DYNAMIC LOAD PROPERTIES OF NEW ZEALAND BASECOURSE

Transfund New Zealand Research Report No 151

DYNAMIC LOAD PROPERTIES OF NEW ZEALAND BASECOURSE

A DODDS, T LOGAN, B FULFORD, M McLACHLAN and J PATRICK Opus Central Laboratories, Lower Hutt, New Zealand

Transfund New Zealand Research Report 151

ISBN 0-478-11559-8
ISSN 1174-0574

PO Box 2331, Lambton Quay, Wellington New Zealand
Telephone (04) 473-0220; Facsimile (04) 499-0733

A Dodds, T Logan, B Fulford, M McLachlan and J Patrick. Dynamic Load Properties of New Zealand Basecourse *Transfund New Zealand Research Report 151*, 30 pp.

Keywords: basecourse, subgrade, aggregates, resilient modulus, permanent strain

AN IMPORTANT NOTE FOR THE READER

CONTENTS

EXECUTIVE SUMMARY

The dynamic properties of unbound granular basecourse materials play an integral part in the design and repair of New Zealand pavements. There is, however, a need to improve our knowledge of these dynamic properties so that the Austroads Pavement Design Guide (recently adopted by New Zealand) can be fully implemented. This will encourage the use of performance based specifications and maximise the use of locally available materials.

The function of an unbound basecourse is to dissipate the load from a vehicle and thus protect the subgrade from high stress. It is also required to have sufficient shear strength under traffic so that rutting and deformation does not occur. Both the load spreading ability and the shear strength can be determined using the repeated load triaxial (RLT) test. The same apparatus and similar test procedures are used to determine the *resilient modulus* – the ability of the basecourse to dissipate load – and the *permanent strain* – the shear strength of the basecourse material.

An Australian Standard for the test (AS 1289.6.8.1) has been developed, but there are concerns surrounding the direct adoption of this Standard for use in New Zealand. In particular:

- The Australian Standard applies to unbound pavement materials with a particle size not exceeding 19 mm and uses a 100 mm diameter by 200 mm length specimen volume. New Zealand basecourses typically have a maximum particle size of 40 mm and tests are carried out on 150 mm diameter by 300 mm length specimen volumes.
- The test sample conditions of unconsolidated and undrained material may be too severe to reliably rank material performance for New Zealand basecourses. These conditions are different from those developed in US, British and French research.

The objective of this research project was to compare the performance of three basecourse materials under a range of test conditions in order to develop a testing protocol that had the potential to distinguish between material that could be regarded as a premium basecourse and material whose performance could be suspect.

Three materials were selected for the test programme:

- Sample A was an aggregate fully complying with the TNZ M/4 specification for basecourse.
- Sample B was an aggregate that failed the M/4 specification due to a high content of plastic fines.
- Sample C was an aggregate that failed the M/4 specification due to a high content of plastic fines and by having a particle size distribution outside the specification in the amount of fines.

Resilent Modulus

The resilient moduli of the three aggregates were determined using the RLT test, with 150 mm diameter by 300 mm length specimen volumes. Each sample was tested using saturated-drained, saturated-undrained, and optimum water content (OWC)-drained conditions.

Two different stress sequences were used – the Australian Standard and a proposed New Zealand sequence.

Permanent Strain

The three aggregate types were tested in the RLT at two levels of compaction, 90% and 95%, under five conditions: maximum dry density (MDD), under-drained, undrained, optimum moisture content (OMC) and fully-saturated. Up to 10^5 cycles of stress were used with a confining stress of 188 kPa, and deviator stress of 560 kPa. Pore pressures were also measured. In all cases, the samples were allowed to consolidate under the confining stress before testing commenced.

Lime and Cement Stablisation

Material C was treated with two concentrations of cement (1% and 2%) and two concentrations of lime (2% and 4%) and cured for 3, 7 and 25 days.

Permanent strain tests were then performed under saturated-undrained conditions with the same stress factors as used in the previous tests.

ABSTRACT

This report follows on from Opus Report 95-526264.01, which recommended a test procedure for New Zealand basecourse materials. The adoption of the Australian Standard test is problematic because the proposed New Zealand test procedure is slightly different and New Zealand basecourses and conditions also differ from those in Australia. This report compares the performance of three basecourse materials under a range of conditions using both the Australian Standard test and the proposed New Zealand test and recommends a test protocol that will distinguish between material that could be regarded as a premium basecourse and material whose performance could be suspect.

1. INTRODUCTION

1.1 Background

The dynamic properties of unbound granular basecourse materials play an integral part in the design and repair of New Zealand pavements. There is, however, a need to improve our knowledge of these dynamic properties so that the Austroads Pavement Design Guide (Austroads – 1992) (recently adopted by New Zealand) can be fully implemented. This will encourage the use of performance based specifications and maximise the use of locally available materials.

The function of an unbound basecourse is to dissipate the load from a vehicle and thus protect the subgrade from high stress. It is also required to have sufficient shear strength under traffic so that rutting and deformation does not occur. Both the load-spreading ability and the shear-strength can be determined using the repeated load triaxial (RLT) test. The same apparatus and similar test procedures are used to determine the *resilient modulus* – the ability of the basecourse to dissipate load – and the *permanent strain* – the shear-strength of the basecourse material.

An Australian Standard for the test (AS 1289.6.8.1 – 1995) has been developed, but there are concerns surrounding the direct adoption of this standard for use in New Zealand. In particular:

- The Australian Standard applies to unbound pavement materials with a particle size not exceeding 19 mm and uses a 100 mm diameter by 200 mm length specimen volume. New Zealand basecourses typically have a maximum particle size of 40 mm and tests are carried out on 150 mm diameter by 300 mm specimen volumes.
- The test sample conditions of unconsolidated and undrained material may be too severe to reliably rank material performance for New Zealand basecourses. These conditions are different from those developed in US, British and French research.

The direct adoption of the Australian research into New Zealand is also considered inappropriate due to the significant differences in materials used (plastic fines can be specified), and the generally much drier moisture conditions prevailing in Australian pavements.

1.2 Previous Research

Opus Central Laboratories have previously carried out research on aspects of AS 1289.6.8.1 and its applicability to New Zealand conditions (Opus Report 95-526264.01). As a result of these studies, the following test procedure for New Zealand basecourse materials was recommended:

- The sensitivity and precision of the load and deformation measuring equipment should comply with Australian Standard AS 1289.6.8.1.
- The shape of the load pulse, load duration and frequency should comply with AS 1289.6.8.1.

- For aggregates with a 40 mm maximum particle size, a specimen volume of 150 mm diameter by 300 mm length is recommended. Material greater than 30 mm should be replaced with an equal mass of material between 10 mm and 30 mm from the same source.

- The test sample should be compacted to 95% of the MDD, as measured by the vibrating hammer test.

- For permanent strain tests, up to 10^5 cycles of stress should be used with a cell pressure of 188 kPa and a deviator stress of 560 kPa.

It was also apparent from these studies that there was a lack of knowledge as to the appropriate sample conditions to use when testing the performance of New Zealand basecourse materials. Specimens can be tested saturated or at OWC, and drained or undrained. It was considered that the behaviour in terms of resilient modulus and permanent strain would vary significantly depending on these conditions.

It was also not clear how the stress sequencing specified in AS 1289.6.8.1 would affect the test results. The sequencing is significantly different from that specified in the equivalent test developed in the USA under the Strategic Highway Research Programme (SHRP). It was considered that the stresses specified in the Australian test could exceed the likely static shear strength of many aggregates. A stress sequence considered more realistic was proposed as a result of Opus Central Laboratories Report 52626401 1995.

Subsequently, the applicability of the test conditions used to determine the resilient modulus of basecourse was also questioned in Transfund Research Report 124, which found a poor correlation between the laboratory values and the Loadman Portable Deflection Tester. In the limited study performed, a material tested using the SHRP protocol gave a very similar result to that obtained using the Loadman.

Two courses of action, therefore, were identified from these studies:

- The need to determine the loading conditions – including stress, saturation and drainage conditions – that could adequately model the field behaviour of granular materials.

- The need to determine the test conditions that would differentiate between materials that would perform well in the field, and those that would fail.

1.3 Objectives

The objective of this Transfund Research Project 0203/305 was to establish appropriate sample conditions for use in the RLT test for determining the resilient modulus and permanent strain characteristics of unbound granular aggregates used in New Zealand. The study was carried out in two stages. Stage 1 involved the following tasks:

- Material Selection. One sample complying with the TNZ M/4 specification for basecourse and two outside the specification were selected.

- Resilient Modulus Tests. The three sample materials were tested for resilient modulus under saturated-drained, saturated-undrained and OWC-drained conditions using both the Australian and proposed New Zealand test procedures.

- Permanent Strain Tests. The three sample materials were tested for permanent strain at two levels of compaction (90% MDD and 95% MDD), and under saturated-drained, saturated-undrained, OWC-drained and OWC-undrained conditions. These tests were all carried out using the proposed New Zealand test procedure.

At the conclusion of Stage 1, a meeting was held between Opus Central Laboratories staff and three experts in this field. The reviewers consisted of Greg Arnold from Transit NZ, Graham Duske from the University of Auckland and Bruce Stephen from the University of Canterbury. The meeting's objective was to reach agreement on the RLT test procedures and conditions that are appropriate for New Zealand based on the Stage 1 results and previous research. Table A.1 in the Appendix lists the procedures and conditions agreed at the meeting.

In Stage 2 of the project, the test conditions agreed from Stage 1 were used to determine the permanent strain characteristics of lime and cement stabilised basecourse (failing the TNZ M/4 specification) for curing times of 3, 7 and 28 days. Two concentrations of cement (+1% and +2%), and two concentrations of lime (+2% and +4%) were used.

1.4 Scope of the Report

Specific benefits of the project will be seen in:

- More accurate assessment of the residual modulus of a basecourse resulting in the ability to optimise the basecourse thickness.

- A methodology that will allow the selection of aggregates for different traffic volumes (i.e., the highest quality materials will not need to be specified for all construction).

- The ability to demonstrate that some marginal materials could be used in heavy duty pavements. This will be especially beneficial in areas where "high quality" aggregates are scarce (e.g., Auckland and Gisborne).

- A methodology to demonstrate, through accurate modulus values used in the Austroads Pavement Design Manual, the benefits of lime and cement stabilisation.

2. MATERIAL SELECTION

Three materials (A, B and C) were selected for the test programme:

- Sample A was an aggregate fully complying with the TNZ M/4 specification for basecourse.
- Sample B was an aggregate that failed the M/4 specification due to a high content of plastic fines.
- Sample C was an aggregate that failed the M/4 specification due to a high content of plastic fines and having a particle size distribution outside the specification in the amount of fines.

Materials B and C were created from material A by adding crusher dust.

The objective of the selection process, based on the traditional 'recipe' specification of good and bad materials, was to have a good sample, a borderline to bad sample and a worse sample.

All the materials were characterised in terms of the TNZ M/4 specification tests, and vibratory compaction curves were performed to obtain the MDD and OWC. The particle size distributions are shown in Figure 1, and the material parameters are listed in Table 1.

Table 1: Material Parameters

Sample	M/4 Grading	Sand Equivalent	% Passing 75 µm	Plasticity Index	MDD (t/m3)	OWC (%)
A	Pass	48	2.3	n/a	2.36	4.5
B	Pass	31	5.3	9	2.37	4.5
C	Fail	25	9.5	9	2.38	4.3

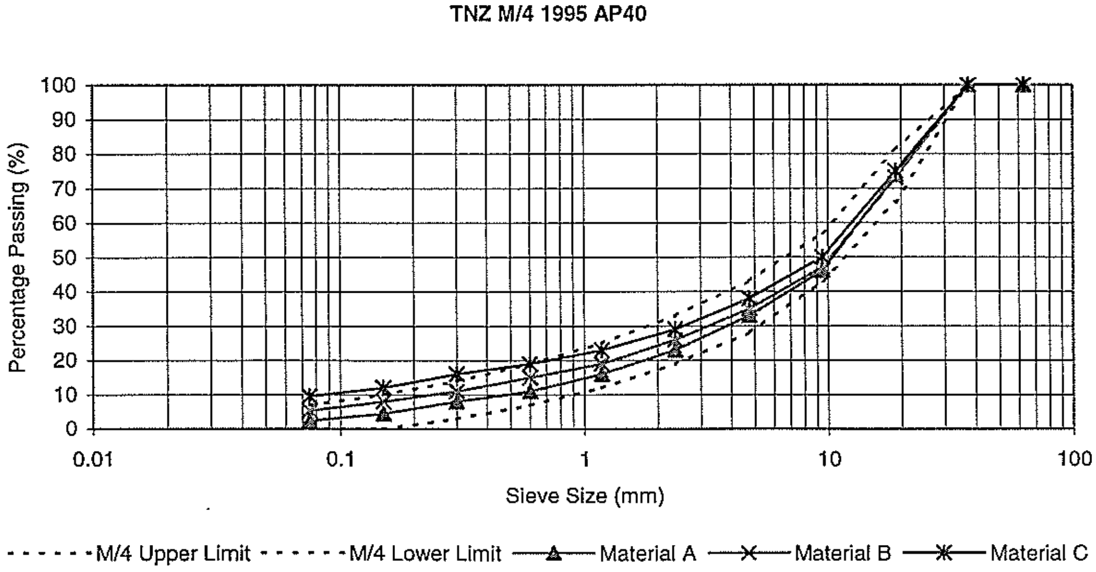


Figure 1: Particle Size Distribution

3. RESILIENT MODULUS TESTS

The resilient moduli of the three aggregates were determined by the RLT test, with 150 mm diameter by 300 mm length specimen volumes, using the Australian and the proposed New Zealand test procedures. Each sample was tested using saturated-drained, saturated-undrained, and OWC-drained conditions. Table 2 shows the various test combinations and Table 3 shows the stress sequence used.

Table 2: Resilient Modulus Test Combinations

Test Procedure	
Australian	New Zealand
Material Types (refer to Table 1)	
A, B, C	A, B, C
Sample Conditions	
Saturated-Drained Saturated-Undrained OWC-Drained	Saturated-Drained Saturated-Undrained OWC-Drained

Table 3: Repeated Load Triaxial Test Stress Sequence

Sequence	Cell Pressure	Deviator Stress
Preconditioning	0.375p	0.375p
2	0.075p	0.075p
3	0.075p	0.150p
4	0.075p	0.225p
5	0.125p	0.125p
6	0.125p	0.250p
7	0.125p	0.375p
8	0.250p	0.250p
9	0.250p	0.500p
10	0.250p	0.750p
11	0.375p	0.250p
12	0.375p	0.375p
13	0.375p	0.750p
14	0.500p	0.375p
15	0.500p	0.500p
p = estimated vertical stress at the top of the layer		

The vertical stress at the top of the basecourse in an unbound layer is the same as the tyre pressure of the design vehicle. The latest amendment to the Austroads Pavement Design Guide recommends a design tyre pressure of 750 kPa. This value of p was used as the input into Table 2 to determine the stress level in the testing programme.

The test results were loaded into a bulk stress model in the following form, and log-linear regression coefficients determined: (Austroads)

$$Er = k\theta^n$$

$$\begin{aligned} \text{where } Er &= \text{the resilient modulus} \\ \theta &= \text{the bulk stress} \\ k, n &= \text{material constants} \end{aligned}$$

The bulk stress model allows a linear comparison of the results. The results of the bulk stress analysis are shown in Tables 4 and 5, and are graphed in Figures 2 to 7. It should be noted that one sample was used for all stress sequences.

Table 4: Bulk Stress Analysis Results – Australian Test Procedure

Sample	Saturated-Drained			Saturated-Undrained			OWC-Drained		
	Log k	N	r^2	Log k	n	r^2	Log k	n	r^2
A	0.43	0.81	0.99	0.19	0.88	0.94	0.73	0.68	1.00
B	0.34	0.85	0.99	0.22	0.88	0.99	0.46	0.80	0.99
C	0.36	0.81	0.99	0.27	0.86	0.99	0.71	0.70	0.99

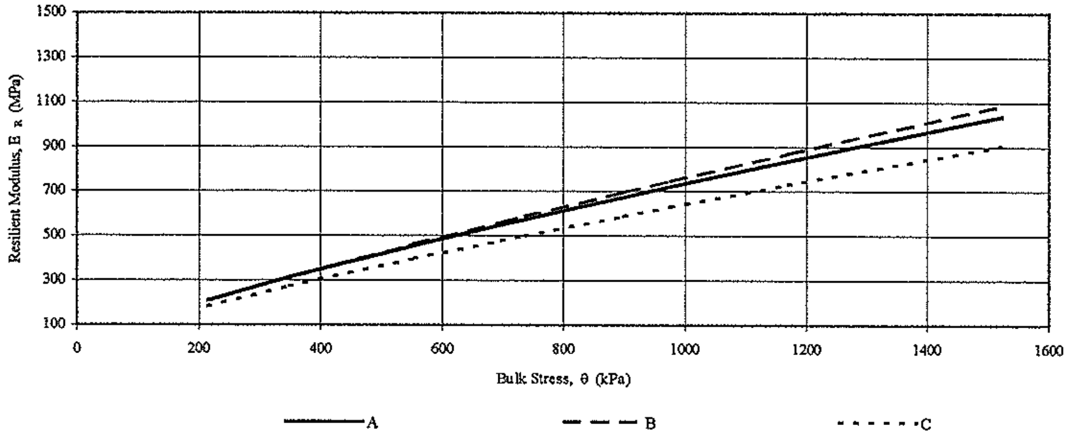
Note: Sample A, saturated-undrained had an unexplained outlier which was removed from the analysis. The outlier altered the r^2 of the model from 0.94 to 0.63 when included.

Table 5: Bulk Stress Analysis Results – Proposed New Zealand Test Procedure

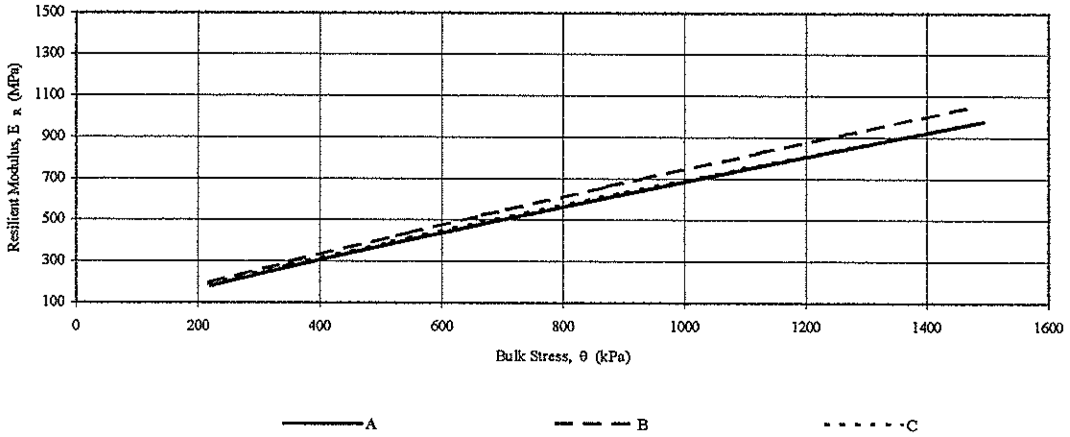
Sample	Saturated-Drained			Saturated-Undrained			OWC-Drained		
	Log k	n	r^2	Log k	n	r^2	Log k	n	r^2
A	0.91	0.66	0.98	1.15	0.60	0.98	1.34	0.52	0.83
B	1.13	0.58	0.96	0.94	0.65	0.96	1.10	0.59	0.97
C	1.11	0.57	0.96	0.81	0.68	0.97	1.27	0.51	0.97

The above tables and the following figures show that the New Zealand procedure with saturated-undrained conditions provides a clear distinction between the samples at all stress levels, and the best fit to the bulk stress model. The Australian procedure, however, does not provide a clear distinction under any conditions.

Saturated-Drained



Saturated-Undrained



OWC-Drained

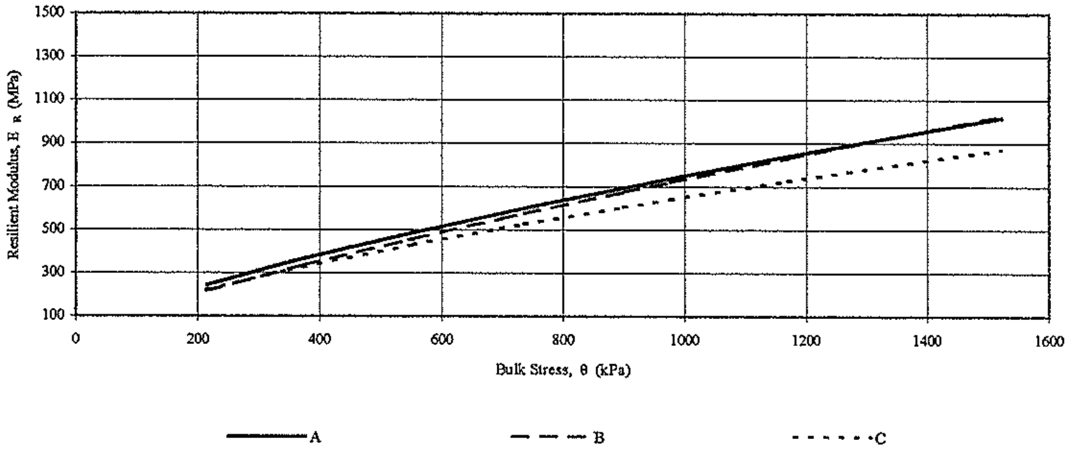


Figure 2: Bulk Stress Analysis Results – Australian Procedure

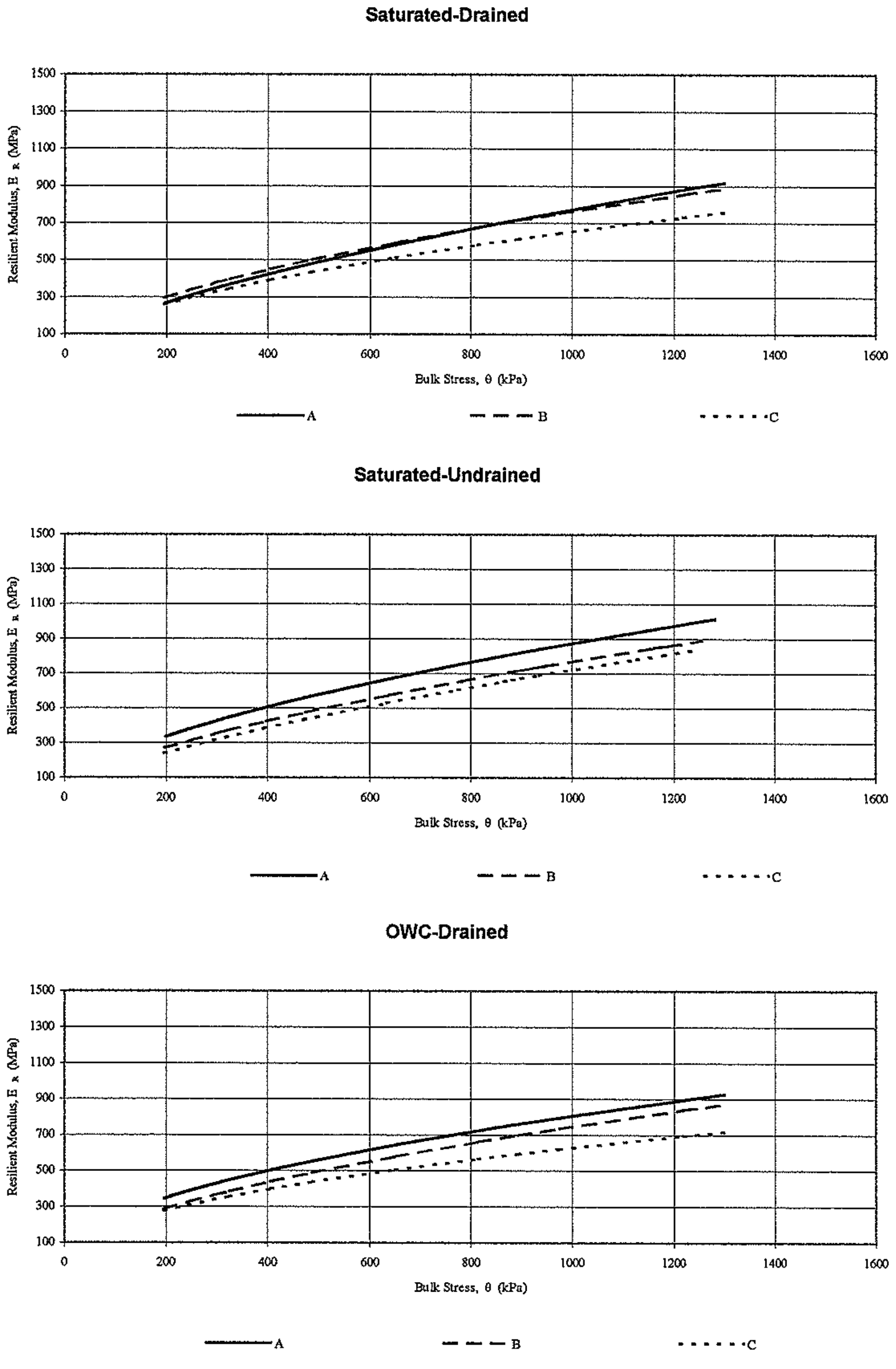


Figure 3: Bulk Stress Analysis Results – Proposed New Zealand Procedure

4. PERMANENT STRAIN TESTS

The three aggregate types were tested in the RLT at two levels of compaction, 90% and 95%, under five conditions: MDD, under-drained, undrained, OMC and fully-saturated. Up to 10^5 cycles of stress were used with a confining stress of 188 kPa, and deviator stress of 560 kPa. Pore pressures were also measured. In all cases, the samples were allowed to consolidate under the confining stress before testing commenced. Table 6 shows the various test combinations.

Table 6: Permanent Strain Test Combinations

Density	
90 % Maximum Dry Density	95% Maximum Dry Density
Material Types	
A, B, C	A, B, C
Sample Conditions	
Saturated-Drained Saturated-Undrained OWC-Drained OWC-Undrained	Saturated-Drained Saturated-Undrained OWC-Drained OWC-Undrained

The results of the permanent strain tests are shown in Tables 7 and 8 and are graphed in Figures 4 to 8. In the following tables, a sample was considered to "pass" the test if the permanent strain remained steady over the full number of stress cycles. However, a rapid increase in gradient, as shown in some of the tests, does not necessarily indicate sudden failure of the material, but only that the accumulation of permanent strain is not slowing down according to the log relationship. This is demonstrated in Figure 6 which is Figure 5 plotted at a natural scale.

Table 7: Permanent Strain Test Results – 95% MDD

Sample Condition	Observations		
	Sample A	Sample B	Sample C
Saturated-Drained	Passes	Passes	Passes
Saturated-Undrained	Passes, pore pressure rises then falls, dilation occurs	Passes, pore pressure rises then falls, dilation occurs	Fails, pore pressure keeps rising
OWC-Drained	Passes	Passes	Passes
OWC-Undrained	Passes	Looks like failing, slope of B steeper than A	Fails

Table 8: Permanent Strain Test Results – 90% MDD

Sample Condition	Observations		
	Sample A	Sample B	Sample C
Saturated-Drained	Passes	Passes	Fails
Saturated-Undrained	Fails, pore pressure keeps rising	Fails, pore pressure keeps rising	Fails, pore pressure keeps rising
OWC-Drained	Passes	Passes	Looks like failing, slope of C steeper than A and B
OWC-Undrained	Passes	Looks like failing, slope of B steeper than A	Fails

Tables 7 and 8, and Figures 4 to 8 show that OWC-undrained conditions are preferable to distinguish between the material types (i.e., material A passes while materials B and C fail, or start to fail). However, Table 8 and Figure 8 show that OWC-undrained conditions show materials A and B to be acceptable at 90% MDD. The reason for this is not clear. Field experience has shown that compaction to 90% MDD is likely to lead to problems. Therefore, it would be preferable to use saturated-undrained conditions (Figure 5) since they clearly show that materials at 90% MDD are unacceptable, but they do not distinguish between materials A and B. This point will be expanded on in the Discussion.

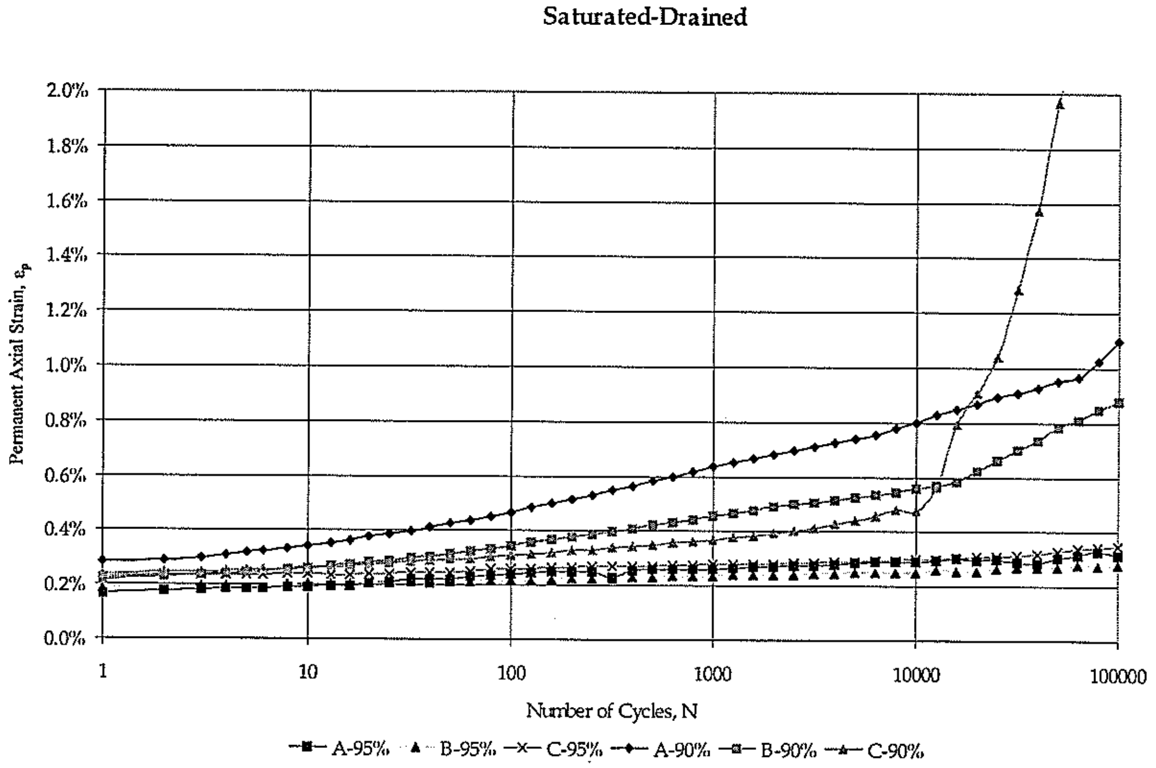


Figure 4: Permanent Strain Test Results – Saturated-Drained Conditions

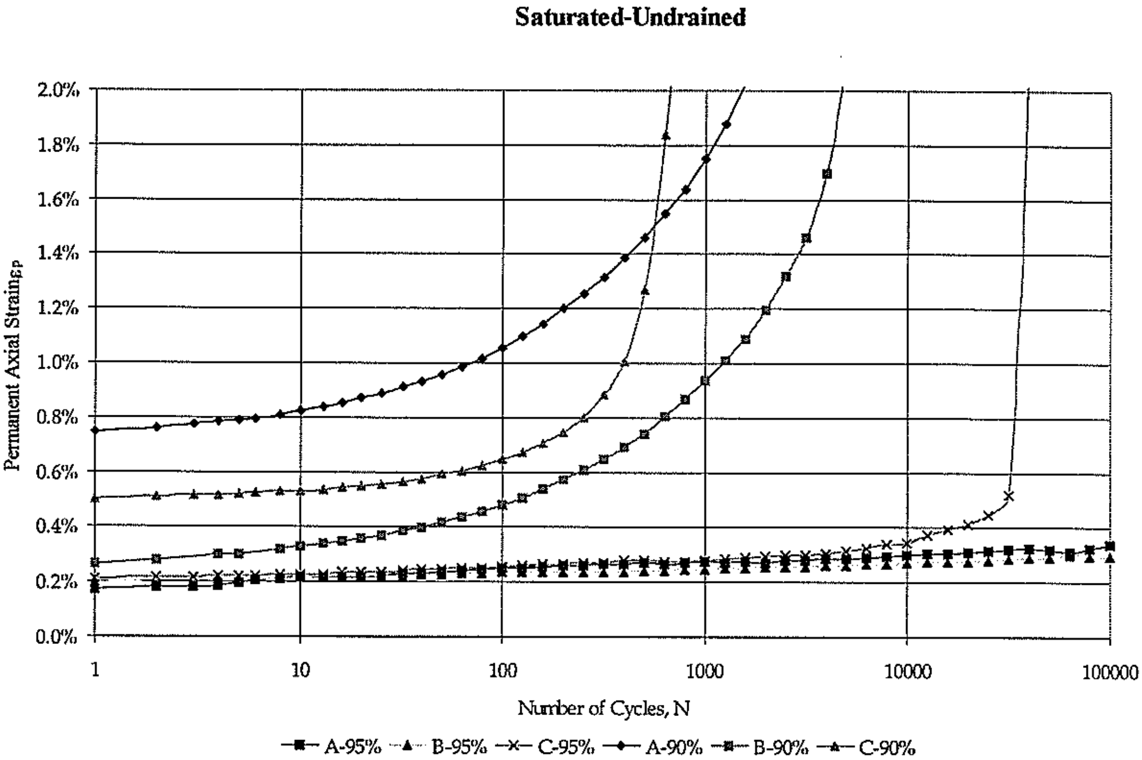


Figure 5: Permanent Strain Test Results – Saturated-Undrained Conditions

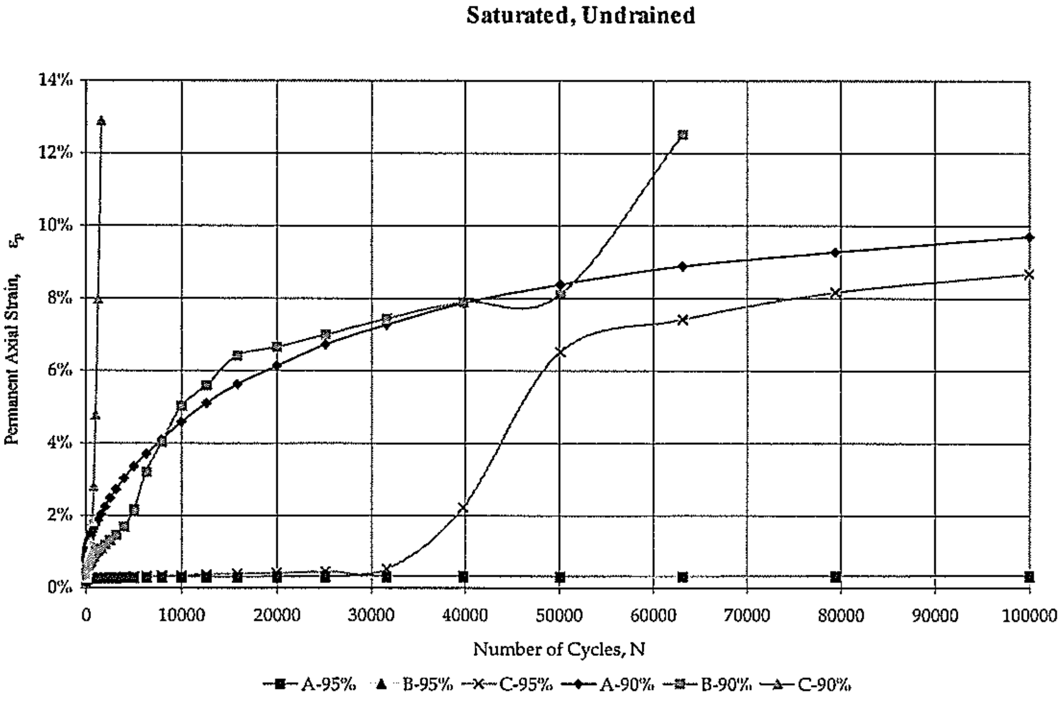


Figure 6: Permanent Strain Test Results – Saturated-Undrained Conditions

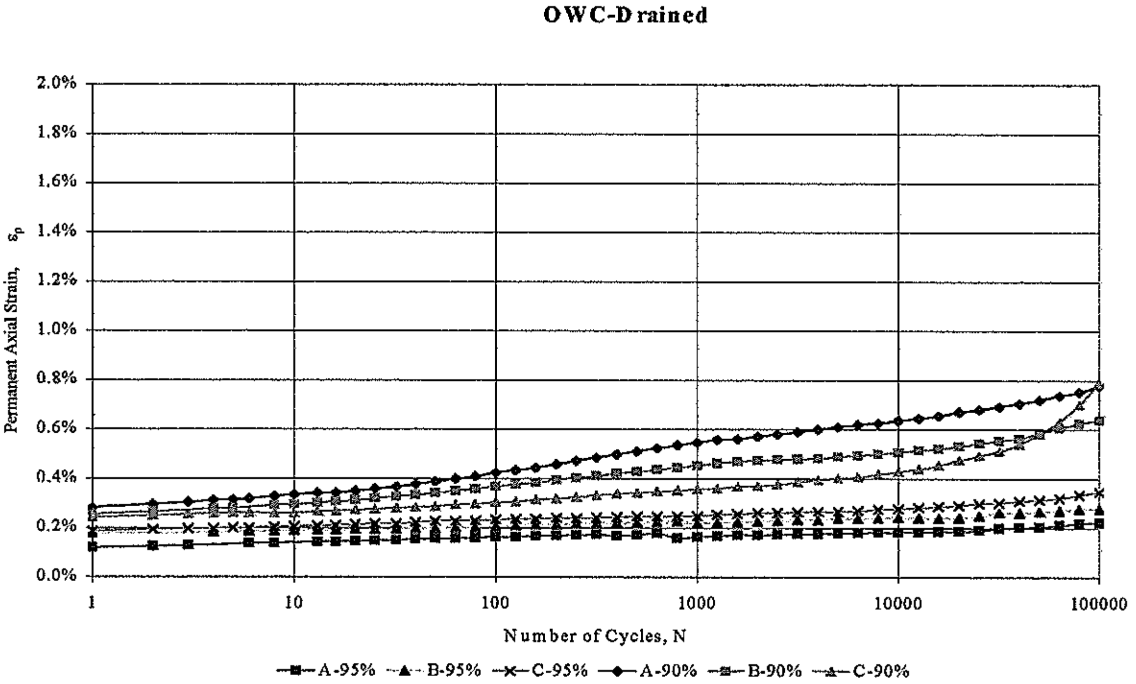


Figure 7: Permanent Strain Test Results – OWC-Drained Conditions

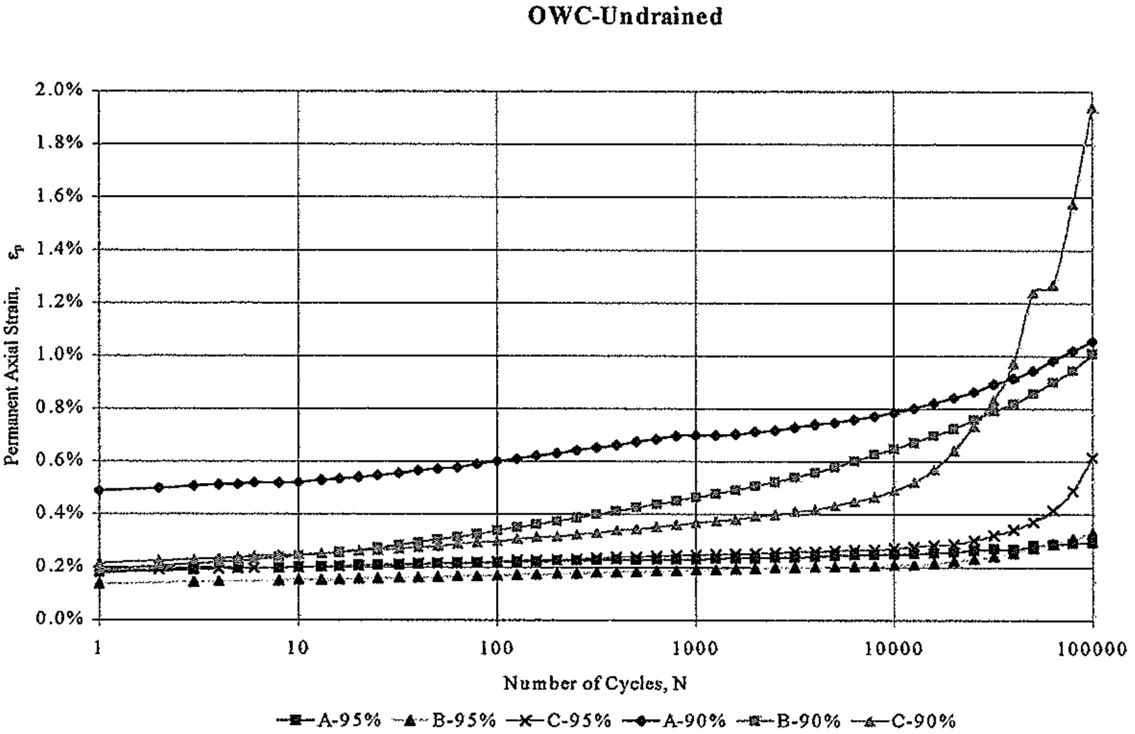


Figure 8: Permanent Strain Test Results – OWC-Undrained Conditions

5. LIME AND CEMENT STABILISATION TESTS

In this phase of the study, the test conditions agreed by the review team and Opus Central Laboratories staff (refer Appendix) were used to determine the permanent strain characteristics of lime and cement stabilised basecourse. Sample C was used for the tests with two concentrations of cement (+1% and +2%), and two concentrations of lime (+2% and +4%) in combination with curing times of 3, 7 and 28 days. Table 9 shows the various test combinations.

Table 9 Lime and Cement Stabilisation Test Combinations

Method of Stabilisation	
Added Lime	Added Cement
Amount Added	
2% and 4%	1% and 2%
Curing Time	
3, 7 and 28 days	3, 7 and 28 days

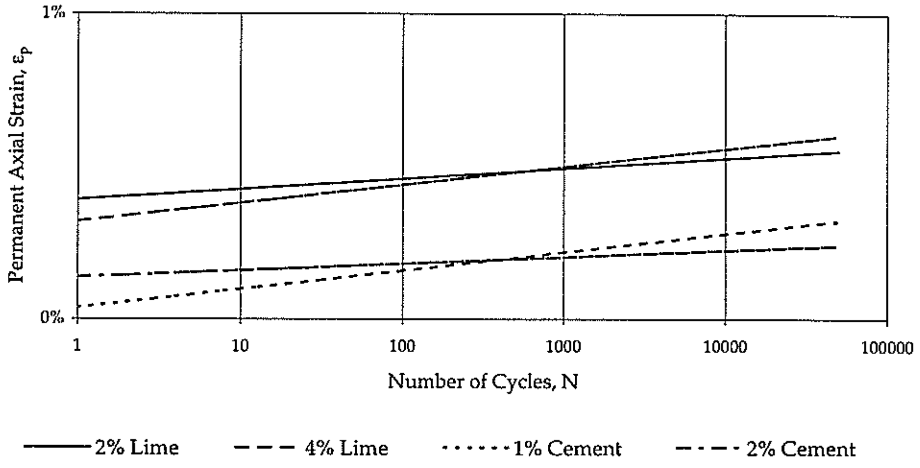
A log-linear regression analysis was carried out on the data from the stabilisation, permanent strain tests. The regression constants are listed in Table 10, and the regression fit curves are graphed in Figure 9 below (note that both axes are log scales).

Table 10 Lime and Cement Stabilisation Test Results

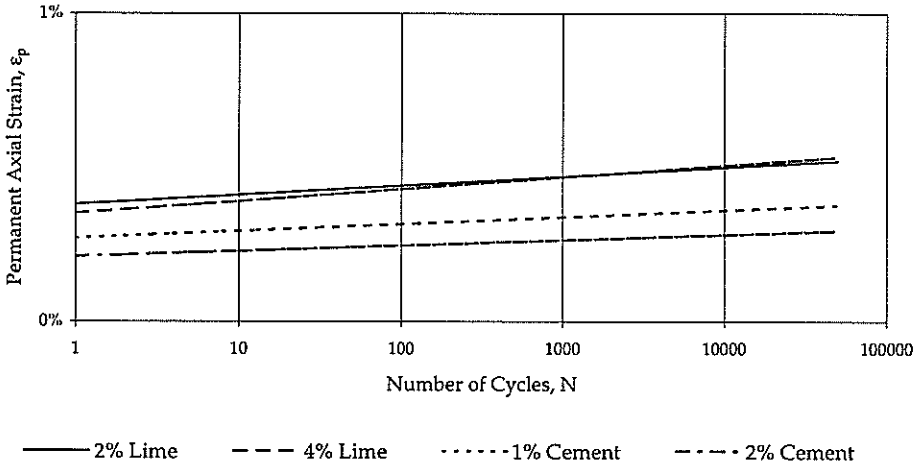
Test	**3 Day**			**7 Day**			**28 Day**		
	Intercept	**Slope**	**r^2**	**Intercept**	**Slope**	**r^2**	**Intercept**	**Slope**	**r^2**
2% Lime	-2.61	0.0338	0.99	-2.62	0.0297	1.00	-2.76	0.0231	0.88
4% Lime	-2.68	0.0592	0.95	-2.65	0.0387	1.00	-2.69	0.0233	0.96
1% Cement	-2.96	0.0603	0.87	-2.73	0.0224	0.96	-2.89	0.0149	0.78
2% Cement	-2.86	0.0219	0.97	-2.79	0.0175	0.94	-2.94	0.0054	0.46

It can be seen from Table 10 that 7 day curing provides the best data fit to a log-log relationship. Figure 8 also shows that lime or cement stabilisation significantly improve the strength of the basecourse under dynamic loading, and that cement stabilisation is more effective than lime. The results also suggest that there is a certain optimum amount of lime which will adequately stabilise a given basecourse, and increases beyond this amount may provide little additional improvement.

3 Day Cure



7 Day Cure



28 Day Cure

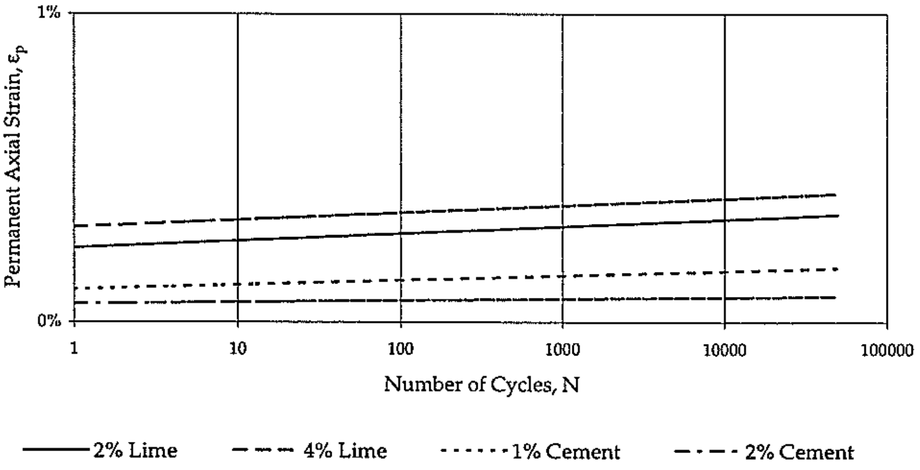


Figure 9: Stabilisation Tests – Saturated-Undrained Conditions

6. DISCUSSION

6.1 Material Selection

One of the primary objectives of this study was to identify test procedures that could be used to accept material that does not currently comply with all aspects of the TNZ M/4 specification.

The samples selected for testing would be traditionally ranked as either 'good', if they complied with the TNZ M/4 specification (Sample A), or 'bad', if they failed to meet the specification (Samples B and C). In practice, however, there is a gradation from good to bad. For example, the inclusion of plastic fines in Sample B put it outside the M/4 specification, but the quantity of plastic fines was not excessive and in practice such a basecourse could perform well.

6.2 Test Conditions

A second key objective of this study was to identify test conditions which could be used by pavement designers for specific projects in order to optimise pavement design and drainage. For example, if a particular site lacked suitable basecourse materials because of excessive plastic fines, the pavement designer may prefer to improve the drainage than import a more suitable material. The adequacy of the option could then be confirmed using appropriate test conditions.

Various sample conditions were used to assess their influence on the resilient modulus and permanent strain test results. Of these, the saturated-undrained condition is the most severe. An unconsolidated sample would be even more severe, but this was considered to be unrealistic. While in Australia saturated basecourses are less common, basecourses in New Zealand can often become saturated, so this was considered to be a realistic condition to test for.

6.3 Resilient Modulus Tests

The results of the resilient modulus tests indicate that the proposed New Zealand test procedure with saturated-undrained conditions is the preferred method of testing. It provides a clear distinction between the different materials tested, and the best data fit to the bulk stress model. The following additional observations were made:

- The resilient modulus obtained from the test is not the 'actual' resilient modulus obtained from instrumented pavements or instruments such as the Falling Weight Deflectometer (FWD), but it does effectively distinguish between different materials.

- It has been assumed that the resilient modulus of the materials should be different, and should remain different, with increasing bulk stress.

- The Australian procedure does not appear to over-stress the materials involved in this experiment. This is suggested by the fact that the bulk stress resilient modulus model behaves well under both sets of conditions. However, over-stressing may occur with other materials.

- The saturated-undrained conditions are also preferable because the effective stress on the sample can be monitored and the stress state is well-understood.

- The New Zealand procedure provides higher resilient moduli, which is preferable when comparing them with those obtained from instrumented pavements or with the FWD.

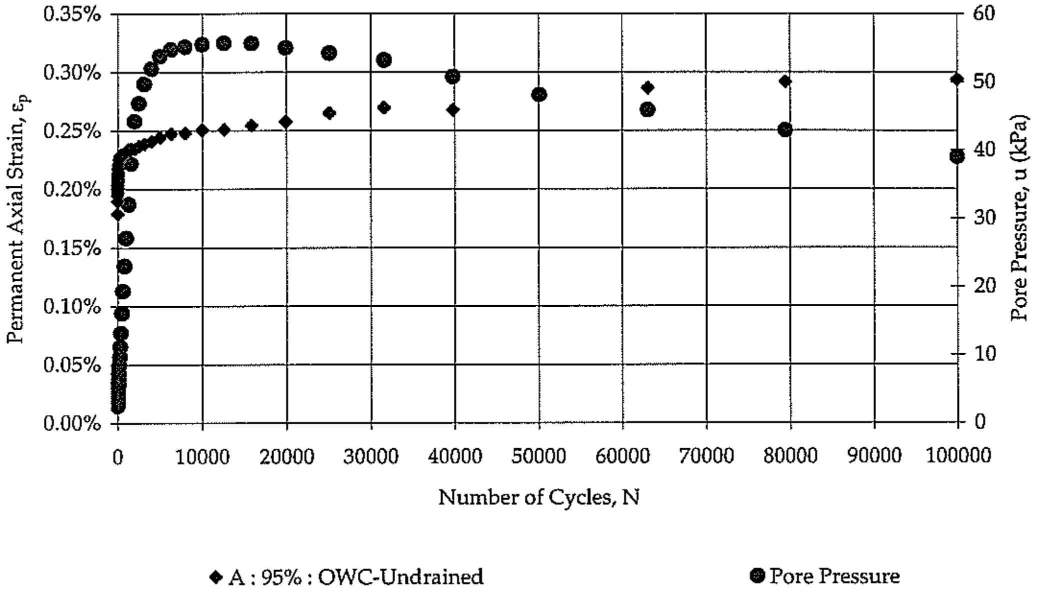
6.4 Permanent Strain Tests

The dynamic permanent strain experiment has produced some very interesting results. It initially appears that the OWC-undrained conditions are the optimal under which to distinguish between the materials at 95% MDD and 90% MDD. However, a number of questions arise from this observation. Firstly, for material B at 95% MDD, the OWC-undrained specimen performs worse than the saturated-undrained specimen. This observation goes against traditionally held views and on closer inspection of the OWC-undrained specimen there is unexpected pore pressure development.

A review of all the 95% MDD OWC-undrained and saturated-undrained specimens (Figures 10 to 12) shows that there is pore pressure development in all the OWC specimens, and the behaviour is very similar to that of the saturated material with the exception that the pore pressure is slower to develop and slower to dissipate when the sample starts to dilate. Post-water contents of the samples suggest that the degree of saturation in the OWC samples only ranged from 60% to 80%.

The disadvantage of the OWC-undrained test is that it accepts material at 90% MDD – a level traditionally considered unacceptable. The saturated-undrained condition, however, rejects this material. The fact that the saturated-undrained case accepts material B at 95% MDD is not unreasonable because, as noted earlier, material B is only slightly outside the M/4 specification.

Therefore, the saturated-drained condition is preferable because it is more sensitive to compaction than the OWC-undrained condition. Also, there is less understanding of what is happening in the OWC-undrained samples because we are dealing with a partially saturated material. It should also be remembered that the test is not an exact simulation of what is occurring in the road, but an attempt to rank materials used in construction and assign benefits to using better materials.



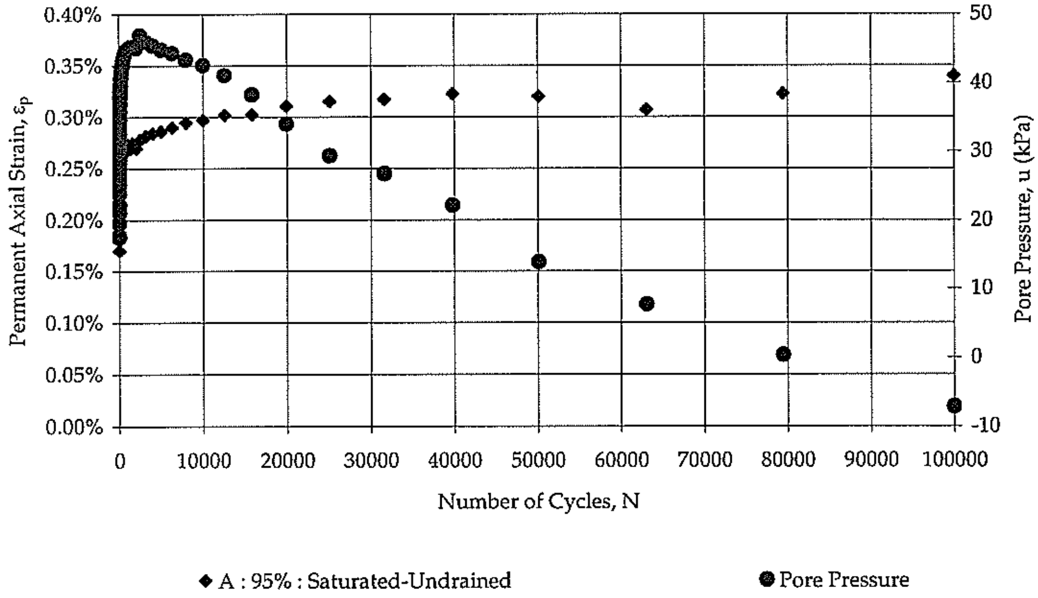


Figure 10: Permanent Strain and Pore Pressure vs Number of Cycles – Sample A

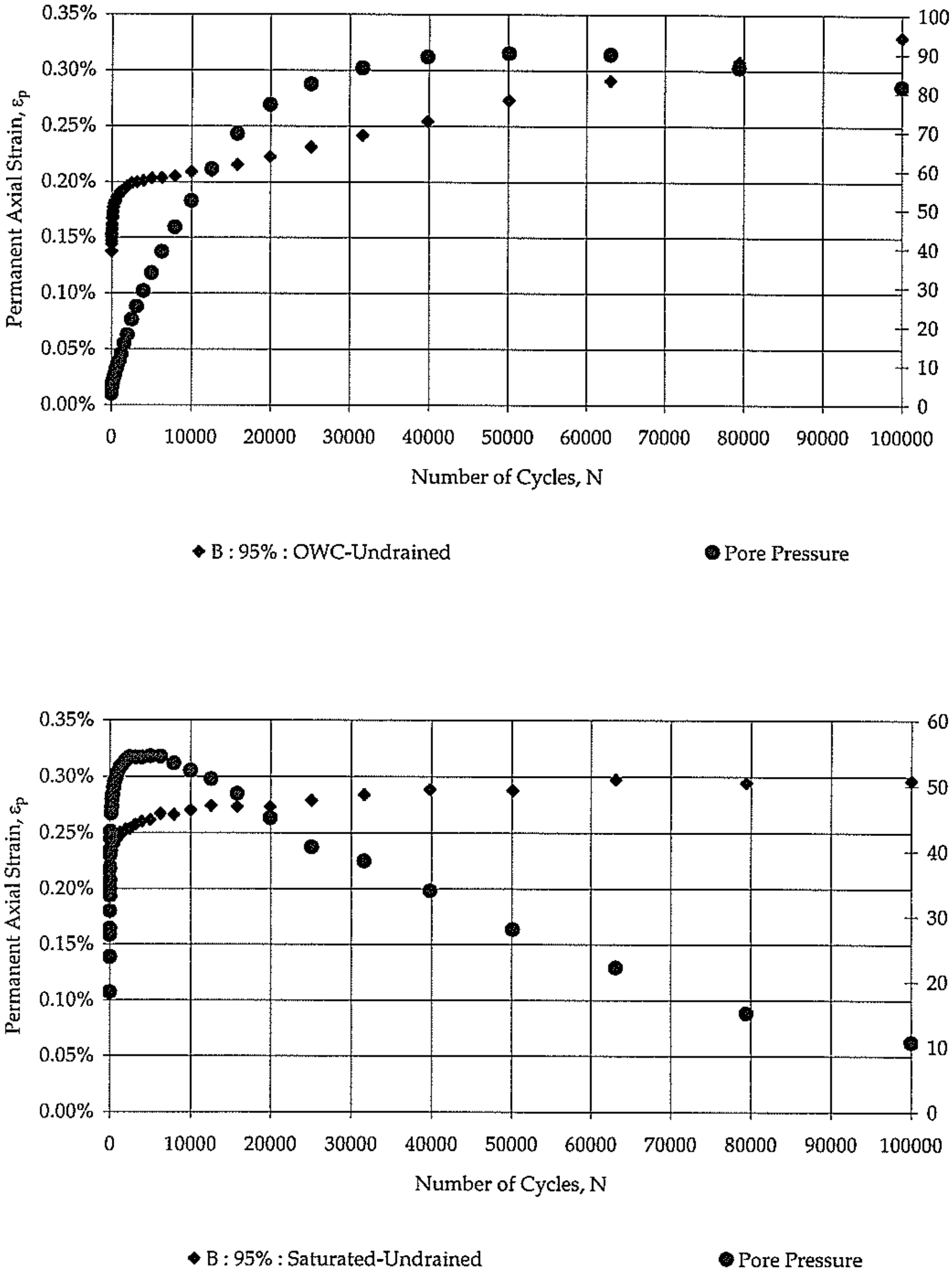
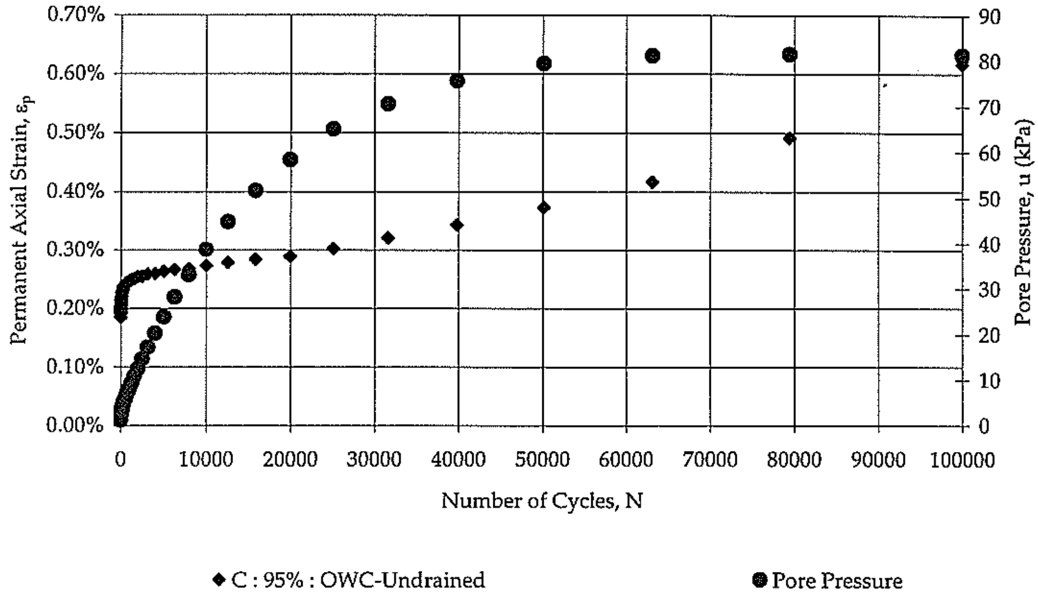


Figure 11: Permanent Strain and Pore Pressure vs Number of Cycles – Sample B



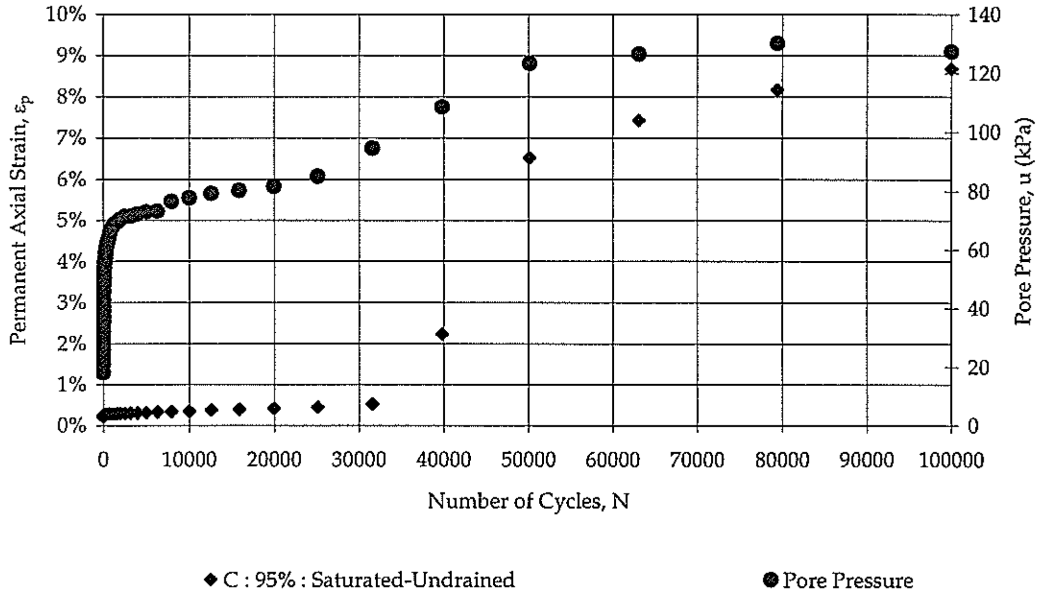


Figure 12: Permanent Strain and Pore Pressure vs Number of Cycles – Sample C

7. CONCLUSIONS

7.1 Resilient Modulus Tests

The main conclusions from the resilient modulus tests are as follows:

- The New Zealand test procedure with saturated-undrained conditions effectively distinguishes between the materials tested.
- The Australian test procedure does not distinguish well between the materials tested under any conditions. However, it does not appear to over-stress the materials as was first thought.
- The bulk stress model for determining the resilient modulus works very well.
- The New Zealand test procedure with OWC-drained conditions distinguishes between the materials; however, it is preferable to use saturated conditions as the effective stress on the sample can be reliably monitored.

7.2 Permanent Strain Tests

The preferred option for testing is with saturated-undrained conditions because they allow degrees of compaction to be clearly distinguished and there is a clear understanding of the stresses applied to the sample. The test condition also distinguishes between a 'good' and a 'poor' New Zealand basecourse.

7.3 Line and Cement Stabilisation Tests

Lime and cement stabilisation significantly improved the strength of the materials tested under dynamic loading, with cement stabilisation being more effective than lime. The preferred curing time for permanent strain tests of stabilised materials is at least seven days.

8. RECOMMENDATIONS

Our recommendations from this study are as follows:

- Use the proposed New Zealand test procedure with saturated-undrained conditions for resilient modulus testing.
- Use saturated-undrained conditions for dynamic permanent strain testing.

Further studies should be carried out on samples taken from actual pavements which have failed prematurely. This would confirm the findings of this investigation and give confidence to pavement engineers.

Also further research should be performed on the repeatability and reproducibility of the method.

9. REFERENCES

Austroads (1992): *Pavement Design.* A Guide to the Structural Design of Road Pavement. Austroads Pavement Research Group.

Australian Standard, *AS 1289.6.8.1* (1995): Methods of testing soils for engineering purposes. Method 6.8.1: Soil strength and consolidation tests – Determination of the resilient modulus and permanent deformation of granular unbound pavement materials.

Opus Central Laboratories *Report 95-526264.01.* Influence of Grading Variations within TNZ M/4 on Repetitive Load Triaxial Performance.

Transfund: Evaluation of the Loadman Portable Falling Weight Deflectometer for Determination of Elastic Modulus of Pavement Materials. *Transfund Research Report 124.*

APPENDIX: Agreed Test Procedure and Conditions

Table A.1: Repeated Load Triaxial Test Procedures and Conditions

Item	Agreed	Comment
Specimen diameter	150 mm	Most appropriate standard size.
Scalping	Scalp at 30 mm to ensure that mass of particles above 30 mm is no more than 10% of the total mass.	Consistent with SHRP protocol P46.
Target density	95% of MDD determined by vibrating hammer compaction.	
No. of compaction layers	Minimum of 6 layers.	
Compaction technique	Vibrating hammer compaction. Aggregate to be placed not poured in the mould.	Minimise segregation.
Internal/external displacement and load measurement	External by default. The test report must state the system used.	
Test conditions	Saturated, undrained.	Other conditions may be specified for particular projects.
Saturation method	Either CO_2 flushing or back-pressure saturation is acceptable.	
Consolidation	Specimens to be consolidated.	
Pre-conditioning	NZ stress level and number of cycles.	
Stress sequence for modulus test	NZ stress sequence.	
Upper limit on modulus	No specific figure agreed.	Be aware that RLT test may not be appropriate for very stiff specimens.
No. of loading cycles, permanent deformation test	50,000	
Assumed tyre contact pressure for permanent deformation test	550 kPa	
Accuracy statement	Regression line through modulus test data must include error statistics.	Desirable to establish repeatability of test results.