</tbody>
</table>

### Notes

JANZ Accreditation does not apply to inferred CBR values or pavement descriptions.

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### IANZ Approved Signatory

**Designation:** Laboratory Manager

**Date:** 27/04/01

---

Opus International Consultants Limited
Hamilton Laboratory

Quality Management Systems Certified to ISO 9001

<table>
<thead>
<tr>
<th>Fox Street</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Bag 3057</td>
</tr>
<tr>
<td>Hamilton, New Zealand</td>
</tr>
</tbody>
</table>

| Telephone: +64 7 856 2670 |
| Facsimile: +64 7 856 2673 |
| Website: www.opus.co.nz |
Volcanic Soil Project Site 5: Bennydale

Project No: 5-22480.00
Lab Ref No: 01/310/001/5

SH 30
Pavement Pit 1
@ 60m RHS, OWT

SH 30
Pavement Pit 2
@ 140m RHS, OWT
Project: Volcanic Soils Project (Site 6, Stratford - Inglewood)
Location: Tarki Rd © 80m RHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: V Rowe. (Opus Laboratory, New Plymouth)
Date Sampled: 04/04/01
Sampling method: NZS 4407: 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSAL Grade 3.</td>
</tr>
<tr>
<td>25</td>
<td>BASECOARSE AP 40. Well graded, very firm, stabilised.</td>
</tr>
<tr>
<td>100</td>
<td>SUBBASE AP 40. Finely graded, contaminated, firm.</td>
</tr>
<tr>
<td>190</td>
<td>SUBBASE II AP 65. Well graded, firm.</td>
</tr>
<tr>
<td>430</td>
<td>SUBGRADE (Natural) Light brown Silty CLAY, soft, moist, moderately plastic.</td>
</tr>
<tr>
<td>530</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Insitu CBR Test Results</th>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 430 - 530mm.
Depth at scale penetrometer started: 430mm.

<table>
<thead>
<tr>
<th>Subgrade Density</th>
<th>450mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Push tube results at:</td>
<td>450mm</td>
</tr>
<tr>
<td>Wet density (t/m³):</td>
<td>1.51</td>
</tr>
<tr>
<td>Dry density (t/m³):</td>
<td>0.91</td>
</tr>
<tr>
<td>W/C %:</td>
<td>45.9</td>
</tr>
</tbody>
</table>

Test Methods:
- Determination of Penetration Resistance of a Soil, NZS 4407: 1988, Test 6.3.2
- Intrinsic Density, sampling tube method, NZS 4402: 1986, Test 5.1.3
- California Bearing Ratio (insitu), NZS 4402: 1986, Test 6.1.3
- Inferred CBR values taken from Austroads pavement design manual 1992

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IANZ Approved Signatory
Designation: Laboratory Manager
Date: 01/05/01

Page 1 of 1
**Project:** Volcanic Soils Project (Site 6, Stratford - Inglewood)  
**Location:** Tariki Rd @ 160m RHS OWT  
**Client:** Opus International Consultants Ltd  
**Contractor:** N/A  
**Sampled by:** V Rowe. (Opus Laboratory, New Plymouth)  
**Date Sampled:** 04/04/01  
**Sampling method:** NZS 4407:1991 Test 2.4.8.2  
**Sample condition:** Natural  
**Pavement pit number:** 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 3.</td>
</tr>
<tr>
<td>25</td>
<td>BASECOURSE AP 40. Well graded, very firm, stabilised.</td>
</tr>
<tr>
<td>110</td>
<td>OLD CHIPSEAL</td>
</tr>
<tr>
<td>130</td>
<td>BASECOURSE II AP 40. Pit metal, finely graded, loose.</td>
</tr>
<tr>
<td>330</td>
<td>SUBGRADE (Natural) Dark brown Silty CLAY, firm to soft, moist, moderately plastic.</td>
</tr>
<tr>
<td>430</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

**In-situ CBR Test Results**  
<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>330mm</td>
<td>11</td>
<td>5.0</td>
<td>58.1</td>
</tr>
</tbody>
</table>

Base course sample not recovered.  
Subbase sample not recovered.  
Subgrade sample recovered at 330 - 430mm.  
Depth at scale penetrometer started 330mm.

**Test Methods**  
Determination of Penetration Resistence of a Soil, NZS 4402:1988, Test 6.5.2  
In situ Density, sampling tube method, NZS 4402:1986, Test 5.1.3  
California Bearing Ratio (in situ), NZS 4402:1988, Test 6.1.3  
Inferred CBR values taken from Austroads pavement design manual 1992

**Subgrade Density**  
<table>
<thead>
<tr>
<th>Push tube results at</th>
<th>330mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet density (t/m³)</td>
<td>1.59</td>
</tr>
<tr>
<td>Dry density (t/m³)</td>
<td>1.00</td>
</tr>
<tr>
<td>W/C %</td>
<td>38.3</td>
</tr>
</tbody>
</table>

**Notes:**  
IANZ Accreditation does not apply to inferred CBR values or pavement descriptions  
Sampling and testing is covered by IANZ Accreditation  
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**IANZ Approved Signatory**  
**Designation:** Laboratory Manager  
**Date:** 01/05/01  
**Date tested:** 04/04/01  
**Date reported:** 18/04/01

---

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**Telephone:** +64 7 856 2870  
**Facsimile:** +64 7 856 2873  
**Website:** www.opus.co.nz
**PAVEMENT INVESTIGATION LOG**

**TEST REPORT**

- **Project:** Volcanic Soils Project (Site 7, Waitara - Urenui)
- **Location:** Upper Epilah Rd @ 80m LHS OWT
- **Client:** Opus International Consultants Ltd
- **Contractor:** N/A
- **Sampled by:** V Rowe. (Opus Laboratory, New Plymouth)
- **Date Sampled:** 04/04/01
- **Sampling method:** NZS 4407 : 1991 Test 2.4.8.2
- **Sample condition:** Natural
- **Pavement pit number:** 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL</td>
</tr>
<tr>
<td></td>
<td>Grade 3.</td>
</tr>
<tr>
<td>30</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td></td>
<td>AP 65, Finely graded, contaminated, loose.</td>
</tr>
<tr>
<td>200</td>
<td>SUBGRADE (Natural)</td>
</tr>
<tr>
<td></td>
<td>Dark brown Sandy CLAY, some Silt, stiff, dry, slightly plastic.</td>
</tr>
<tr>
<td>300</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

---

**Insitu CBR Test Results**

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>200mm</td>
<td>30</td>
<td>5.6mm</td>
<td>33.6</td>
</tr>
</tbody>
</table>

- Basecourse sample not recovered.
- Subbase sample not recovered.
- Subgrade sample recovered at: 200 - 300mm.
- Depth at scale penetrometer started: 200mm.

**Test Methods**

- Determination of Penetration Resistance of a Soil, NZS 4402: 1988, Test 6.5.2
- Insitu Density, sampling tube method, NZS 4402: 1986, Test 5.1.3
- California Bearing Ratio (Insitu), NZS 4402: 1988, Test 6.1.3
- Inferred CBR values taken from Austroads pavement design manual 1992

**Notes**

- IANZ Accreditation does not apply to inferred CBR values or pavement descriptions

**Sampling and testing is covered by IANZ Accreditation**

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**IANZ Approved Signatory**

**Designation:** Laboratory Manager

**Date:** 01/04/01

---

**Contact Information**

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Quality Management Systems Certified to ISO 9001

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Facsimile: +64 7 855 2873
Website: www.opus.co.nz
**PAVEMENT INVESTIGATION LOG**
**TEST REPORT**

Project: Volcanic Soils Project (Site 7, Waitara - Urenui)
Location: Upper Epitha Rd @ 160m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: V Rowe. (Opus Laboratory, New Plymouth)
Date Sampled: 04/04/01
Sampling method: NZS 4407:1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL, Grade 3.</td>
</tr>
<tr>
<td>45</td>
<td>BASECOARSE, AP 65. Finely graded, contaminated, loose.</td>
</tr>
<tr>
<td>210</td>
<td>SUBGRADE (Natural). Light brown silty CLAY, firm, moist, moderately plastic.</td>
</tr>
<tr>
<td>310</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In situ CBR Test Results</th>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>210mm</td>
<td>18</td>
<td>5.0mm</td>
<td>79.4</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 210 - 300mm.
Depth at scale penetrometer started: 210mm.

**Scale Penetrometer**

<table>
<thead>
<tr>
<th>Inferred CBR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
</tr>
<tr>
<td>0.10</td>
</tr>
<tr>
<td>0.20</td>
</tr>
<tr>
<td>0.30</td>
</tr>
<tr>
<td>0.40</td>
</tr>
<tr>
<td>0.50</td>
</tr>
<tr>
<td>0.60</td>
</tr>
<tr>
<td>0.70</td>
</tr>
<tr>
<td>0.80</td>
</tr>
<tr>
<td>0.90</td>
</tr>
</tbody>
</table>

**Subgrade Density**

- Push tube results at: 210mm
- Wet density (t/m³): 1.52
- Dry density (t/m³): 0.85
- W/C %: 79.4

Test methods:
- Determination of Penetration Resistance of a Soil, NZS 4402:1988, Test 6.5.2
- In situ Density, sampling tube method, NZS 4402:1986, Test 5.1.3
- California Bearing Ratio (in situ), NZS 4402:1988, Test 6.1.3

Inferred CBR values taken from Austroads pavement design manual 1992

Date tested: 04/04/01
Date reported: 18/04/01

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IANZ Approved Signatory: [Signature]
Designation: Laboratory Manager
Date: 01/05/01

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Hamilton Laboratory
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Hamilton, New Zealand

Telephone +64 7 553 2870
Facsimile +64 7 556 2878
Website www.opus.co.nz
Volcanic Soil Project Site 7: Waitara to Urenui

Upper Epihia Road
Pavement Pit 1
@ 80m LHS, OWT

Upper Epihia Road
Pavement Pit 2
@ 160m LHS, OWT
Project: Volcanic Soils Project (Site 8, Whangamomona)
Location: SH43 @ 20 RHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: V Rowe. (Opus Laboratory, New Plymouth)
Date Sampled: 10/04/01
Sampling method: NZS 4407:1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 3.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE AP 40. Well graded, firm.</td>
</tr>
<tr>
<td>380</td>
<td>SUBBASE AP65. Finely graded, firm.</td>
</tr>
<tr>
<td>340</td>
<td>SUBGRADE (Natural) Brown/grey Clayey Silt, firm, moist, moderately plastic.</td>
</tr>
<tr>
<td>440</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

**In situ CBR Test Results**

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>340mm</td>
<td>12</td>
<td>5.6mm</td>
<td>24.8</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 340 - 440mm.
Depth at scale penetrometer started: 340mm.

**Test Methods:**
- Determination of Penetration Resistance of a Soil, NZS 4402:1986. Test 6.5.2
- In situ Density, sampling tube method. NZS 4402:1986. Test 5.1.3
- Inferred CBR values taken from Ausroads pavement design manual 1992

**Notes:**
- IANZ Accreditation does not apply to inferred CBR values or pavement descriptions

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Date tested: 10/04/01
Date reported: 18/04/01

IANZ Approved Signatory

Designation: Laboratory Manager
Date: 01/05/01

---

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Fax: +64 7 835 6879
Website: www.opus.co.nz
**PAVEMENT INVESTIGATION LOG**

**TEST REPORT**

- **Project:** Volcanic Soils Project (Site 8, Whangamomona)
- **Location:** SH43 @ 100 RHS OWT
- **Client:** Opus International Consultants Ltd
- **Contractor:** N/A
- **Sampled by:** V Rowe, (Opus Laboratory, New Plymouth)
- **Date Sampled:** 10/04/01
- **Sampling method:** NZS 4407:1991 Test 2.4.8.2
- **Sample condition:** Natural
- **Pavement pit number:** 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 3.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE AP 40. Well graded, firm.</td>
</tr>
<tr>
<td>100</td>
<td>SUBBASE AP 65. Finely graded, firm.</td>
</tr>
<tr>
<td>310</td>
<td>SUBGRADE (Natural) Brown/grey Clayey SILT, firm, moist, moderately plastic.</td>
</tr>
<tr>
<td>410</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

**In-situ CBR Test Results**

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>310mm</td>
<td>25</td>
<td>5.0mm</td>
<td>23.4</td>
</tr>
</tbody>
</table>

- Basecourse sample not recovered.
- Subbase sample not recovered.
- Subgrade sample recovered at: 310 - 410mm.
- Depth at scale penetrometer started: 310mm.

**Subgrade Density**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>310mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture density (t/m³):</td>
<td>2.02</td>
<td></td>
</tr>
<tr>
<td>Dry density (t/m³):</td>
<td>1.63</td>
<td></td>
</tr>
<tr>
<td>W/C %:</td>
<td>23.4</td>
<td></td>
</tr>
</tbody>
</table>

**Notes**

- IAANZ Accreditation does not apply to inferred CBR values or pavement descriptions.
- Sampling and testing is covered by IAANZ Accreditation.
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**Designation:** Laboratory Manager

**Date:** 01/05/01

---

**Scale Penetrometer**

**Inferred CBR %**

---

---

**Opus International Consultants Limited**

**Hamilton Laboratory**

**Quality Management Systems Certified to ISO 9001**

---

**For: Street**

**Private Bag 3057**

**Hamilton, New Zealand**

**Telephone:** +64 7 855 2670

**Facsimile:** +64 7 855 2673

**Website:** www.opus.co.nz
Volcanic Soil Project Site 8: Whangamomona

Project No: 5-22480.00
Lab Ref No: 01/310/001/8

SH 43
Pavement Pit 1
@ 20m RHS, OWT

SH 43
Pavement Pit 2
@ 100m RHS, OWT
**PAVEMENT INVESTIGATION LOG**  
**TEST REPORT**

**Project:** Volcanic Soils Project (Site 9, Pio Pio)  
**Location:** Maira Rd @ 100m RHS OWT  
**Client:** Opus International Consultants Ltd  
**Contractor:** N/A  
**Sampled by:** A Ingoe. (Opus Laboratory, Hamilton)  
**Date Sampled:** 26/04/01  
**Sampling method:** NZS 4407 : 1991 Test 2.4.8.2  
**Sample condition:** Natural  
**Pavement pit number:** 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL</td>
</tr>
<tr>
<td></td>
<td>Grade 4. Worn, some flushing.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td></td>
<td>AP 40. Slightly weathered angular GREYWACKE. Dense, moist, well graded.</td>
</tr>
<tr>
<td>140</td>
<td>SUBBASE</td>
</tr>
<tr>
<td></td>
<td>GAP65. Moderately weathered angular GREYWACKE excess Clayey SILT, some old chipseal intermixed (30 - 260mm), rare 80mm subangular cobbles, dense, moist, non plastic.</td>
</tr>
<tr>
<td>360</td>
<td>SUBGRADE</td>
</tr>
<tr>
<td></td>
<td>Dark orange brown homogeneous Clayey SILT, firm, moist, slightly plastic.</td>
</tr>
<tr>
<td>510</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In-situ CBR Test Results</th>
<th>Test Depth</th>
<th>CBR %</th>
<th>400mm Penetration</th>
<th>Water Content %</th>
<th>2.5mm 112.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basecourse sample not recovered.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subbase sample not recovered.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgrade sample recovered at: 400 - 510mm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density at which scale penetrometer started: 400mm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Test Methods**
- Determination of Penetration Resistance of a Soil, NZS 4402 : 1988, Test 6.5.2
- In-situ Density, sampling tube method, NZS 4402 : 1986, Test 5.1.3
- California Bearing Ratio (in-situ), NZS 4402 : 1988, Test 6.1.3
- Inferred CBR values taken from Australasian pavement design manual 1992

**Notes**
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- Sampling and testing is covered by IANZ Accreditation
- This report may only be reproduced in full

**IANZ Approved Signatory**
- Laboratory Manager

**Date:** 27/04/01

---

**Scale Penetrometer**

<table>
<thead>
<tr>
<th>Blows / 100gms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
</tr>
<tr>
<td>0.20</td>
</tr>
<tr>
<td>0.40</td>
</tr>
<tr>
<td>0.60</td>
</tr>
<tr>
<td>0.80</td>
</tr>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>1.20</td>
</tr>
<tr>
<td>1.40</td>
</tr>
<tr>
<td>1.60</td>
</tr>
<tr>
<td>1.80</td>
</tr>
<tr>
<td>2.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth below test line (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
</tr>
<tr>
<td>0.15</td>
</tr>
<tr>
<td>0.30</td>
</tr>
<tr>
<td>0.45</td>
</tr>
<tr>
<td>0.60</td>
</tr>
<tr>
<td>0.75</td>
</tr>
<tr>
<td>0.90</td>
</tr>
<tr>
<td>1.05</td>
</tr>
<tr>
<td>1.20</td>
</tr>
<tr>
<td>1.35</td>
</tr>
<tr>
<td>1.50</td>
</tr>
<tr>
<td>1.65</td>
</tr>
<tr>
<td>1.80</td>
</tr>
<tr>
<td>1.95</td>
</tr>
<tr>
<td>2.10</td>
</tr>
<tr>
<td>2.25</td>
</tr>
<tr>
<td>2.40</td>
</tr>
<tr>
<td>2.55</td>
</tr>
<tr>
<td>2.70</td>
</tr>
<tr>
<td>2.85</td>
</tr>
<tr>
<td>3.00</td>
</tr>
</tbody>
</table>

**Subgrade Density**

- Push Tube result at: 400mm
- Wet density (t/m³): 1.08
- Dry density (t/m³): 0.51
- W / C %: 112.5

---

**Project No:** S-22450.00  
**Lab. Ref No:** 01/316/00019  
**Client Ref No:** Pio Pio PPI
Project: Volcanic Soils Project (Site 9, Pio Pio)
Location: Maiaoa Rd @ 180m RHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: A Ingoe. (Opus Laboratory, Hamilton)
Date Sampled: 26/04/01
Sampling method: NZS 4407 : 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL&lt;br&gt;Grade 4. Worn, flushed.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE&lt;br&gt;GAP65. Moderately weathered angular GREYWACKE, excess Clayey SILT, some old chipseal, dense, moist, non plastic.</td>
</tr>
<tr>
<td>200</td>
<td>SUBGRADE&lt;br&gt;Yellow brown homogeneous SILT, firm, moist, non plastic.</td>
</tr>
<tr>
<td>430</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

![Pavement Investigation Log Test Report]

In situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>270mm</td>
<td>6</td>
<td>5.0mm</td>
<td>70.9</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 270 - 430mm
Depth at which scale penetrometer started: 270mm

Test Methods

Determination of Penetration Resistance of a Soil, NZS 4402 : 1988, Test 6.5.2
In situ Density, sampling tube method, NZS 4402 : 1986, Test 5.1.3
California Bearing Ratio (in-situ), NZS 4402 : 1988, Test 6.1.3
Inferred CBR values taken from Austroads pavement design manual 1992

Date tested: 26/04/01
Date reported: 27/04/01

IANZ Approved Signatory:  Laboratory Manager
Date: 27/04/01

Notes

IANZ Accreditation does not apply to inferred CBR values or pavement descriptions

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Tests indicated as not accredited are outside the scope of the laboratory's accreditation

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Private Bag 3057
Hamilton, New Zealand

Telephone +64 9 856 2870
Facsimile +64 9 856 2873
Website www.opus.co.nz
# Pavement Investigation Log Test Report

**Project:** Volcanic Soils Project (Site 10, Hamilton - Cambridge)  
**Location:** Day Road @ 20m LHS OWT  
**Client:** Opus International Consultants Ltd  
**Contractor:** N/A  
**Sampled by:** R.S. Warner, (Opus Laboratory, Hamilton)  
**Date Sampled:** 05/04/01  
**Sampling method:** NZS 4407 : 1991 Test 2.4.8.2  
**Sample condition:** Natural  
**Pavement Pit number:** 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 3/6. Worn, sound.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE GAP 40. Fresh, angular GREYWACKE, well graded Silty SAND, moderately dense, slightly moist, non plastic.</td>
</tr>
<tr>
<td>250</td>
<td>SUBBASE GAP 65. Fresh to slightly weathered, angular GREYWACKE, slight excess SAND, some Silt, moderately dense, moist, non plastic.</td>
</tr>
<tr>
<td>480</td>
<td>SUBGRADE Orange Clayey SILT, soft to firm, moist, slightly plastic.</td>
</tr>
<tr>
<td>600</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

### In-situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>500mm</td>
<td>8</td>
<td>6.8</td>
</tr>
<tr>
<td>5.6mm</td>
<td>8</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.  
Subbase sample not recovered.  
Subgrade sample recovered at: 500 - 600mm.  
Depth at which scale penetrometer started: 500mm.

### Test Methods

- Determination of Penetration Resistance of a Soil, NZS 4402 : 1988, Test 6.5.2  
- In-situ Density, sampling tube method, NZS 4402 : 1986, Test 5.1.3  
- California Bearing Ratio (in-situ), NZS 4402: 1988, Test 6.1.3  
- Inferred CBR values taken from Austroads pavement design manual 1992

### Notes

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### IANZ Accreditation

- **Date tested:** 05/04/01  
- **Date reported:** 06/04/01

### IANZ Approved Signatory

- **Designation:** Laboratory Manager  
- **Date:** 06/04/01

---

**Scale Penetrometer**

**Subgrade Density**

- **Push Tube result at:** 500mm  
- **Wet density (t/m³):** 1.49  
- **Dry density (t/m³):** 0.89  
- **W / C %:** 68.1

- **Inferred CBR %**

- **Inferred CBR values not applicable to**

---

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**Hamilton Laboratory**  
**Quality Management Systems Certified to ISO 9001**  
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**Fax:** +64 7 858 2873  
**Website:** www.opus.co.nz
PAVEMENT INVESTIGATION LOG
TEST REPORT

Project: Volcanic Soils Project (Site 10, Hamilton - Cambridge)
Location: Day Road @ 80m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: R.S. Warner. (Opus Laboratory, Hamilton)
Date Sampled: 05/04/01
Sampling method: NZS 4407: 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL</td>
</tr>
<tr>
<td></td>
<td>Grade 3/6. Worn, sound.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td></td>
<td>GAP 40. Fresh, angular GREYWACKE, well graded Silty SAND, moderately dense, slightly moist, non plastic.</td>
</tr>
<tr>
<td>240</td>
<td>SUBBASE</td>
</tr>
<tr>
<td></td>
<td>GAP 65. Fresh to slightly weathered, angular GREYWACKE, slight excess SAND, some Silt, moderately dense, moist, non plastic.</td>
</tr>
<tr>
<td>400</td>
<td>SUBGRADE</td>
</tr>
<tr>
<td></td>
<td>Orange clayey SILT, soft to firm, moist, slightly plastic.</td>
</tr>
<tr>
<td>560</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

In situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>420mm</td>
<td>9</td>
<td>2.5mm</td>
<td>5.8</td>
</tr>
</tbody>
</table>

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Volcanic Soil Project Site 10: Hamilton-Cambridge

Day Road
Pavement Pit 1
@ 20m RHS, OWT

Day Road
Pavement Pit 2
@ 80m RHS, OWT
**PAVEMENT INVESTIGATION LOG**

**TEST REPORT**

**Project:** Volcanic Soils Project (Site 11, Te Poly)

**Location:** Stopfords Rd @ 60m RHS OWT

**Client:** Opus International Consultants Ltd

**Contractor:** N/A

**Sampled by:** A Ingoe. (Opus Laboratory, Hamilton)

**Date Sampled:** 24/04/01

**Sampling method:** NZS 4407: 1991 Test 2.4.8.2

**Sample condition:** Natural

**Pavement pit number:** 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 2. Worn, slightly flushed.</td>
</tr>
<tr>
<td>25</td>
<td>BASECOURSE I GAP40. Moderately weathered angular GREYWACKE</td>
</tr>
<tr>
<td></td>
<td>excess Silty SAND (cement Stabilised), dense, moist,</td>
</tr>
<tr>
<td></td>
<td>non plastic.</td>
</tr>
<tr>
<td>80</td>
<td>OLD CHIPSEAL LAYER</td>
</tr>
<tr>
<td>100</td>
<td>BASECOURSE II Ungraded up to 80mm. Dark reddish brown</td>
</tr>
<tr>
<td></td>
<td>subrounded Quarry stripings/ Silty SAND conglomerate,</td>
</tr>
<tr>
<td></td>
<td>dense, moist, non plastic.</td>
</tr>
<tr>
<td>220</td>
<td>SUBGRADE Yellow brown homogeneous SILT, rare Clay,</td>
</tr>
<tr>
<td></td>
<td>firm, moist, very slightly plastic.</td>
</tr>
<tr>
<td>450</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In situ CBR Test Results</th>
<th>Test Depth</th>
<th>280mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CBR %</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Penetration</td>
<td>2.5mm</td>
</tr>
<tr>
<td></td>
<td>Water Content %</td>
<td>61.6</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 180 - 450mm.

**Inferred CBR values taken from Ausroads pavement design manual 1992**

**Subgrade Density**

- **Push Tube test results:**
  - 280mm
  - Wet density (t/m³): 1.54
  - Dry density (t/m³): 0.83
  - W / C %: 61.0

**Notes**

IANZ Accreditation does not apply to inferred CBR values or pavement descriptions.

Sampling and testing is covered by IANZ Accreditation.

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**IANZ Approved Signatory**

**Designation:** Laboratory Manager

**Date:** 27/04/01

**CFSL 20F7 (2001)**

Printed by: 26

Tests indicated as not accredited are outside the scope of the laboratory's accreditation.

**Opus International Consultants Limited**

Hamilton Laboratory

Quality Management Systems Certified to ISO 9001

**Fox Street**

Private Bag 3057

Hamilton, New Zealand

**Telephone:** +64 7 856 2870

**Facsimile:** +64 7 856 2873

**Website:** www.opus.co.nz
PAVEMENT INVESTIGATION LOG
TEST REPORT

Project: Volcanic Soils Project (Site 11, Te Poi)
Location: Stopfords Rd @ 160m RHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: A Ingoe. (Opus Laboratory, Hamilton)
Date Sampled: 24/04/01
Sampling method: NZS 4407 : 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
</table>
| 0          | CHIPSEAL  
Grade 2, Worn, slightly flushed. |
| 30         | BASECOURSE I  
GAP40. Moderately weathered angular GREYWACKE  
excess Silty SAND (cement Stabilised), dense, moist, non plastic. |
| 110        | OLD CHIPSEAL LAYER |
| 130        | BASECOURSE II  
Ungraded up to 80mm. Dark reddish brown subrounded  
Quary strippings/Silty SAND conglomerate, dense, moist, non plastic. |
| 310        | SUBGRADE  
Yellow brown homogeneous SILT, rare Clay,  
firm, moist, very slightly plastic. |
| 550        | END OF PIT |

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>370mm</td>
<td>6</td>
<td>2.5mm</td>
<td>63.5</td>
</tr>
</tbody>
</table>

Instu CBR Test Results

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 370 - 550mm.
Depth at which scaled penetrometer started: 370mm.

Test Methods

Determination of Penetration Resistance of a Soil, NZS 4402 : 1988, Test 6.5.2
In situ Density, sampling tube method, NZS 4402 : 1986, Test 5.1.3
California Bearing Ratio (Instu), NZS 4402 : 1986, Test 6.1.3
Inferred CBR values taken from Ausroads pavement design manual 1992

Date tested: 24/04/01
Date reported: 27/04/01

IANZ Accredited Signatory

Designation: Laboratory Manager
Date: 27/04/01

Notes

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Sampling and testing is covered by IANZ Accreditation
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Tests indicated as not accredited are outside the scope of the laboratory's accreditation.
Stopfords Road
Pavement Pit 1
@ 60m RHS, OWT

Stopfords Road
Pavement Pit 2
@ 160m RHS, OWT
Project: Volcanic Soils Project (Site 12, Pukekohe)
Location: Coles Road, @ 40m RHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: R.S. Warner (Opus Laboratory, Hamilton)
Date Sampled: 04/04/01
Sampling method: NZS 4407:1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 4. Worn.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE GAP 40. Slightly weathered, angular to subangular GREYWACKE, slight excess Sand, some Silt, moderately dense to loose, moist, non-plastic.</td>
</tr>
<tr>
<td>220</td>
<td>SUBBASE I GAP 65. Slightly weathered, angular to subangular GREYWACKE / Sandy SILT Mixture, moderately dense, moist, non-plastic.</td>
</tr>
<tr>
<td>380</td>
<td>SUBBASE II Dark brown Silty CLAY, some Aggregates intermixed, soft to firm, moist, moderately plastic.</td>
</tr>
<tr>
<td>460</td>
<td>SUBGRADE Orange CLAY, some Silt, firm, moist, moderately plastic.</td>
</tr>
<tr>
<td>500</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

| Depth 10mm | CBR % 2.5mm Water Content % 58.0 |
| 0-450mm    | In Situ CBR Test Results |

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at 450-600mm.
Depth at which scale penetrometer started: 480mm.

Test Methods
- Determination of Penetration Resistance of a Soil, NZS 4402:1986, Test 6.5.2
- California Bearing Ratio (CIR), NZS 4402:1986, Test 6.1.3
- Inferred CBR values taken from Austroads pavement design manual, 1992

Notes
- IANZ Accreditation does not apply to inferred CBR values or pavement descriptions
- Sampling and testing is covered by IANZ Accreditation

Date tested: 04/04/01
Date reported: 05/04/01

IANZ Approved Signatory: [Signature]

Laboratory Manager: [Signature]

Date: 05/04/01
**PAVEMENT INVESTIGATION LOG**

**TEST REPORT**

Project: Volcanic Soils Project (Site 12, Pukekohe)
Location: Coles Road @ 160m RHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: R.S. Warner. (Opus Laboratory, Hamilton)
Date Sampled: 04/04/01
Sampling method: NZS 4407: 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL Grade 4. Worn.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE GAP 40. Slightly weathered, angular to subangular GREYWACKE, slightly excess Sand, some Silt, moderately dense to loose, moist, non plastic.</td>
</tr>
<tr>
<td>130</td>
<td>SUBBASE Dark brown / grey Silty SAND, occasional AP 65 Aggregate, moderately dense, moist, non plastic.</td>
</tr>
<tr>
<td>250</td>
<td>SUBGRADE Orange CLAY, some Silt, firm, moist, moderately plastic.</td>
</tr>
<tr>
<td>380</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

**Insitu CBR Test Results**

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>260mm</td>
<td></td>
<td>12</td>
<td>5.0mm</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td>45.5</td>
</tr>
</tbody>
</table>

**Scalp Penetrometer**

<table>
<thead>
<tr>
<th>Blows /cm²</th>
<th>0.00</th>
<th>0.20</th>
<th>0.40</th>
<th>0.60</th>
<th>0.80</th>
<th>1.00</th>
<th>1.20</th>
<th>1.40</th>
<th>1.60</th>
<th>1.80</th>
<th>2.00</th>
</tr>
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<tr>
<td>1</td>
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<td></td>
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<td></td>
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<tr>
<td>2</td>
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<td>3</td>
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<tr>
<td>5</td>
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<tr>
<td>6</td>
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</tr>
<tr>
<td>8</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>9</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>10</td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Subgrade Density**

<table>
<thead>
<tr>
<th>Push tube results at:</th>
<th>250mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet density (t/m³):</td>
<td>1.08</td>
</tr>
<tr>
<td>Dry density (t/m³):</td>
<td>0.73</td>
</tr>
<tr>
<td>W/C %</td>
<td>46.5</td>
</tr>
</tbody>
</table>

**Test Methods**

- Determination of Penetration Resistance of a Soil, NZS 4402: 1986, Test 6.5.2
- Insitu Density, sampling tube method, NZS 4402: 1986, Test 5.1.3
- California Bearing Ratio (insitu), NZS 4402: 1988, Test 6.1.3
- Inferred CBR values taken from Austroads pavement design manual 1992

**Notes**

- IANZ Accreditation does not apply to inferred CBR values or pavement descriptions
- Sampling and testing is covered by IANZ Accreditation
- This report may only be reproduced in full

**IANZ Approved Signatory**

Designation: Laboratory Manager
Date: 05/04/01

---

Opus International Consultants Limited
Hamilton Laboratory
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Facsimile: +64 7 858 2873
Website: www.opus.co.nz
Volcanic Soil Project Site 12: Pukekohe

Coles Road
Pavement Pit 1
@ 40m RHS, OWT

Coles Road
Pavement Pit 2
@ 160m RHS, OWT
### Pavement Investigation Log

**Test Report**

**Project:** Volcanic Soils Project (Site 13, Taupiri)

**Location:** Jew Road @ 20m LIHS OWT

**Client:** Opus International Consultants Ltd

**Contractor:** N/A

**Sampled by:** R.S. Warner (Opus Laboratory, Hamilton)

**Date Sampled:** 04/04/01

**Sampling method:** NZS 4407: 1991 Test 2.4.8.2

**Sample condition:** Natural

**Pavement pit number:** 1

---

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL</td>
</tr>
<tr>
<td></td>
<td>Grade 6. Worn, sound.</td>
</tr>
<tr>
<td>20</td>
<td>BASECOARSE</td>
</tr>
<tr>
<td></td>
<td>GAP 40. Fresh, angular GREYWACKE, well graded SAND, some Silt, moderately dense, moist, non plastic.</td>
</tr>
<tr>
<td>190</td>
<td>SUBBASE</td>
</tr>
<tr>
<td></td>
<td>Orange / brown SILT, occasional Topsil clay and aggregates, firm, moist, non plastic.</td>
</tr>
<tr>
<td>290</td>
<td>SUBGRADE</td>
</tr>
<tr>
<td></td>
<td>Orange / brown Silty CLAY, firm to stiff, slightly moist, moderately plastic.</td>
</tr>
<tr>
<td>500</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

---

### In Situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR %</td>
</tr>
<tr>
<td>Penetration</td>
</tr>
<tr>
<td>Water Content %</td>
</tr>
</tbody>
</table>

- Basecourse sample not recovered.
- Subbase sample not recovered.
- Subgrade sample recovered at: 340 - 500mm.
- Depth at which CBR meterometer started: 340mm.

### Test Methods

- Determination of Penetration Resistance of a Soil, NZS 4402: 1983, Test 6.5.2
- In situ Delta, sampling tube method, NZS 4402: 1986, Test 5.1.3
- California Bearing Ratio (in situ), NZS 4402: 1988, Test 6.1.3
- Inferred CBR values taken from Austroads pavement design manual 1992

### Notes

- IANZ Accreditation does not apply to inferred CBR values or pavement descriptions
- Sampling and testing is covered by IANZ Accreditation
- This report may only be reproduced in full

---

**Date tested:** 04/04/01

**Date reported:** 05/04/01

**IANZ Approved Signatory:**

**Designation:** Laboratory Manager

**Date:** 05/04/01

---

Opus International Consultants Limited
Hamilton Laboratory
Quality Management Systems Certified to ISO 9001

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Hamilton, New Zealand

Telephone: +64 7 856 2670
Facsimile: +64 7 855 2673
Website: www.opus.co.nz
Project: Volcanic Soils Project (Site 13, Taupiri)
Location: Jew Road @ 200m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: R.S. Warner, (Opus Laboratory, Hamilton)
Date Sampled: 04/04/01
Sampling method: NZS 4407: 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 2

Depth
(mm)
Pavement Description
0
CHIPSEAL
Grade 6. Worn, sound.
20
BASECOURSE
GAP 40. Fresh, angular GREYWACKE, well graded SAND, some Silt, moderately dense, moist, non plastic.
150
SUBBASE I
Orange / brown highly weathered GREYWACKE (ROTTEN ROCK), some Clayey Silt, moderately dense to dense, slightly moist, non plastic.
240
SUBBASE II
GAP 65. Slightly weathered, angular to subangular GREYWACKE, some Silty Sand, dry, dense, non plastic.
330
SUBGRADE
Orange / brown Silty CLAY, some clayey pockets, stiff, slightly moist, moderately plastic.
500
END OF PIT

Insitu CBR Test Results
Test Depth
CBR %
Penetration
Water Content %
355mm
30
5.0mm
26.2

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 350 - 500mm.
Depth at which scale penetrometer started: 350mm.

Test Methods
Determination of Penetration Resistance of a Soil, NZS 4402: 1986, Test 6.5.2
Insite Density, sampling tube method, NZS 4402: 1986, Test 5.1.3
California Bearing Ratio (minu), NZS 4402: 1986, Test 5.1.3
Inferred CBR values taken from Ausroads pavement design manual 1992

Date tested: 04/04/01
Date reported: 05/04/01

IANZ Approved Signatory:

Designation: Laboratory Manager
Date: 05/04/01

Sampling and testing is covered by IANZ Accreditation
This report may only be reproduced in full

IANZ Accreditation does not apply to inferred CBR values or pavement descriptions

Tests indicated as not accredited are outside the scope of the laboratory's accreditation
Jew Road
Pavement Pit 1
@ 20m LHS, OWT

Jew Road
Pavement Pit 2
@ 200m LHS, OWT
PAVEMENT INVESTIGATION LOG
TEST REPORT

Project: Volcanic Soils Project (Site 14, Te Awamutu)
Location: Bowman Road @ 20m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: R.S.Warner (Opus Laboratory, Hamilton)
Date Sampled: 05/04/01
Sampling method: NZS 4407:1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
</table>
| 0          | CHIPSEAL
            | Grade 3/5. Sound.                                        |
| 20         | BASECOURSE
            | GAP 40. Fresh, angular GREYWACKE, well graded Sandy
            | SILT, moderately dense, moist, non plastic.             |
| 120        | OLD CHIPSEAL                                             |
| 140        | OLD BASECOURSE                                           |
            | GAP 40. Slightly weathered, angular to subangular
            | GREYWACKE/Sandy SILT mixture, moderately dense, moist, |
            | non plastic.                                             |
| 200        | SUBGRADE
            | Orange/brown medium to coarse SAND, dense to very      |
            | dense, moist, non plastic.                               |
| 450        | END OF PIT                                               |

In situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>300mm</td>
<td>89</td>
<td>5.0mm</td>
</tr>
<tr>
<td>9.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scala Penetrometer

| Depth Below End of Pit (m) | 0.00 | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 0.60 | 0.70 | 0.80 | 1.00 | 1.10 | 1.20 | 1.30 | 1.40 | 1.50 | 1.60 | 1.70 | 1.80 | 1.90 | 2.00 |
|---------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                           | 0    | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   |

Subgrade Density

Push tube results are:
Wet density (t/m³): Unable to test
Dry density (t/m³): by Push tube
W/C %: 8.0

Notes

IANZ Accreditation does not apply to inferred CBR values or pavement descriptions.

Date tested: 05/04/01
Date reported: 06/04/01

IANZ Approved Signatory

Designation: Laboratory Manager
Date: 06/04/01

Sampling and testing is covered by IANZ Accreditation. This report may only be reproduced in full.
Project: Volcanic Soils Project (Site 14, Te Awamutu)
Location: Bowman Road @ 100m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: R.S. Warner. (Opus Laboratory, Hamilton)
Date Sampled: 05/04/01
Sampling method: NZS 4407: 1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL</td>
</tr>
<tr>
<td>20</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td>120</td>
<td>OLD CHIPSEAL</td>
</tr>
<tr>
<td>140</td>
<td>OLD BASECOURSE</td>
</tr>
<tr>
<td>200</td>
<td>SUBGRADE</td>
</tr>
<tr>
<td>400</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td>120</td>
<td>OLD CHIPSEAL</td>
</tr>
<tr>
<td>140</td>
<td>OLD BASECOURSE</td>
</tr>
<tr>
<td>200</td>
<td>SUBGRADE</td>
</tr>
<tr>
<td>400</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

**Insitu CBR Test Results**

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>300mm</td>
<td>100</td>
<td>2.5mm</td>
<td>10.6</td>
</tr>
</tbody>
</table>

- Basecourse sample not recovered.
- Subbase sample not recovered.
- Subgrade sample recovered at: 300 - 400 mm.
- Depth at which scale penetrometer started: 300 mm.

**Test Methods**

- Determination of Penetration Resistance of a Soil, NZS 4402: 1988, Test 6.5.2
- Insitu Density, sampling tube method, NZS 4402: 1986, Test 5.1.3
- California Bearing Ratio (Insitu), NZS 4402: 1988, Test 6.1.3

**Subgrade CBR**

<table>
<thead>
<tr>
<th>Penetration (m)</th>
<th>CBR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>0.40</td>
<td>100</td>
</tr>
<tr>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

**Notes**

- Lanz Accreditation does not apply to inferred CBR values or pavement descriptions.
- Sampling and testing is covered by Lanz Accreditation.
- This report may only be reproduced in full.

**Designation:** Laboratory Manager

**Date:** 06/04/01

**Lanz Approved Signatory**

**Date tested:** 05/04/01

**Date reported:** 06/04/01

**Lab: Laboratory Manager**
Volcanic Soil Project Site 14: Te Awamutu

Bowman Road
Pavement Pit 1
@ 20m LHS, OWT

Bowman Road
Pavement Pit 2
@ 100m LHS, OWT
Project: Volcanic Soils Project (Site 15, Cambridge)
Location: Peake Rd @ 20m LHS OWT
Client: Opus International Consultants Ltd
Contractor: N/A
Sampled by: R. S. Warner (Opus Laboratory, Hamilton)
Date Sampled: 16/05/01
Sampling method: NZS 4407:1991 Test 2.4.8.2
Sample condition: Natural
Pavement pit number: 1

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSEAL</td>
</tr>
<tr>
<td>40</td>
<td>BASECOURSE G40, Slightly weathered, subangular, GREYWACKE/Medium SAND mixture, moderately dense, moist, non plastic</td>
</tr>
<tr>
<td>240</td>
<td>SUBBASE Yellow/brown medium SAND, some Gravels, moderately dense, moist, non plastic</td>
</tr>
<tr>
<td>360</td>
<td>SUBGRADE (Natural) Mid to dark brown Sandy SILT, rare Clay, soft, moist, very slightly plastic</td>
</tr>
<tr>
<td>370</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

### In-situ CBR Test Results

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>CBR %</th>
<th>Penetration</th>
<th>Water Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>370mm</td>
<td>9</td>
<td>2.5</td>
<td>20.1</td>
</tr>
</tbody>
</table>

Basecourse sample not recovered.
Subbase sample not recovered.
Subgrade sample recovered at: 370 - 470mm.
Depth at scale penetrometer started: 370mm

### Subgrade Density

- Push tube results at: 370mm
- Wet density (t/m³): 1.48
- Dry density (t/m³): 1.15
- W/C %: 20.1

**Test Methods**

- Determination of Penetration Resistance of a Soil, NZS 4402:1986, Test 6.5.2
- In-situ Density, sampling tube method, NZS 4402:1986, Test 5.1.3
- California Bearing Ratio (CBA), NZS 4402:1988, Test 6.1.3
- Inferred CBR values taken from Ausroads pavement design manual 1992

**Notes:**

IANZ Accreditation does not apply to inferred CBR values or pavement descriptions

Sampling and testing is covered by IANZ Accreditation

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**IANZ Approved Signatory:**

Designation: Laboratory Manager
Date: 18/05/01

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Facsimile: +64 7 855 2873
Website: www.opus.co.nz
**Project:** Volcanic Soils Project (Site 15, Cambridge)
**Location:** Peake Rd @ 180m LHS OWT
**Client:** Opus International Consultants Ltd
**Contractor:** N/A
**Sampled by:** R.S. Warner (Opus Laboratory, Hamilton)
**Date Sampled:** 16/05/01
**Sampling method:** NZS 4407:1991 Test 2.4.8.2
**Sample condition:** Natural
**Pavement pit number:** 2

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Pavement Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CHIPSBAL</td>
</tr>
<tr>
<td>40</td>
<td>BASECOURSE</td>
</tr>
<tr>
<td>120</td>
<td>SUBBASE</td>
</tr>
<tr>
<td>240</td>
<td>SUBGRADE (Natural)</td>
</tr>
<tr>
<td>250</td>
<td>END OF PIT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Depth</th>
<th>250mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBR %</td>
<td>12</td>
</tr>
<tr>
<td>Penetration</td>
<td>2.5</td>
</tr>
<tr>
<td>Water Content %</td>
<td>54.1</td>
</tr>
</tbody>
</table>

- Insitu/CRB Test Results
- Subgrade sample not recovered.
- Subbase sample not recovered.
- Subgrade sample recovered at: 250 - 350mm.
- Depth at scale penetrometer stared: 250mm.

**Test Methods:** Determination of Penetration Resistance of a Soil, NZS 4402:1988, Test 6.3.2
In situ Density, sampling tube method. NZS 4402:1986, Test 5.1.3
California Bearing Ratio (in situ), NZS 4402:1988, Test 6.1.3
Inferred CBR values taken from Austroads pavement design manual 1992.

**Date tested:** 16/05/01
**Date reported:** 18/05/01

**IANZ Accredited Signatory:**
**Designation:** Laboratory Manager
**Date:** 18/05/01

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**Subgrade Density**
- Push tube results at: 250mm
- Wet density (t/m³): 1.54
- Dry density (t/m³): 1.00
- W / C %: 56.1

Note: IANZ Accreditation does not apply to inferred CBR values or pavement descriptions.

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