

Proof Testing Pavement Materials in the Laboratory the New Zealand Experience

Dr Greg Arnold

Pavespec Ltd

www.RepeatedLoadTriaxial.com

Abstract

Aggregates are a necessary and important resource for the construction and maintenance of roads. In order to conserve this resource and to reduce the risk of early failure it is important to utilise a wider range of materials appropriate to their use, either in wet or dry environments and low, medium or high traffic loadings. Research by Dr Arnold at the University of Nottingham in England and recently with the New Zealand Transport Agency, ARRB and Austroads has shown that the Repeated Load Triaxial (RLT) apparatus can measure the deformation / rutting resistance of aggregates in wet and dry states at a range of loading conditions. The results from the RLT tests enable the performance / rutting in the road to be predicted to enable the aggregate to be categorised for use according to:

- wet or dry conditions;
- low, medium or high traffic loadings.

Many RLT tests have been conducted on New Zealand aggregates where Quarry owners are increasing the sustainability of their quarries by promoting the use of marginal aggregates as premium base quality aggregates through modification with typically lime or cement. Often the modified marginal aggregate shows superior performance in the RLT test compared with traditional premium quality basecourse aggregates especially in wet conditions. The increase use of modified aggregates has led to concerns of cracking and hence research is currently underway conducting flexural beam fatigue tests utilising the RLT equipment on a range of modified aggregates to determine their life before fatigue cracking occurs. Results of the flexural beam tests has shown some promising results where the beams can be successfully compacted in moulds and the fatigue life of the modified aggregates determined by flexural beam tests is 2 Million times more than that predicted by the Austroads design criteria for cracking.

Hence the Repeated Load Triaxial test and associated equipment and analysis gives the ability to proof test aggregate mixtures in the laboratory in terms of both rutting and cracking. This enables designers to determine the suitability of an aggregate mixture for a particular road project given the design traffic and environmental conditions. This paper reports on research to date and shows that the large database already collected on aggregates performance enables comparisons to be made, increases confidence in the predictions and allows the development of pass/fail criteria for specifications based on actual data from currently good performing traditional aggregates complying to the road agency's specifications.

Introduction

Pavement design and material selection has been relatively simple for the Pavement Engineer. The pavement thickness is determined by a chart and the pavement materials used are required to comply with the appropriate road controlling authority specifications. In comparison with our cousins in the geotechnical engineering field there is little engineering involved for the design of pavements and the selection of materials. However, behind the development of the thickness design charts and pavement material specifications a significant amount of engineering and research has been undertaken.

Much of the development of pavement material specifications was in a time of the former Ministry of Works and National Roads Board. During this time the Road Research Unit prioritised, managed and disseminated the research. The National Roads Board readily paid for and accepted the risk for pavement test sections established to evaluate new materials. Today's environment for research is significantly different. It is difficult to establish pavement test sections for the purpose of testing an alternative pavement material. Road controlling authorities are not willing to accept responsibility of failures and are restricted to using current approved specifications.

Performance Based Specifications

To provide an incentive for Contractors to be innovative and use local materials (stabilised or otherwise) in 1999 Transit introduced two new specifications: *Performance Based Specification for Structural Design and Construction of Flexible Unbound Pavements* TNZ B/3 and *TNZ M/22 Notes for the Evaluation of Unbound Road Base and Sub-base Aggregates*. These performance based specifications allowed Contractors to use alternative materials provided they met certain performance criteria being durability and rut resistance and accepted a 12 month warranty/maintenance period for the final constructed pavement.

Expectation in 1999 by Transit was Quarry operators would use TNZ M22 to develop their own aggregates that are more readily produced with less wastage. A Contractor would then utilise this aggregate to compete for a performance based contract as per TNZ B3. Nine years later the use of TNZ M22 and B3 has been minimal. Two examples of its use were near Nelson where a local aggregate that did not meet the crushing percentages in TNZ M4 could be used and Stevensons in Drury used a lime modified aggregate in Auckland.

Some reasons for the low uptake of performance based specifications TNZ M22 and B3 are:

- Contractors not willing to take the risk;
- Quarry operators not proactive in testing and marketing their local materials;
- For sites trialling the use of TNZ B3 the finished road pavement did not meet the expectations of Transit's project engineers and asset managers:
 - thus many debates over whether or not the pavement met the performance requirements of B3.

More recently the Repeated Load Triaxial test as developed from a single stage test to a

a multi-stage test that results in a relationship between stress and deformation/rutting to be determined to enable to predict the rut depth in a pavement. This method has been validated by trials at the New Zealand Agency test track CAPTIF (Arnold 2004 and Werkmeister 2004). Based on this development the New Zealand Transport Agency is developing pass/fail criteria from the Repeated Load Triaxial test for use in their Specification for Premium Basecourse Aggregate (M4). The reasoning for this is that passing the Repeated Load Triaxial test gives added assurance that the aggregate used will give adequate performance with low risk of premature failure. RLT testing of basecourse aggregates to date has identified some aggregates that pass the specification but are suspected in causing pavement failures and perform poorly in the the RLT test, inclusion of a RLT test in the specification will exclude these more risky pavement materials for use on high traffic roads. Another reason for the inclusion of an RLT test is to allow for alternative pavement materials to be used that do not comply with the specification but are proven in the RLT testing to give the same or better performance than a traditional premium quality basecourse aggregate.

Waste and Energy Minimisation

Since 1999 the New Zealand Transport Agency (NZTA) have an environmental strategy that recognises government objectives to minimise waste and reduce energy usage. Efficient use of the aggregate resource by utilising locally available and waste materials was recognised as one way to reduce waste and energy use. However, the specification for basecourse aggregate TNZ M4 is restrictive allowing only premium quality crushed rock from quarries for construction of state highways. Transit are now open to adding as regional variants in M4 alternatives to premium quality crushed rock provided it can be proven to have similar performance through RLT testing. Recent additions to TNZ M4 include Recycled Crushed Concrete and Melter Slag Aggregate from the Glenbrook Steel Mill being waste materials that would otherwise be used as landfill.

NZTA are confident in the performance of Recycled Crushed Concrete due to its extensive use for many years in Australia and results from testing at their accelerated pavement testing facility CAPTIF. The Melter Slag has been used for many years already by Franklin District council and the roads have shown adequate performance. These waste product have already a history of use and thus more easily approved as an alternative to quarried crushed rock. For other waste materials such as mixtures of aggregate and glass approval is more difficult. Although, this will soon change with the introduction of the Repeated Load Triaxial Test for predicting performance in the specification for basecourse aggregate to allow alternatives to be assessed and is discussed more in the following sections.

Use of marginal and local aggregates modified or otherwise that do not currently comply with TNZ M4 specification are also recognised as reducing waste and energy. This will result in less wastage at the quarry less transportation of aggregates over long distances. An example was the use of a local borrow pit aggregate modified with 3% lime on a seal extension project in the central North Island, New Zealand. The motivation for this example was to save costs by finding a local source of aggregate. In the process the solution achieved waste and energy reductions, saved costs and reduced the risk of early pavement failure.

Prevention of Premature Pavement Distress

A key component in a pavement relies on the pavement materials performing adequately. Pavement materials are required to:

1. spread the wheel loads to reduce the load on the soft underlying subgrade (soil) and/or other weaker pavement materials ;
2. not fail in shear (i.e. shoving or rutting) with the application of wheel loads (Figure 1);
3. have minimal deformation, where most of the deformation occurs in the subgrade;
4. not deteriorate structurally over the design life;
5. adequately hold and support the surfacing; and
6. not be detrimental to the performance of the surfacing (e.g. cracking).



Figure 1 – Shear failure of basecourse aggregate.

The requirement to adequately spread the load over the subgrade is currently ensured by providing adequate pavement thickness as determined using the pavement thickness design procedures in the Austroads Pavement Design Guide. All the other requirements listed are satisfied by using an unbound granular aggregate that complies with the specification for basecourse aggregate TNZ M4. This specification is a recipe for quarries to make a basecourse that has been proven over time. However, recent early pavement failures being a result of the pavement basecourse aggregate having insufficient strength when wet has questioned the ability of TNZ M4 to produce an adequate material.

In New Zealand there is anecdotal evidence (and more recently RLT test results) that compliant M4 aggregate from different quarries perform differently. This is of particular

concern for very high trafficked roads when the aggregate with the greatest resistance to rutting are required. As discussed in the next section the Repeated Load Triaxial test will provide a means to identify aggregates more suitable for very high trafficked roads.

The current specification for basecourse aggregate TNZ M4 due to its empirical/recipe approach to selecting aggregates cannot distinguish differences in performance between aggregate types. Further, it is expected a modified aggregate with small quantities of cement or lime will provide superior performance in terms of rut resistance in wet conditions to that of traditional aggregates that comply with TNZ M4. Evidence of this is in Northland where a modified local GAP 65 aggregate which does not comply with TNZ M4 was found to solve the rutting problems that was occurring with traditional M4 aggregates. The Transfield PSMC01 contract on SH3 has also found the same conclusion. Current methods of design do not recognise the superior rut resistance of a local modified material which is not affected by moisture. Also current specifications do not allow the use of a local modified aggregate. Thus, a local modified aggregate that could solve any rutting problems of traditional M4 aggregates are not used. The introduction of the RLT test into specifications should alleviate some of these problems and allow alternatives materials that give better performance.

Repeated Load Triaxial Testing

The RLT apparatus tests cylindrical samples of soils or granular materials. Figure 2 illustrates a typical Repeated Load Triaxial apparatus test set up. For RLT tests the axial load supply is cycled for as many cycles as programmed by the user. The axial load type is usually programmed as a sinusoidal vertical pulse. Two types of repeated load tests are usually conducted, being either a resilient or permanent deformation test.

Triaxial testing is a research tool with the aim to simulate as closely as possible the range of conditions that will be experienced in a pavement.

The RLT (Repeated Load Triaxial) apparatus applies repetitive loading on cylindrical materials for a range of specified stress conditions, the output is deformation (shortening of the cylindrical sample) versus number of load cycles (usually 50,000) for a particular set of stress conditions. Multi-stage RLT tests are used to obtain deformation curves for a range of stress conditions to develop models for predicting rutting. The method of interpreting the RLT results involves relating stress to permanent deformation found from the test. From stresses computed in a pavement model of a standard cross-section at Transit's accelerated pavement testing facility CAPTIF the permanent deformation is calculated using the relationship found from RLT testing. This approach effectively predicts the amount of rutting that would have occurred in a test at CAPTIF if the aggregate tested in the RLT apparatus was used in the pavement. A range of deformation parameters are calculated from the simulated CAPTIF test as detailed in Table 1. One parameter, the number of heavy axle passes to achieve 10mm of Rutting within the aggregate layer is calculated and is deemed the design traffic loading limit. This method of assessment was validated with accelerated pavement tests at CAPTIF (Arnold, 2004 and Arnold et al, 2008).

Arnold et al, (2008) simplified the RLT test to a 6 stage test and the rut depth prediction method to enable an approximate prediction of the traffic loading limit (no. of passes to a 10mm rut) to be obtained from the average slope from the RLT test. Transit New Zealand has developed a draft specification (TNZ T/15) to incorporate the simplified RLT test and analysis which is currently being revised based on the

results of commercial RLT tests on many different aggregates and to consider the use of a RLT test at saturated undrained conditions that have been conducted commercially with some interesting results.



Figure 2 – Repeated Load Triaxial Apparatus.

The saturated undrained test is a repeat of the RLT test detailed in TNZ T/15 (Transit, 2007) but the sample is soaked for at least two hours in a water bath (Figure 3) until all the voids are filled with water. After soaking and while still in the water bath the platens are placed top and bottom and sealed to keep the water in the sample. During the RLT test the sample is sealed with no drainage to ensure saturation throughout the test. It is considered that this test is severe and testing has shown that all unbound aggregates (i.e. TNZ M4 Basecourses) show varying degrees of poor performance (< traffic loading limit < 2 Million ESAs), while stabilised aggregates generally show good results but can on occasions show poor results. Thus the saturated test is recommended when considering aggregates for use on high traffic State Highways where a stabilised/modified aggregate is probably more appropriate.

Table 1 - Description of outputs from analysis of Repeated Load Triaxial Test Results.

CAPTIF Pavement 300mm Aggregate over 10CBR Subgrade			
	Total Pavement	Aggregate only	Aggregate only
Material	N, ESAs to get 25mm rut <i>Million ESAs</i>	N, ESAs to get 10mm rut in aggregate. <i>Million ESAs</i>	Long term rate of rutting within aggregate <i>mm per 1 Million ESAs</i>
Description of the aggregate and if applicable stabilisation method used. Further information than reported here is required to describe the aggregate and stabilisation method. In particular density and moisture content are important factors which will influence the result. Hence the RLT results reported are only valid for this aggregate at one particular set of testing conditions.	This the amount of heavy axle passes until a rut depth of 25mm occurs and includes rutting in both the aggregate and subgrade. It represents the result as if the aggregate tested was used at CAPTIF (Transit NZ accelerated pavement testing facility).	The amount of heavy axle passes until 10mm of rutting occurs within the aggregate layer and it is this value which is considered the traffic loading limit to be used in Transit NZ specifications. Values >15 M ESA result in no restrictions of aggregate use provided the pavement does not become saturated.	This is the amount of rutting that will occur within the aggregate for every 1 Million heavy axle passes and it ignores the initial seating in and compaction that occurs at the beginning of the RLT test, hence a more consistent measure when comparing aggregates. Values <0.5 mm/1M ESA are excellent.
			Aggregate
			Resilient Modulus at Top of Pavement (MPa)
			Slope %/1M from 25k to 50k same as TNZ T/15
			Average Slope
			This is a simplistic analysis of the RLT result by simply looking at the slope in the RLT raw results as shown in the Figure. Values < 0.5%/1M are excellent.

Transformation of Multi-Stage RLT Data to Single Stages

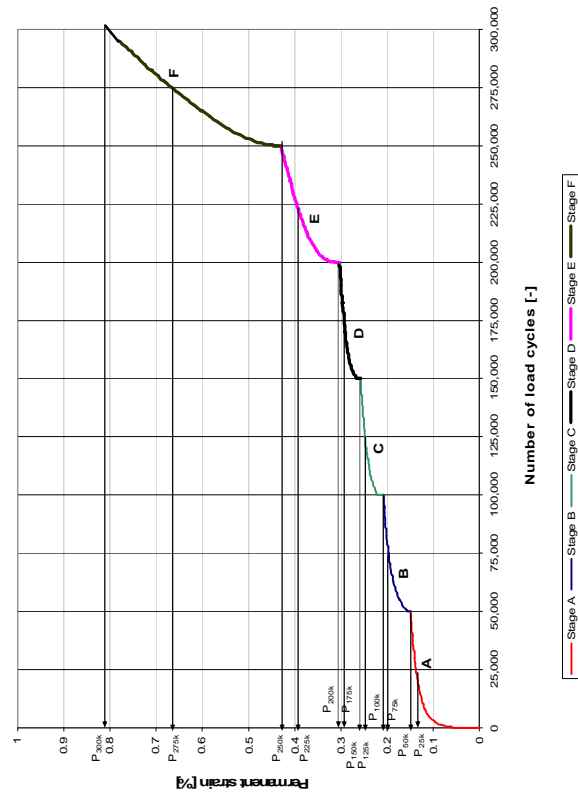


Table 5: Calculation of average permanent strain slope from 6 stage RLT test.

RLT Test Stage (Table 2)	Permanent Strain (%) (see Figure 1)	Permanent Strain (Slopes)	Permanent Strain Slope (%/1M)
Stage A	P _{25k}	$(P_{50k} - P_{25k}) / (0.025M)$	
Stage B	P _{50k}		
Stage C	P _{75k}	$(P_{100k} - P_{75k}) / (0.025M)$	
Stage D	P _{100k}		
Stage E	P _{125k}	$(P_{150k} - P_{125k}) / (0.025M)$	
Stage F	P _{150k}		
Average		$(P_{200k} - P_{150k}) / (0.025M)$	$= P_{avg} = (\sum \text{Slopes}) / 6$



Figure 3 – Soaking sample for saturated undrained RLT test.

Repeated Load Triaxial Testing Results

In the past 3 years a significant amount of Repeated Load Triaxial testing on sub-base and base quality aggregates both unmodified and modified have been undertaken for commercial and research purposes. In all the tests the same test method and rut depth predictions were undertaken. This has resulted in a database of test results where the performance can be compared to one another along with the ability to determine appropriate “pass/fail” limits for various levels of traffic that will not disallow materials already successfully used in pavement construction. A selection of these tests are reported below including: results of good and poor performing New Zealand Transport Agency (NZTA) basecourse aggregates; sub-base aggregates and cement modified aggregates. Included for comparison are some Australian aggregates.

RLT tests were conducted at both saturated/undrained and dry/drained conditions on New Zealand and Australian aggregates. Typical results raw RLT plots and predicted performance in terms of the number of Heavy Axle Passes required to cause 10mm of rutting within the aggregate tested are shown in Figures 4 to 7.

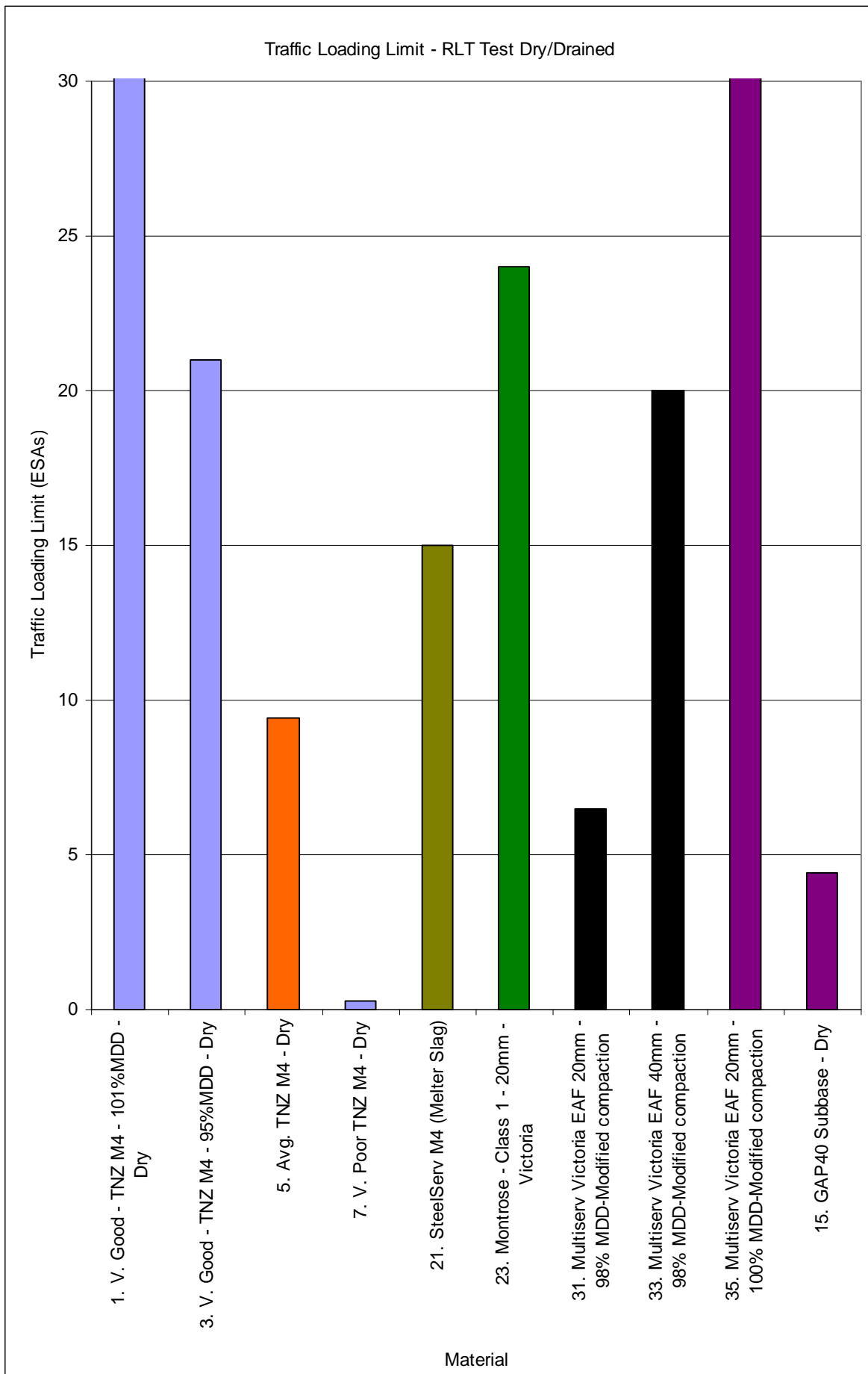


Figure 4. Typical Traffic Loading Limits (ESAs) For Various Unbound Aggregates found from RLT Testing in Dry/Drained conditions.

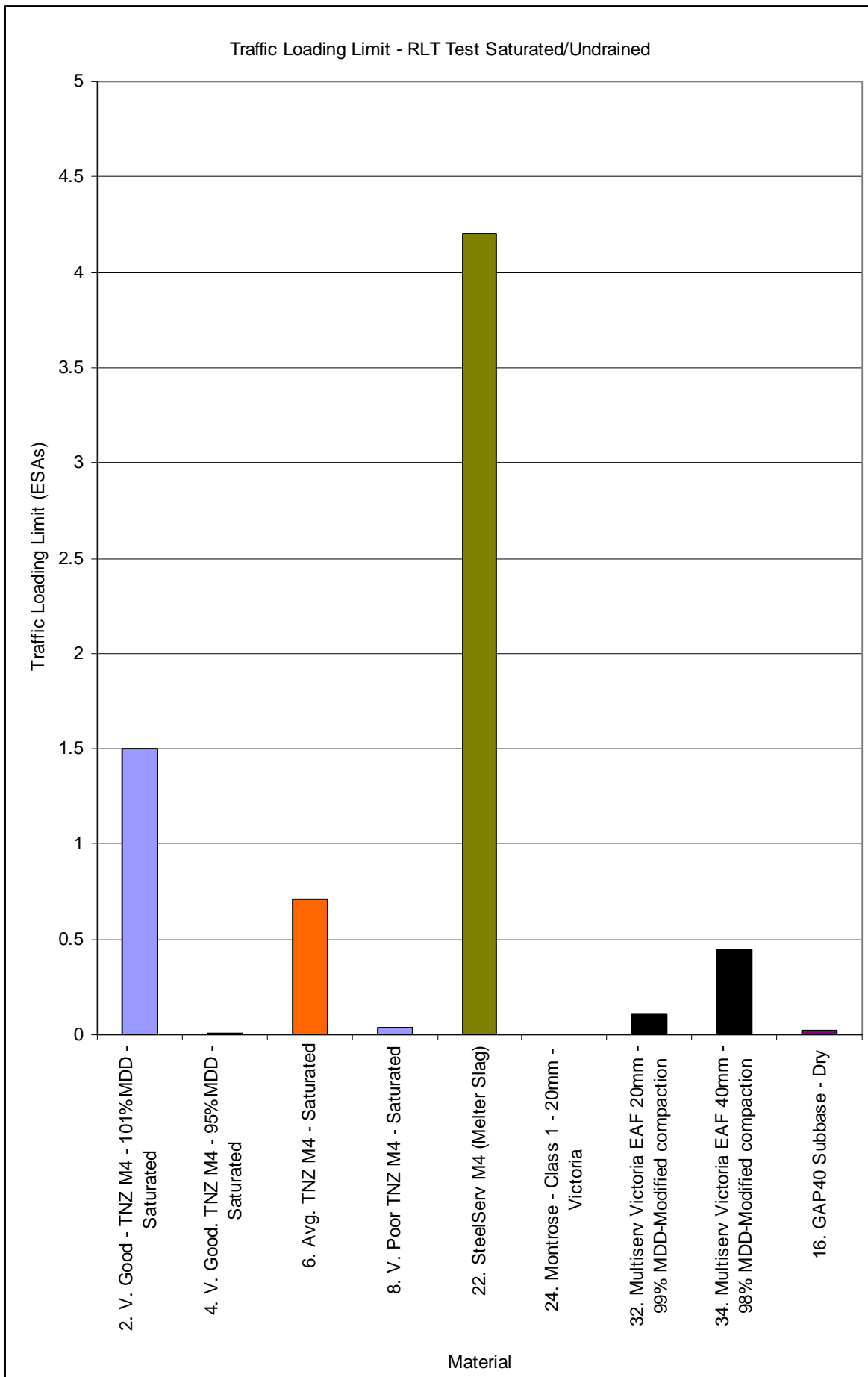


Figure 5. Typical Traffic Loading Limits (ESAs) For Various Unbound Aggregates found from RLT Testing in Saturated/Undrained conditions.

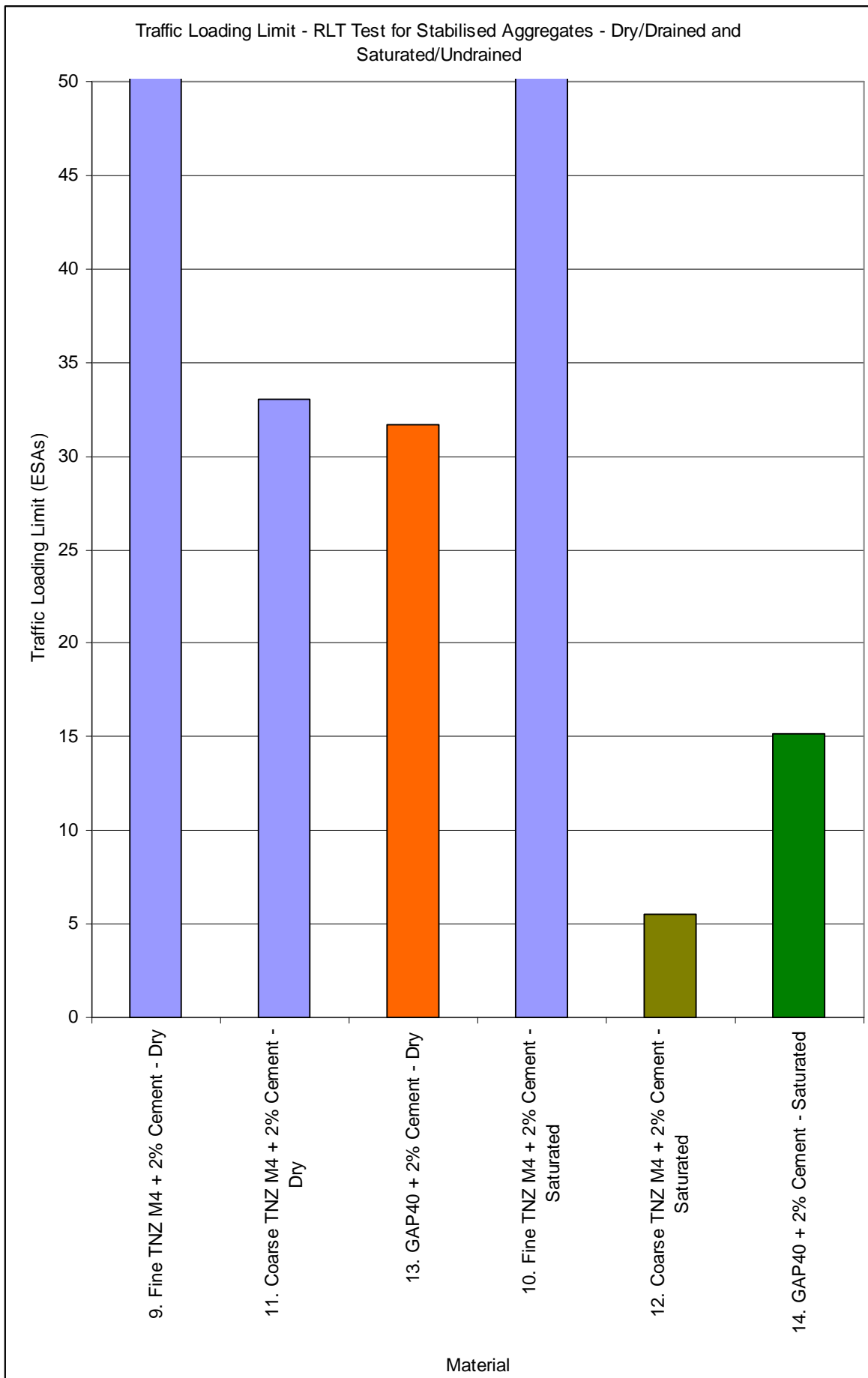


Figure 6. Typical Traffic Loading Limits (ESAs) For Various Stabilised Aggregates found from RLT Testing.

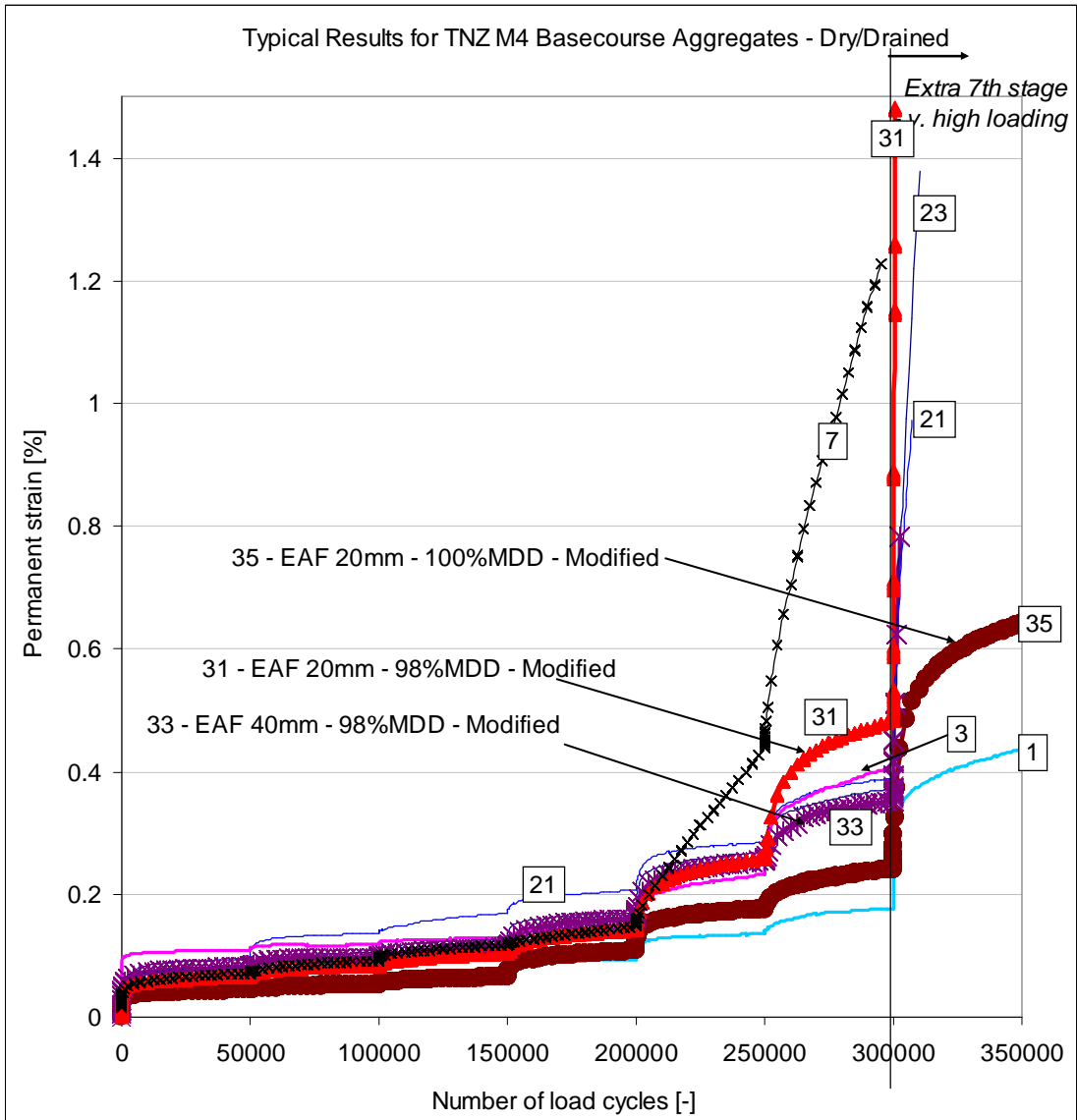


Figure 7 – Typical RLT Results for TNZ M4 Basecourse in Dry/Drained conditions.

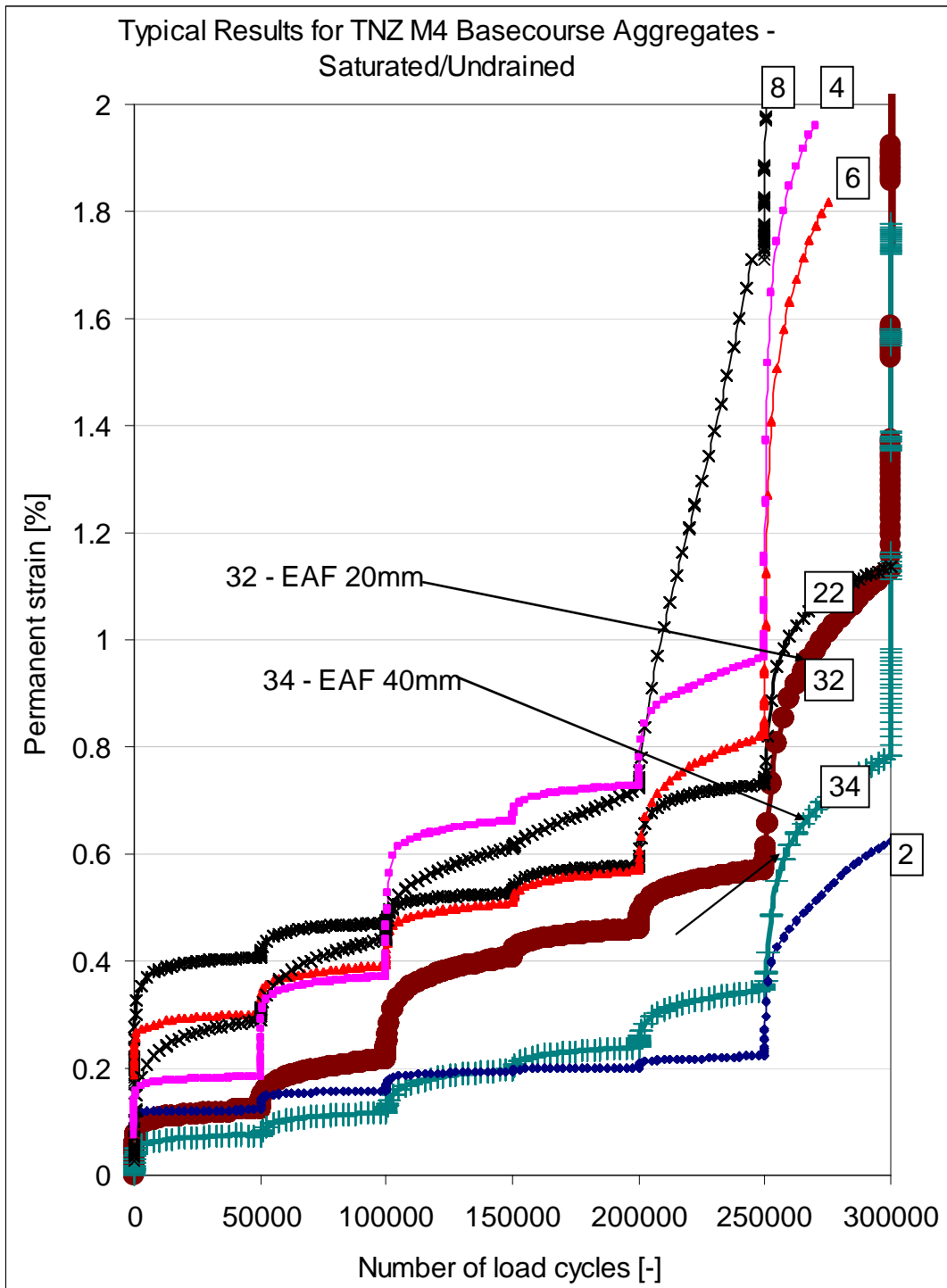


Figure 8 – Typical RLT Results for TNZ M4 Basecourse in Saturated/Undrained conditions.

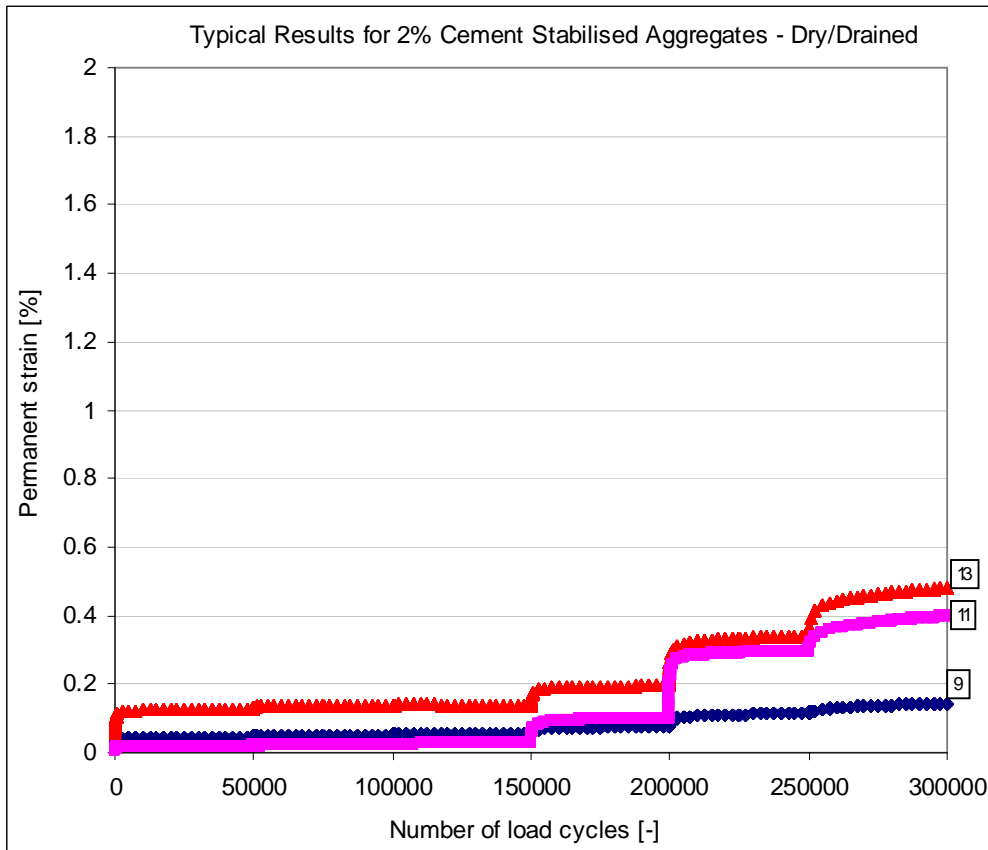


Figure 9 – Typical RLT Results for 2% Cement Stabilised Aggregates – Dry/Drained Test Conditions.

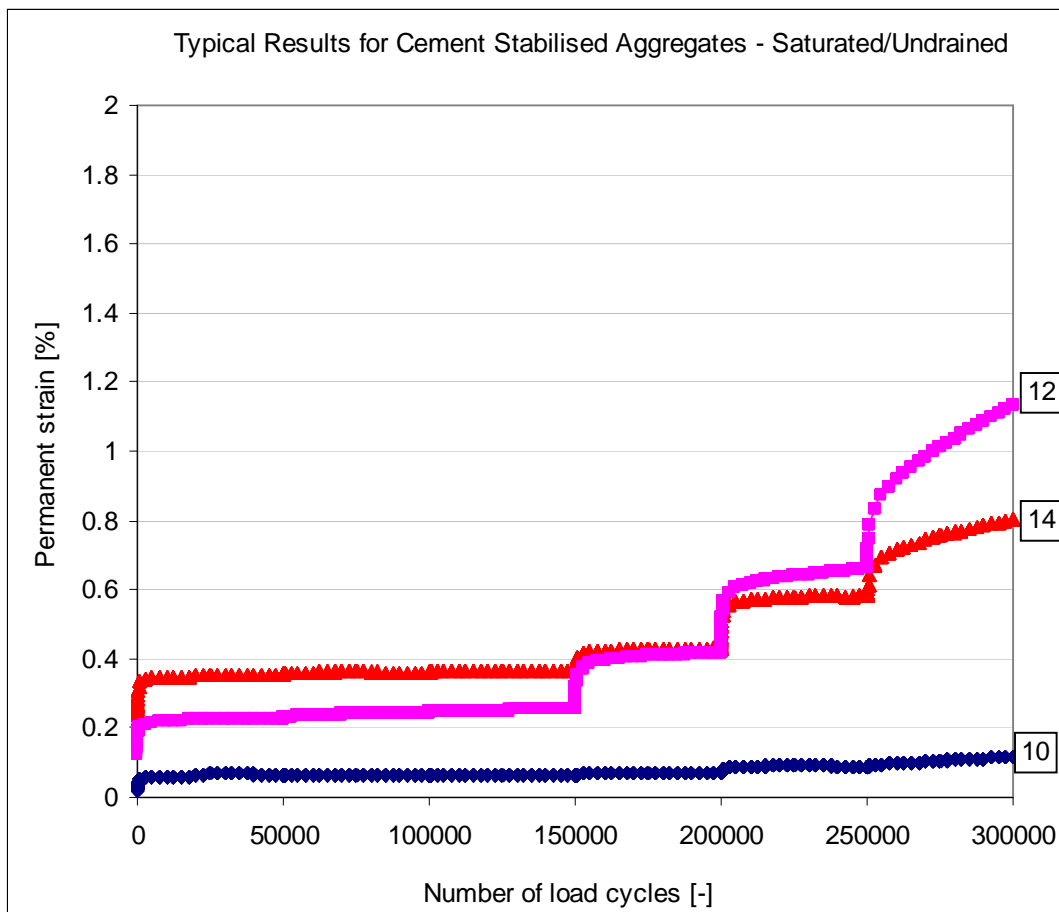


Figure 10 – Typical RLT Results for 2% Cement Stabilised Aggregates – Saturated/Undrained Test Conditions.

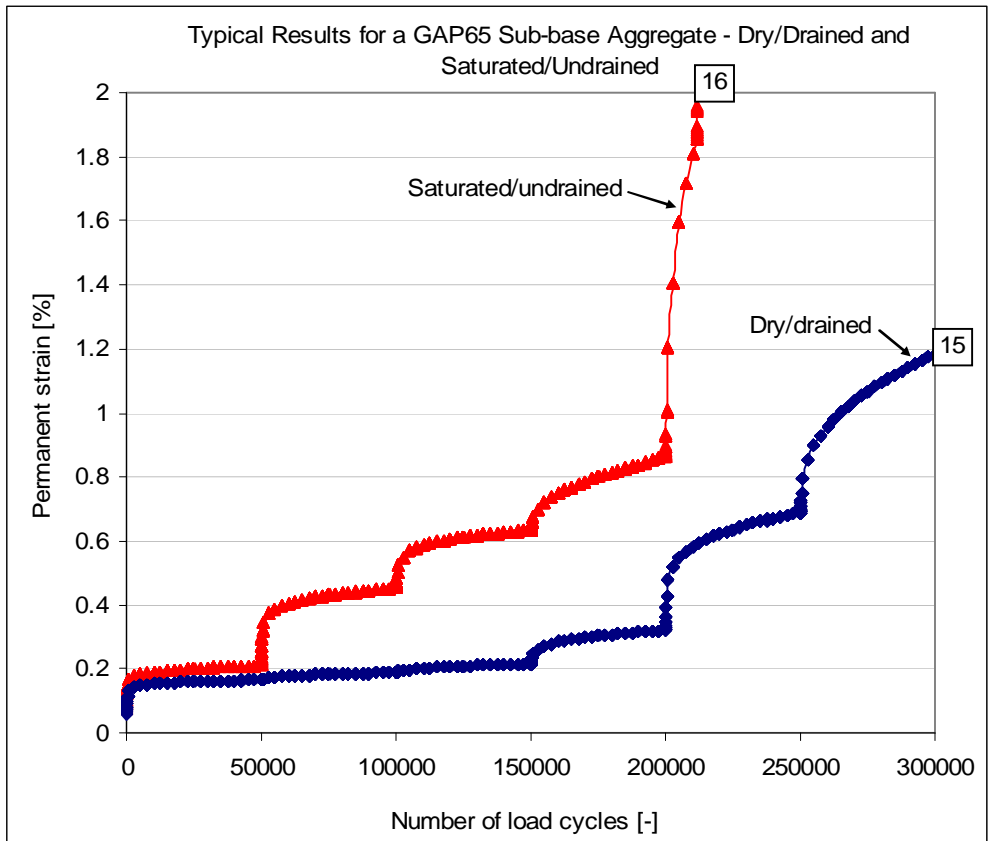


Figure 11 – Typical RLT Results for GAP65 Sub-base Aggregate – Dry/Drained and Saturated/Undrained Test Conditions.

RLT Test Summary

The multi-stage permanent strain Repeated Load Triaxial test as detailed in Transit New Zealand’s specification TNZ T/15 with associated rut depth modelling enables comparisons in performance for a range of aggregate mixtures to be determined. Predicting the number of heavy axle passes until a 10mm rut is obtained within the aggregate when analysing the RLT results is considered a reasonable method to determine the traffic loading limit as it was validating at CAPTIF and appears to give reasonable/expected results for a range of aggregates. A summary of results is shown in the Table 5.

Table 5 – RLT Result Summary.

Material	Repeated Load Triaxial Test Result and Rut Depth Prediction
TNZ M4 Basecourse	<p>Typically the Traffic Loading Limit is from 10 to 20 Million ESAs in the standard dry test and generally always < 1 Million ESAs when saturated, higher compaction does improve these results.</p> <p>There are a few TNZ M4 basecourses that show very poor performance in the RLT test (<1 Million ESA when dry) which generally are involved in a few early pavement failures.</p>
Montrose Class 1 20mm Aggregate from Victoria Australia	<p>The result from the RLT test was the same as a good New Zealand TNZ M4 Basecourse aggregate achieving a traffic loading limit of 24 Million ESAs.</p>
Multiserv Melter Slag and EAF aggregate from New Zealand and Australia	<p>The performance found from the RLT test was slightly better than a good New Zealand TNZ M4 Basecourse aggregate in the dry test (achieving 20 to 30 Million ESAs) and substantially better in the saturated test (achieving 0.1 to 4 Million ESAs). Extra compaction to obtain a higher density does improve the results.</p>
Cement Stabilised Aggregates	<p>Materials with a high fines content such as GAP40 or GAP65 with low plasticity and TNZ M4 on the fine side of the grading envelope react well with cement and result in Traffic Loading Limits both dry and saturated >30 Million ESAs.</p> <p>However, some coarse aggregates with lack of fines when saturated show result in a relatively poor performance in the RLT test with a Traffic Loading limit around 5 Million ESAs. Although, this is still significantly better than the result for a unmodified TNZ M4 basecourse.</p>
Sub-base	<p>Typically a sub-base performs well in the RLT test in dry conditions with a Traffic Loading Limit around 4 Million ESAs if used as a basecourse or around 17 Million ESA if used as a sub-base. However, sub-base aggregates are very sensitive to moisture and do not get past the 5th stage of a 6 stage test which results in a Traffic Loading limit of around 10,000 ESA if used as a basecourse or 30,000 ESA when used as a sub-base.</p>

There are many factors that ensure good performance of a basecourse including: aggregate shape; grading; preventing saturation of the basecourse (eg. a permeable sub-base); preventing segregation during construction; sealing in prolonged good/dry

weather; achieving as high a density as possible (ie. even higher than NZTA B2 or an appropriate specification); good shoulder support. If all these factors are achieved then it is likely that aggregate will perform better than predicted from the RLT test. The results of Repeated Load Triaxial tests should be viewed comparably along with it's intended use (pavement drainage, traffic etc) and used to indicate the risk of early failure. Those aggregates with poor RLT performance are possibly less forgiving and if one of the factors above is not achieved during construction then there is a higher chance of early failure than an aggregate showing good performance in the RLT test. This higher risk of failure should not necessarily ban the aggregate but rather more care and awareness of this fact during construction and design.

NZ Transport Agency (formerly Transit New Zealand) is wanting to minimise the risk of early pavement failure and is moving in the direction of structural asphalt for the very high trafficked urban state highways (approx. > 25 Million ESAs) and for other high trafficked state highways (>15 Million ESAs) a modified/cemented aggregate is recommended. Pavespec Ltd is currently working with the NZTA to develop specification criteria utilising the Repeated Load Triaxial test for a modified/cemented aggregate. The specification for a modified aggregate will include a requirement for the saturated RLT test and hence it is likely only a modified/cemented aggregate will pass this test.

Flexural Beam Testing

The Austroads Pavement Design Guide (Austroads 2004) determines the life of Cemented layers using a tensile fatigue criterion that relates the number of allowable Equivalent Standard Axles (ESAs) to the tensile strain (ϵ_{t_ctb} , Figure 12) at the base of the cemented layer. Austroads (2004) suggests a relationship between tensile strain and ESAs but this has never been tested or validated in New Zealand for New Zealand materials.

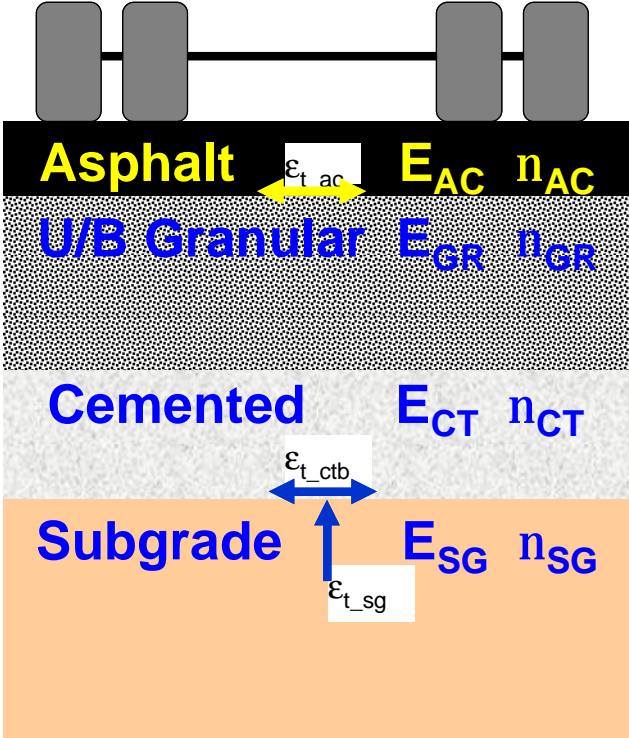


Figure 12 – Inputs required for mechanistic pavement design.

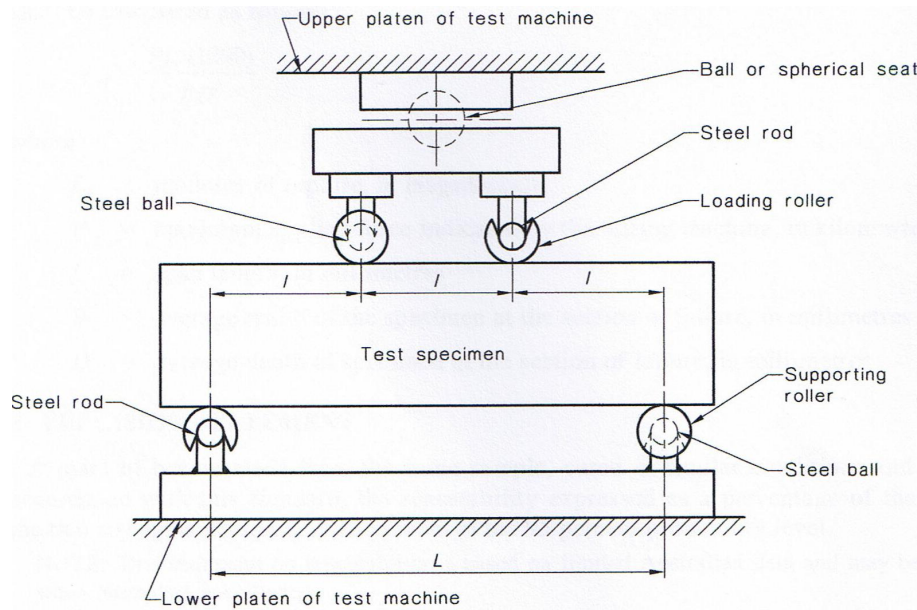


Figure 14 - Four point beam testing apparatus

A fatigue test on beams (Figure 14) is being developed for stabilised aggregates used in New Zealand to ensure that designers consider cracking as a mode of failure in their design approach, which is currently being ignored due to the conservative nature of the Austroads criteria. The test develop needs to allow for ease of manufacture such that it can be readily conducted as routine testing in design, as such a rectangular foot on a mounted vibrating hammer will be used to compact the beam samples in moulds to the required density.

NZ Beam Manufacture

The draft Austroads Test method for flexural beam testing reported in the Austroads Technical Report - AP-T101/08 (Austroads, 2008) allows for two different beam sizes. The larger beam size was chosen for testing New Zealand 40mm cemented aggregates.

Austroads recommends saw cutting the beams to the required dimensions after slab compaction although compaction in a mould with a rectangular foot is mentioned as acceptable provided the edges remain intact. As there is not a slab compactor large enough in New Zealand to compact the 530mm long by 150mm square beam suitable for 40mm size aggregates it was decided to compact the beams in a mould.

Pavespec Ltd's compaction frame with a rectangular foot (Figure 15) was used to enable accurate control on finished compacted height and thus density (as the dry weight of material is controlled). Cemented aggregate was compacted into a 530mm long by 150mm square beam mould with removable sides and base-plates as detailed in Figure 16.



Figure 15 – Compaction frame with vibrating hammer and foot for beam manufacture.



Figure 16 – Beam mould.

A 4% cement stabilised aggregate mixture as used at CAPTIF was used to trial the beam manufacturing process using a mould and vibrating hammer with a rectangular

foot. The method of compaction was considered a success provided some care was taken on the compaction of the final surface layer and the mould was lined with plastic film. Figure 17 shows the final compacted beam after curing for 5 days kept in the mould and sealed in a plastic bag in the 21 degree concrete curing room.



Figure 17 – Compacted and cured beam ready for testing.

Flexural Beam Test

Pavespec Ltd testing frame, measuring and recording equipment for Repeated Load Triaxial testing was modified and adapted for testing the flexural beam properties (flexural modulus, tensile strength, tensile fatigue) for this research. A support and loading frame of the correct dimensions was built by Stevenson's Engineering. The LVDT's for measuring deflection were supported on the loading frame with the complete setup shown in Figures 18 and 19. Software is used to run the test which is very versatile allowing the use to specify the type of type of loading (repetitive or continuously increasing), loading speed, load magnitude and number of load cycles. The breakage test requires the user to specify either stress or strain controlled and a loading rate (e.g. 3.3kN per minute or 1mm per minute). For the flexural modulus the loading speed, magnitude and number of load cycles of 100 is specified. Fatigue testing is the same as the modulus test but the number of load cycles is set to at least 1 million or until the sample breaks.

The beam test procedure is detailed in Appendix A an Austroads Test Method reported in Austroads (2008). However, initial testing on the New Zealand materials has discovered some changes in the guidance notes being required.



Figure 18– Test setup for measuring flexural beam properties.



Figure 19 – Result after breakage or fatigue test.

Initial Flexural Beam Test Results

Flexural beam fatigue tests results were plotted in Figure 20 to compare with the

Austrroads tensile fatigue criteria. As can be seen in the plot the Austrroads criteria is more conservative compared to the lab test results. For a tensile micro-strain of 300 Austrroads predicts a life of 100 cycles while the lab tests predict a life of 5 Million load cycles. This promising result supports the apparent success of thin stabilised layers typically used in New Zealand pavements. Although, the New Zealand pavements with a stabilised basecourse of 150 to 200mm were designed as an unbound granular pavement, fatigue cracking is unlikely based on the fatigue criterion found from the lab tests. Although the Austrroads fatigue criterion predicted fatigue cracking failure usually less than 1 load cycle.

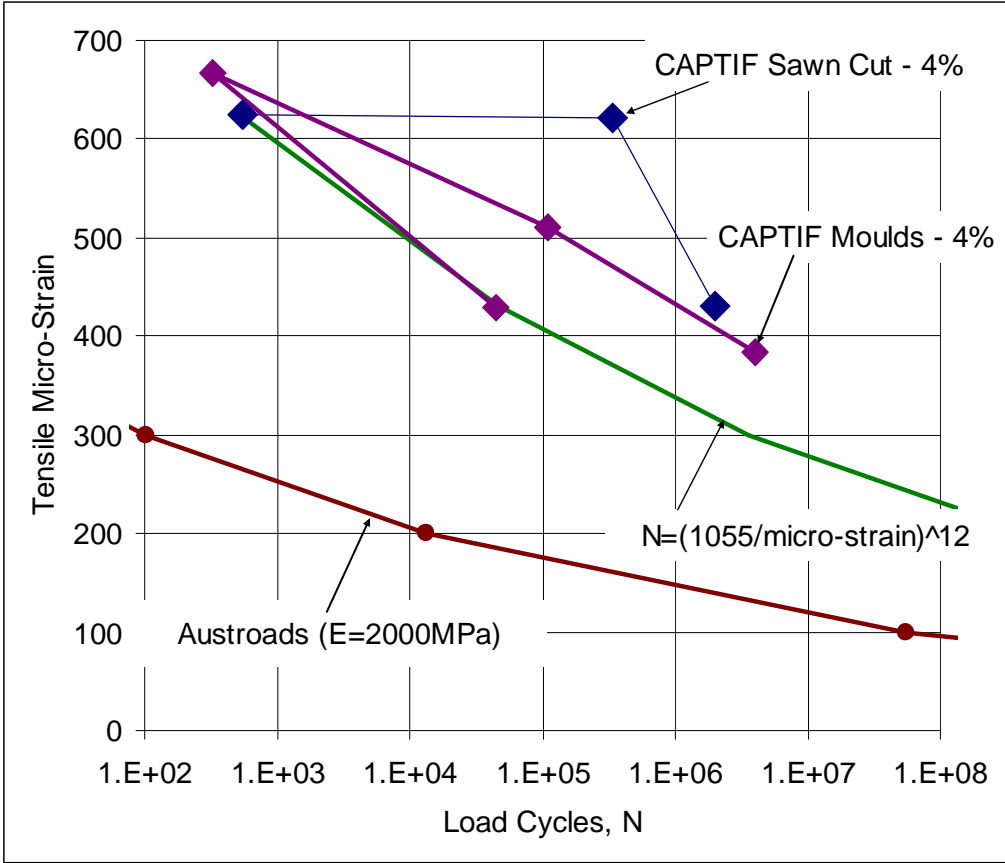


Figure 20 – Fatigue criteria for a 4% Cement Stabilised Aggregate Found from Flexural Beam Tests Compared with Austrroads.

Reducing Risk Of Pavement Failure

Table 6 – Reducing the risk of pavement failure for granular and modified granular pavements.

Issue	Factors to consider	Discussion/ comment	Reducing the risk of failure
Pavement Depth	Subgrade Strength	The critical factor in getting the depth right to avoid shear failure in subgrade.	<ul style="list-style-type: none"> Soaked subgrade CBR tests to get worst case scenario and check pavement depth (including existing pavement if applicable) using Figure 8.4 of Austroads Design Guide.
	Traffic Loading	The Austroads Guide gives the impression that the risk is reduced by multiplying the traffic up, but research on granular pavements found that increasing depth does not necessarily increase life.	<ul style="list-style-type: none"> Concentrate more on site investigation to get the subgrade strength right or to get existing pavement strength. Consider other factors below.
Pavement Material Shear Strength	Quality of Source Aggregate	Specifications give requirements for source aggregate but from Repeated Load Triaxial testing a range of performance/rut resistance is obtained.	<ul style="list-style-type: none"> Ensure compliance with Specifications; And/or use aggregates that show are suitable from Repeated Load Triaxial Testing (RLTT); Use cement or lime modified aggregates found suitable from RLTT.
	In Place Dry-Density	Achieving adequate compaction is critical to the resulting performance. TNZ B2 specifies minimum compaction targets based on a NZ Vibratory Hammer Compaction Test which is considered error prone	<ul style="list-style-type: none"> Use heavy compaction equipment and compact beyond specification targets as determined by plateau density.
	Prior to sealing moisture content	Research has shown that drying back the aggregate layers to 60% of saturation is necessary to prevent failure for high traffic roads.	<ul style="list-style-type: none"> Do not seal until dry back of 60% of saturation is achieved; If cannot achieve dry back then consider using a modified or non modified aggregate that is not sensitive to moisture as confirmed from RLTT.
Keep Water Out of Granular Pavement Layers	Prevent water from entering pavement	Water will weaken the granular pavement layers and thus the pavement should be designed and constructed to ensure the granular materials are kept as dry as possible and will only be saturated for short time periods.	<ul style="list-style-type: none"> Do not seal in the water and dry back to at least 60% of saturation (or consider stabilisation) or undertake RLT test to test rutting resistance when wet; Apply second coat seal soon after first coat; Provide surface cross-fall to prevent ponding of water; Use a dense graded impermeable basecourse that will not allow water to enter, but its performance may need to be confirmed by RLTT; Do not seal in winter.
	Allow water to escape from the granular layers quickly	No pavement is completely waterproof as research by Opus found multiple chipseal layers to leak, therefore it is important to design escape paths for the water once it has entered to quickly escape from the pavement.	<ul style="list-style-type: none"> Provide cross fall on subgrade formation; Provide surface and subsurface drainage at edge of shoulders; Ensure sub-base is 10 times more permeable than the basecourse layer that sits above the subbase;
Pavement Cracking	Lightly stabilised materials may behave more like bound materials that can crack if in thin layers over weak foundations	Designers often ignore the possibility of tensile fatigue cracking due to the conservatism of the Austroads criteria and consider the stabilised aggregate layer is the same as an unbound granular layer (although sometimes assuming a higher modulus).	<ul style="list-style-type: none"> Use the same design assumptions as an unbound granular pavement (ie. do not assume improved properties to ensure pavement as adequate depth and support for stabilised layer); Undertake as a minimum flexural beam breakage tests and check that the tensile strain and stress in the pavement design is less than 40% of the tensile strain and stress at breakage (it was found at 40% of breakage the beams did not fatigue crack in the lab after 2 Million cycles); Develop and use in design material specific tensile fatigue criteria found from flexural beam tests.

Conclusions

The Repeated Load Triaxial test procedure and associated analysis to predict the magnitude of rutting and allowable design loading (ie. number of wheel passes until a 10mm rut depth) has been undertaken on many New Zealand and a few Australian aggregates (modified and unmodified). In addition, flexural beam tests to predict the life until cracking occurs has been conducted on some modified/stabilised aggregates. This fundamental approach to pavement design (ie. predicting when rutting and cracking will occur) and material selection allows the benefits of modifying materials to be accurately quantified. Further, alternative materials such as those previously wasted (e.g. industrial by-products and recycled materials) can be assessed and used appropriately based on their predicted performance in replace of virgin aggregates. Increase use of waste materials and use of previously discarded aggregates has an environmental benefit through conserving the highest quality aggregates and using waste materials reduces the amount sent to landfill or increases the amount of material available from a quarry for sustainability.

In summary the outputs of the RLT test procedure and associated analysis to predict the magnitude of rutting and flexural beam fatigue tests have the following benefits:

- Reduced number of early rutting failures of new and rehabilitated pavements;
- Quantification of the use of modified materials in terms of their superior resistance to rutting;
- Predict when cracking will occur to check if fatigue life is acceptable;
- Cracking and Rutting life found from actual laboratory tests is less conservative than current Austroads Pavement Design procedures and thus a more cost-effective pavement design is possible.
- Environmental benefits through increased use of waste materials and previously discarded aggregates.

References

Alderson, A. 1999. Structural properties of cement stabilised materials. ARRB TR Contract Report , RC7101A, Austroads, Sydney.

Andrews, R.C., Brimble, R.M. & Mathias, C.M. 1998. Mechanistic characterisation of cementitiously stabilised pavement materials. Materials Technology Research and Development Program Report No. 89-1. Transport SA, Adelaide.

Angelone, S. & Martinez. F. 1996. Dyanamic characteristics of lime-treated soils. Combined 18th ARRB Transport Research Conference and Transit New Zealand Land Transport Symposium, Sep. 1996, Christchurch, New Zealand.

Arnold G., 2004. Rutting of Granular Pavements. PhD Thesis, University of Nottingham, Nottingham, UK.

Arnold, G., Werkemeister, S., Alabaster, D. 2008. Performance tests for road aggregates and alternative materials. Land Transport New Zealand Research Report 335. yy pp.

Arnold, G. Alabaster, D. Steven, B. 2001. Prediction of pavement performance from repeat load triaxial tests on granular materials. Transfund New Zealand Research Report, Wellington, New Zealand.

ASTM International. 2007. Standard Test Method for Measuring Early-Age Compressive Strength and Projecting Later-Age Strength – C 918/C 918M – 07

Arnold, G. 2004. Rutting of Granular Pavements. PhD Thesis, University of Nottingham, Nottingham, UK.

Arnold, G., Werkemeister, S. and Alabaster, D. 2008. Performance tests for road aggregates and alternative materials. Land Transport New Zealand Research Report 335.

Austrroads. 1992. Pavement Design. A guide to the structural design of road pavements. Austrroads. Sydney.

Austrroads. 2004. Pavement Design. A guide to the structural design of road pavements. Austrroads. Sydney.

Austrroads. 2008. The Development and Evaluation of Protocols for the Laboratory Characterisation of Cemented Materials. Austrroads Technical Report - AP-T101/08

Bofinger, H.E. 1965. The fatigue behaviour of soil-cement. Journal of the Australian Road Research Board, Vol 2, No. 4, June 1965.

Bullen, F. 1994. The resilient moduli of cement treated materials. Road and Transport Research, 3(2). ARRB, Vermont South.

Chan, FWK. 1990. Permanent deformation resistance of granular layers in pavements, Ph.D. Thesis, University of Nottingham, Nottingham, UK.

Gnanendran, C.T. & Piratheepan, J. 2008. Characterisation of a lightly stabilised granular material by indirect diametrical testing. International Journal of Pavement Engineering. Vol.9, NO. 6, December 2008, 445-456.

Foley, G. and Australian Stabilisation Expert Group. 2001. Contract Report – Mechanistic Design issues for stabilized pavement materials. Austrroads. RC91022-3.

Horpibulsuk, S., Katkan, W., Sirilerdwattana, W. and Rachan, R. 2006. Strength Development in Cement Stabilized Low Plasticity and Coarse Grained Soils: Laboratory and Field Study. Japanese Geotechnical Society: Soils and Foundations. Vol. 46, NO. 3, June 2006, 351 - 366

Hugo, F., de Vos, E.R. and Tayob H. 2007. Aspects of Cement Stabilised Mozambique Sand Base Material performance under MMLS3 and MLS10 APT trafficking. Proceedings of 26th Southern African Transport Conference, 91-12 July 2007. Pretoria, South Africa.

Korkiala-Tanttu, L. Laaksonen, R. Törnqvist, J. 2003. Effect of the spring and overload to the rutting of a low-volume road. HVS-Nordic-research. Helsinki 2003. Finnish Road Administration. Finnra Reports 22/2003. 39 p. + app. ISSN 1457-9871, ISBN 951-803-052-9, TIEH 3200810E.

Laboratory Central des Ponts et Chaussees (LCPC). French design manual for pavement structures.

Little, P. H. 1993. The design of unsurfaced roads using geo-synthetics, PhD thesis, Dept. of Civil Engineering, University of Nottingham.

Litwinowicz, A. and Brandon, A.N. 1994. Dynamic flexure testing for prediction of cement- treated pavement life. Proceedings 17th ARRB Conference Part 2. ARRB, Vermont South.

Lim, S. and Zollinger, D.G. 2004. Estimation of the compressive strength and modulus of elasticity of cement-treated aggregate base materials. In Transportation Research Record 1837, TRB, National Research Council, Washington, D.C.

Majumder, B.K., Das, A. and Pandey, B.B. 1999. Cement Treated Marginal Aggregates for Roads. Journal of Materials in Civil Engineering. Vol. 11, NO. 3, August 1999, 257 – 265

Masad, E. Castelo Branco, V.T.F., Little, D.N. & Lytton, R. 2008. A unified method for the analysis of controlled-strain and controlled-stress fatigue testing. International Journal of Pavement Engineering, 9:4, 233-246.

Morkel. A.M.C. 2002. The effect of curing temperature on the strength of concrete cylinders. (Unpublished).

NZMP3100, 1999. New Zealand Guide to Concrete Construction. Cement & Concrete Association of NZ and Standards New Zealand, Wellington, New Zealand.

NZS3112.2. 1986. Methods of test for concrete, Part 2. Standards New Zealand.

Otte, E. 1978. A structural design procedure for cement-treated layers in pavements. D.Sc(Eng) Thesis, Faculty of Engineering, University of Pretoria.

Pidwerbesky, B. 1996. Fundamental Behaviour of Unbound Granular Pavements Subjected to Various Loading Conditions and Accelerated Trafficking. PhD Thesis, University of Canterbury, Christchurch, New Zealand, 1996.

Scott, J.L.M. 1974. Flexural stress-strain characteristics of Saskatchewan soil cements. Saskatchewan Dept. of Highways and Transportation, Technical Report 23.

Semmelink, CJ, Jooste, FJ & de Beer, M. 1997. Use of the K-mould in determination of the elastic and shear properties of road materials for flexible pavements, 8th Int. Conf. on Asphalt Pavements, August, Seattle, Washington, USA.

Shen,, C.K. & Mitchell, J.K. 1966. Behaviour of soil-cement in repeated compression and flexure. Highway Research Board Record No. 128.

Smith, W. & Hansen, B. 2003. Detailed investigation of the performance of GB cements in pavement stabilisation. In Proceedings of 21st ARRB & 11th REAAA Conference, May 2003. ARRB, Vermont South.

Standards New Zealand. 1986. Methods of testing soils for civil engineering purposes. New Zealand Standard NZS 4402:1986. Wellington: Standards Association of New Zealand.

Standards Australia. 1995. AS 1289.6.8.1 – Methods of testing soils for engineering purposes. Soil strength and consolidation tests – determination of the resilient modulus and permanent deformation of granular unbound pavement materials. Standards Australia: Sydney, Australia.

Symons, M.G., Poli, D.C. and Potter, R.J. 1996. Properties of stabilised soils in recycled pavements. In Proceedings of the 18th ARRB Conference and Transit NZ Land Transport System Symposium. ARRB. Vermont South.

Thom, N and Brown, S. 1989. The mechanical properties of unbound aggregates from various sources. Proceedings of the Third International Symposium on Unbound Aggregates in Roads, UNBAR 3, Nottingham, United Kingdom, 11-13 April 1989.

Transit. 2006. TNZ M4 (2006) Specification for Basecourse Aggregate. Transit New Zealand, Wellington, New Zealand.

Transit. 2007. Draft TNZ T15 (2007) Specification For Repeated Load Triaxial (RLT) Testing Of Unbound And Modified Road Base Aggregates.

Transit New Zealand (Transit NZ). 2005. TNZ B/02 Specification for construction of unbound granular pavement layers. Wellington: Transit NZ.

Transit New Zealand (Transit NZ). 2006. TNZ M/4 Specification for basecourse aggregate. Wellington: Transit NZ.

Vorobieff, G. 2004. Stabilisation Practices in Australia. In Proceedings of Stabilisation of Road Pavements NZIHT Seminar. June 2004, Auckland.

Vuong, B.T. 2001b. Improved performance-based material specifications and performance prediction models for granular pavements. PhD thesis. Department of Civil and Geological Engineering, Faculty of Engineering, RMIT University: Melbourne, Australia.

Werkmeister, S. 2007. Prediction of Pavement Response Using Accelerated Test Results Of New Zealand's CAPTIF Facility. TU Dresden, Germany.

White, G.W. & Gnanendran, C.T. 2002. The characterisation of cementitious in-situ stabilised pavement materials: The past, the present and the future. Road & Transport Research Journal, Dec 2002. ARRB. Vermont South.

White, G.W. & Gnanendran, C.T. 2005. The influence of compaction method and density on the strength and modulus of cementitiously stabilised pavement materials. International Journal of Pavement Engineering, 6:2,97-110.

White, G.W. 2007. Laboratory characterisation of cementitiously stabilised pavement materials. Masters Thesis, University of New South Wales. Sydney.

Yeo, R. Vuong, B. and Alderson, A. 2002. Contract Report – Towards National test methods for stiffness and fatigue characterisation of stabilised materials. ARRB transport Research. RC 2028-002.