Reducing the risk of pavement failure and utilisation of local materials in New Zealand through Repeated Load Triaxial and Beam Fatigue Tests

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ABSTRACT

Performance testing of New Zealand road aggregates both modified and unmodified has given greater confidence for the designer and client on the chosen pavement design and materials. Given that most premature pavement failures can be traced to a material fault there has been an increasing emphasis in research and commercial testing on a materials performance found under repetitive loading in the laboratory aimed to simulate vehicle loadings. Research at the University of Nottingham (2004) and further research by the New Zealand Transport Agency led to the development of a Repeated Load Triaxial (RLT) test on unmodified and modified granular materials and associated modelling to predict the number of heavy axle passes to achieve a certain rut depth. In the last 3 years at least 150 RLT tests have been conducted on a range of compliant and non compliant aggregates both modified and unmodified. This paper reports trends in results and shows how this test can result in choosing the best material for a particular pavement's loading and environment and thus reduce the risk of pavement failure. In addition to rutting another concern by pavement designers is cracking and as such the New Zealand Transport Agency is funding a research project to undertake beam fatigue tests on large 150 x 150 x 500mm beams with the aim of determining more appropriate tensile fatigue criterion for design. Some interesting results were found and will be reported in this paper showing the fatigue lives of over a million times higher than that predicted by the Austroads Pavement Design Guide were obtained.

1. INTRODUCTION

Granular pavement layers play an important role in the pavement. They are required to provide a rut resistant base layers and reduce compressive stresses on the sub-grade. For thin-surfaced pavements the unbound granular material (UGM) contributes to the full structural strength of the pavement. It is therefore important that the granular materials have adequate stiffness and do not deform. Material specifications usually ensure this is the case. The repeated load triaxial (RLT) (Arnold 2004), hollow cylinder (Chan 1990) and k-mould (Semmelink et al, 1997) apparatuses can in various degrees simulate pavement loading on soils and granular materials. Permanent strain tests in the Repeated Load Triaxial (RLT) apparatus commonly show a wide range of performances for UGMs even though all comply with the same specification (Thom and Brown, 1989). Accelerated pavement tests on thinly sealed pavements show the same results and also report that 30% to 70% of the surface rutting is attributed to the granular layers (Arnold et al., 2001; Little, 1993; Pidwerbesky, 1996; Korkiala-Tanttu et al, 2003).

Furthermore, recycled aggregates and other materials considered suitable for use as unbound base or sub-base pavement layers can often fail the highway agency or project requirement material specifications and thus restrict their use. The New Zealand Transport Agency recognise the potential of the permanent strain test in the RLT (or similar) apparatus to assess the suitability of UGMs for high traffic roads and alternative materials for use at various depths within the pavement (e.g. base, sub-base and lower sub-base). Another use of the Repeated Load Triaxial test is assessing materials performance when saturated and undrained. Hence, research is underway to finalise the draft Transit New Zealand specification TNZ T/15 for Repeated Load Triaxial testing (Transit, 2007) and development of "pass/fail" criteria for high traffic state highways. Research has been conducted using RLT tests to assess the affect of material grading and various amounts of crushed glass on performance of granular materials. There has also been many RLT commercial tests on granular materials to enable appropriate "pass/fail" limits based on actual RLT results to be determined. Pavement design methods utilising the RLT test results are also being researched to develop design criterion for granular pavement layers and to determine a design chart based on rut depth modelling methods .

Another use of the Repeated Load Triaxial test is assessing materials performance when saturated and undrained. Most unbound granular materials fail the saturated RLT test while most modified/stabilised aggregates pass the test with various degrees of performance. RLT test criteria at saturated/undrained conditions is currently being developed for modified/stabilised aggregates as alternatives to basecourse aggregates. In parallel to this work is flexural beam tests on modified aggregates to assess their tensile fatigue performance to develop criteria for material and pavement design to prevent cracking.

2. REPEATED LOAD TRIAXIAL TESTING

The RLT apparatus tests cylindrical samples of soils or granular materials. Figure 1 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 1 – 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 2) 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**	**Aggregate**	**Slope %/1M from 25k to 50k same as TNZ T/15**
Material	**N, ESAs to get 25mm rut**	**N, ESAs to get 10mm rut in aggregate.**	**Long term rate of rutting within aggregate**	**Resilient Modulus at Top of Pavement (MPa)**	**Average Slope**
	Million ESAs	*Million ESAs*	*mm per 1 Million ESAs*		
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 consistant measure when comparing aggregates. Values <0.5 mm/1M ESA are excellent.	The RLT test gives a Resilient Modulus for all stress stages tested, this modulus shown is for the top layer of a thin surfaced pavement, if the aggregate is covered with Asphalt then a different value should be used.	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.

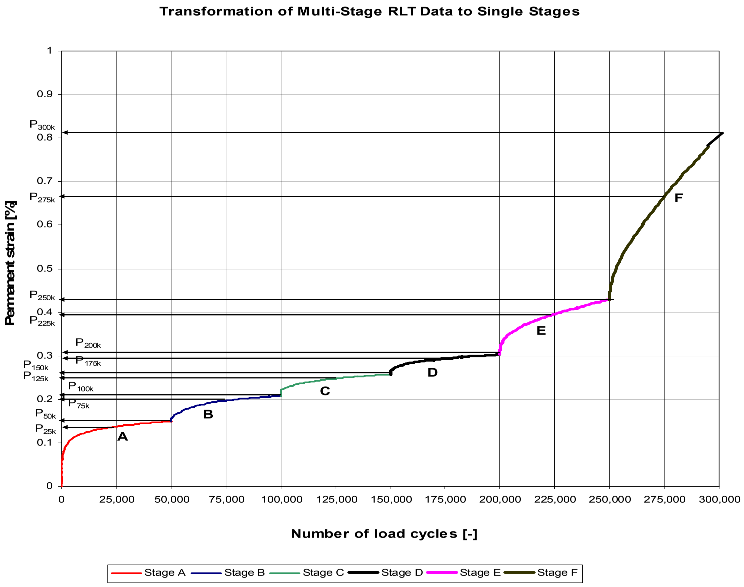

Table 5: Calculation of average permanent strain slope from 6 stage RLT test.

RLT Test Stage (Table 2)	[2]Permanent Strain (%) (see Figure 1)	[1]Permanent Strain Slope (%/1M) (Slopes)
Stage A	P_{25k}	$=(P_{50k}-P_{25k})/0.025M$
	P_{50k}	
Stage B	P_{75k}	$=(P_{50k}-P_{25k})/0.025M$
	P_{100k}	
Stage C	P_{125k}	$=(P_{50k}-P_{25k})/0.025M$
	P_{150k}	
Stage D	P_{175k}	$=(P_{50k}-P_{25k})/0.025M$
	P_{200k}	
Stage E	P_{225k}	$=(P_{50k}-P_{25k})/0.025M$
	P_{250k}	
Stage F	P_{275k}	$=(P_{50k}-P_{25k})/0.025M$
	P_{300k}	
Average		$= P_{avg} = (\sum Slopes)/6$

Figure 2 – Soaking sample for saturated undrained RLT test.

2.1 MODES OF PAVEMENT FAILURES NOT GUARDED AGAINST FROM RLT TESTING

Repeated Load Triaxial testing is an excellent tool to test whether or not an aggregate will have acceptable rutting within the pavement design life. This guards against pavement shear failures caused by weak pavement aggregates particularly if wet. To ensure pre-mature pavement failure does not occur the designer as well as undertaking Repeated Load Triaxial testing should also consider the following factors (Table 2):

Table 2 : Other important factors to consider in Pavement Design to ensure adequate performance.

Factor to Consider	**Pavement Design Considerations**
Surfacing Performance	Ensure the chosen surfacing adheres to the surface, binder application rate is appropriate for the absorption of the aggregate (open graded porous type rocks may need more bitumen), fine graded stabilised surfaces need to be swept and perhaps less bitumen used. Time of year should be summer, otherwise risk of surfacing failure is high.
Water pumping through surface	Porous basecourse aggregates will absorb a lot of water and unless there is adequate sub-surface drainage this water will remain and will be pumped through the surface from the tyre impact forces. This will result in surface dislodgment causing surface potholes.
Compaction	The calculations of pavement life from Repeated Load Triaxial testing assumes the pavement has adequate compaction in accordance with TNZ B2 Specification (or another appropriate specification). Hence, if the required density is not achieved then additional compaction causing rutting will be expected. The dry density achieved in the Repeated Load Triaxial test should also be considered as the minimum density to achieve in pavement construction.
Material Compliance, stabiliser content and curing regime	The actual materials used in pavement construction, their curing, mixing and stabiliser content may not be exactly the same as the materials tested in the Repeated Load Triaxial apparatus. Designers and quarry owners are encouraged to conduct additional RLT tests at conditions of mixing and curing that represent the "worst case" and in particular early strength. Production tests are recommended.
Cracking of Stabilised Aggregates 	The RLT test is a compression test that will predict the amount of rutting and this does not guard against cracking. Pavespec Ltd has recently developed a flexural beam test for strength and tensile fatigue to predict if cracking will occur within the design life. It has been found that even small quantities of cement can result in a bound material that has the potential to crack, a flexural beam test will result in information for design to ensure cracking will not occur.

3. REPEATED LOAD TRIAXIAL TESTING RESULTS

3.1 INTRODUCTION

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.

3.2 TYPICAL RLT TEST RESULTS

RLT tests were conducted at both saturated/undrained and dry/drained conditions on New Zealand and Australian aggregates. Typical results are listed in the Tables 2 to 4 and Figures 3 to 7 shown below.

Table 2 - Typical results for Basecourse Aggregates.

#	Material (unless otherwise stated sample was compacted at 95%MDD and 100%OMC)	RLT Test	N, ESAs to get 10mm rut in aggregate.	Long term rate of rutting within aggregate	Resilient Modulus	Average RLT Slope
			Million ESAs	*mm per 1 Million ESAs*	*MPa*	*%/1M*
1	**Very Good TNZ M4 Basecourse – 101%MDD (over compacted)**	Dry/Drained	84	0.1	594	0.105
2		Saturated	1.5	4.7	496	0.68
3	**Very Good TNZ M4 Basecourse (same agg. as 1 & 2 above)**	Dry/Drained	21	0.4	488	0.378
4		Saturated	0.01	94	451	4.477
5	**Average TNZ M4 Basecourse**	Dry/Drained	9.4	0.95	497	0.506
6		Saturated	0.71	7.5	413	7.152
7	**Very Poor TNZ M4 Basecourse**	Dry/Drained	0.28	19	217	3.2
8		Saturated	0.04	29	183	24.2
21	PS0020 Test # 21 (18/5/09) SteelServ TNZ M4 (Melter Slag Aggregate)	Dry/Drained	**15**	0.6	680	0.3
22	PS0020 Test # 2 (10/12/07) SteelServ TNZ M4 (Melter Slag Aggregate)	Saturated /Undrained	**4.2**	1.5	554	0.6
23	PS0027 Test # 31 (*reanalysed PS0087 Test # 24*) (14/7/09) Montrose, Victoria – Class 1 – 20mm Road Base	Dry/Drained	**24**	0.3	577	0.3
24	PS0027 Test # 10 (3/6/08) Montrose, Victoria – Class 1 – 20mm Road Base	Saturated /Undrained	**0.003**	66	532	>100

Table 3 - Typical results for Basecourse Aggregates continued for Australian materials.

#	Material (unless otherwise stated sample was compacted at 95%MDD and 100%OMC)	RLT Test	N, ESAs to get 10mm rut in aggregate.	Long term rate of rutting within aggregate	Resilient Modulus	Average RLT Slope
			Million ESAs	*mm per 1 Million ESAs*	*MPa*	*%/1M*
31	PS0087 Test # 1 (12/8/09) Multiserv Victoria EAF 20mm Class 4 Aggregate	Dry/Drained	**6.5**	1.2	489	0.52
		98%MDD-Modified (DD=2.62 t/m3) ; 90%OMC (MC=6.8% - compacted at 100% optimum 7.5% but water drained out of specimen when tested). (Note: Easy to compact)				
32	PS0087 Test # 2A (25/8/09) Multiserv Victoria EAF 20mm Class 4 Aggregate	Saturated /Undrained	**0.11**	35	417	1.3
		99%MDD-Modified (DD=2.641 t/m3) ; 137%OMC (MC=10.3%)				
33	PS0087 Test # 3 (17/8/09) Multiserv Victoria EAF 40mm Class 4 Aggregate	Dry/Drained	**20**	0.46	591	0.288
		98%MDD-Modified (DD=2.62 t/m3) ; 86%OMC (MC=6.5%- compacted at 100% optimum moisture content of 7.5% but water drained out of specimen when tested) (Note: more compaction effort required than the 20mm above – compaction effort felt about right)				
34	PS0087 Test # 4 (18/8/09) Multiserv Victoria EAF 40mm Class 4 Aggregate	Saturated /Undrained	**0.45**	12.8	433	0.8
		98%MDD-Modified (DD=2.62 t/m3) ; 128%OMC (MC=9.6%)				
35	PS0087 Test # 5 (26/8/09) Multiserv Victoria EAF 20mm Class 4 Aggregate **– Heavier Compaction**	Dry/Drained	**31**	0.3	713	0.24
		100%MDD-Modified (DD=2.678 t/m3); 90%OMC (MC=6.8% - compacted at 100% optimum 7.5% but water drained out of specimen when tested).				

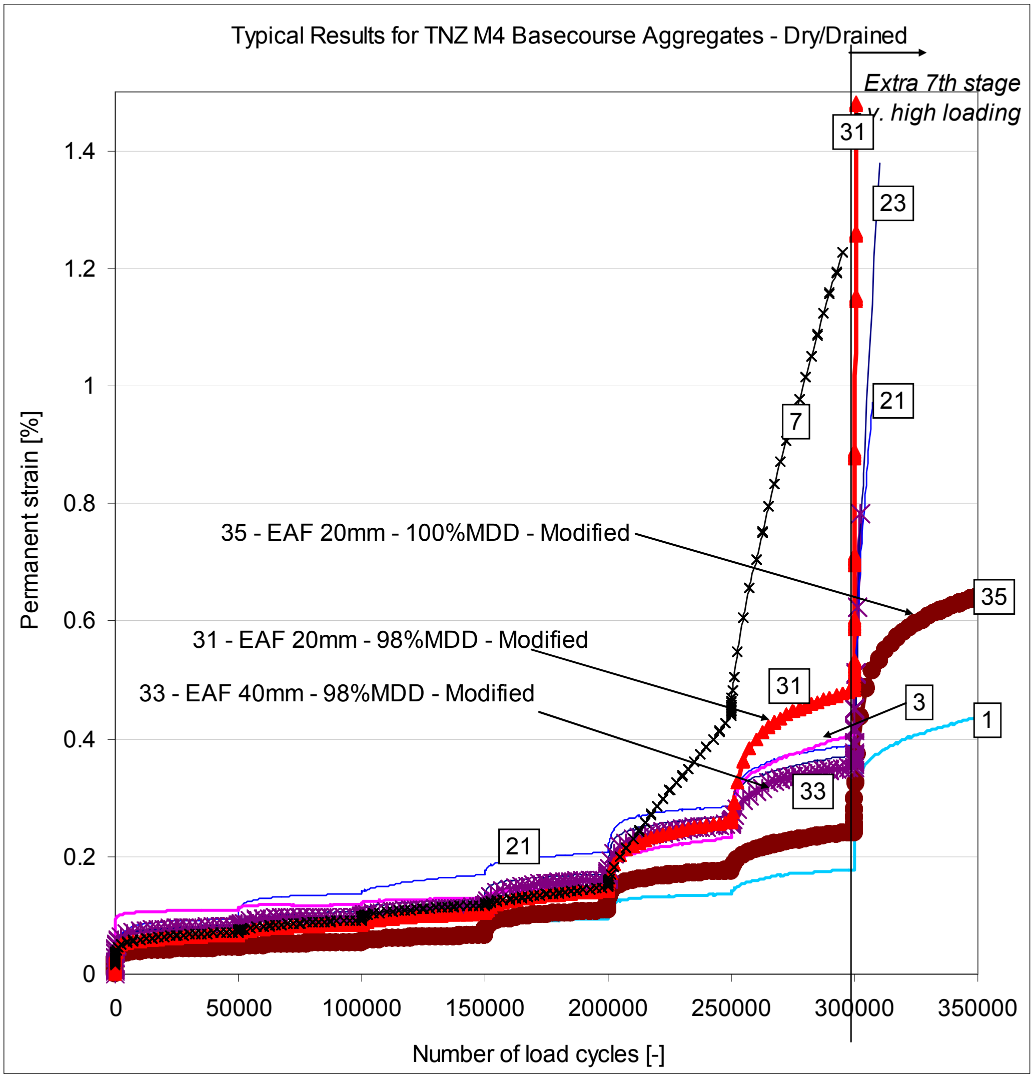

Figure 3 – Typical RLT Results for TNZ M4 Basecourse in Dry/Drained conditions.

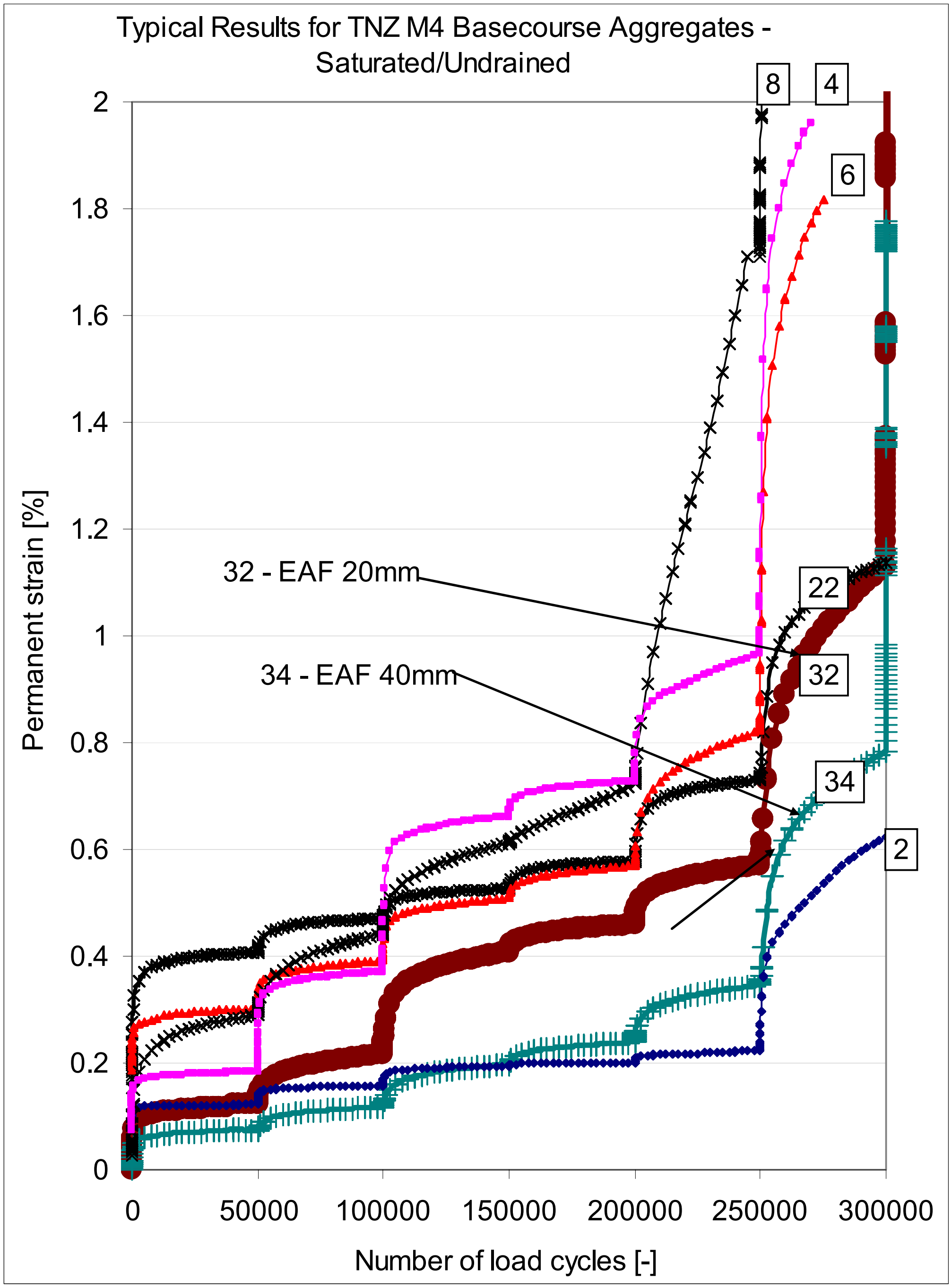

Figure 4 – Typical RLT Results for TNZ M4 Basecourse in Saturated/Undrained conditions.

Table 4 - Typical results for Stabilised Aggregates.

#	Material (unless otherwise stated sample was compacted at 95%MDD and 100%OMC)	RLT Test	N, ESAs to get 10mm rut in aggregate.	Long term rate of rutting within aggregate	Resilient Modulus	Average RLT Slope
			Million ESAs	*mm per 1 Million ESAs*	*MPa*	*%/1M*
9	**2% Cement + TNZ M4 Basecourse – (Fine side of grading envelope)**	Dry/Drained	104	0.1	994	0.1
10		Saturated	87	0.1	524	0.06
11	**2% Cement + TNZ M4 Basecourse – (Course graded - lack of fines)**	Dry/Drained	33	0.26	749	0.2
12		Saturated	5.5	1.5	485	1.07
13	**2% Cement + GAP40 sub-base – (same test and analysis if used as a basecourse)**	Dry/Drained	32	0.3	805	0.160
14		Saturated	15	0.6	684	0.353

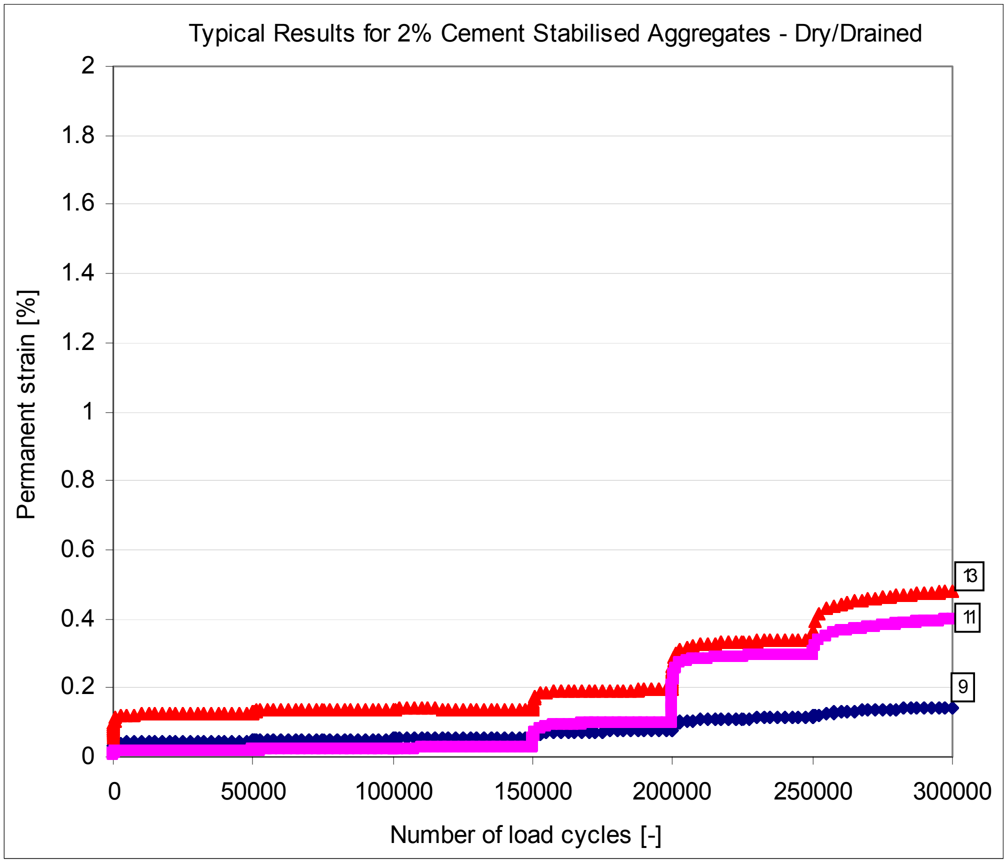

Figure 5 – Typical RLT Results for 2% Cement Stabilised Aggregates – Dry/Drained Test Conditions.

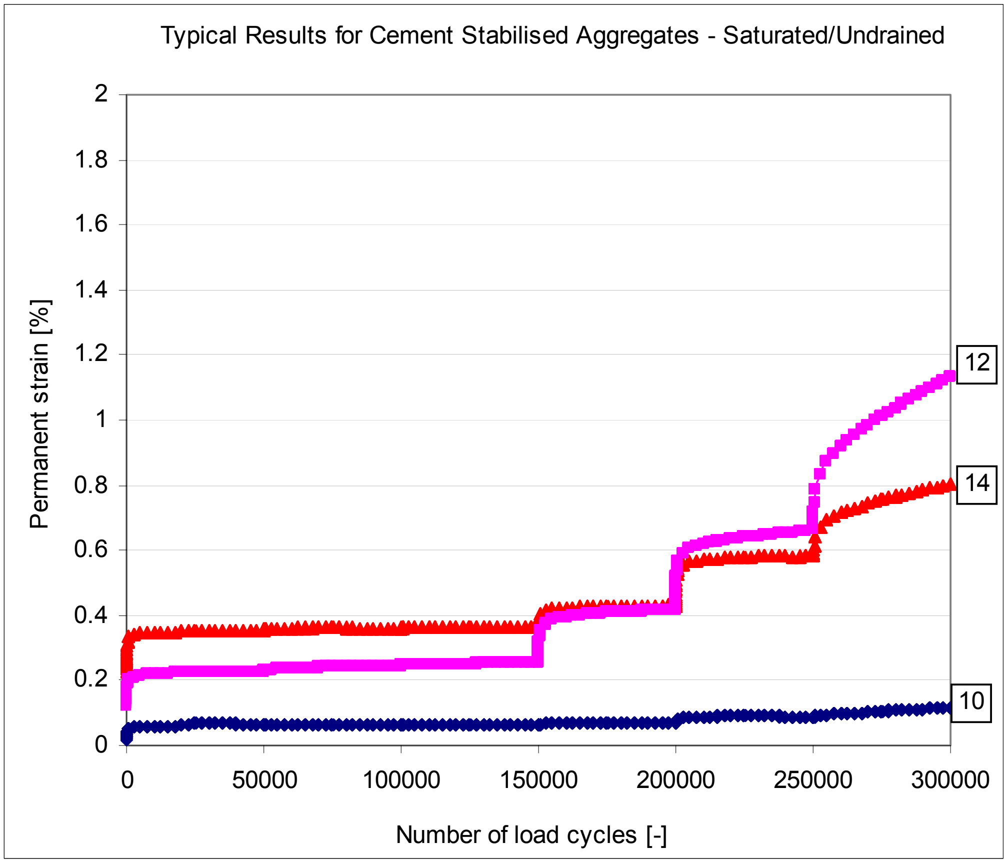

Figure 6 – Typical RLT Results for 2% Cement Stabilised Aggregates – Saturated/Undrained Test Conditions.

Table 5 - Typical result for a Sub-base aggregate GAP65 scalped to a GAP40 – Analysed if used as a basecourse.

			Analysed as a basecourse			
#	**Material (unless otherwise stated sample was compacted at 95%MDD and 100%OMC)**	**RLT Test**	**N, ESAs to get 10mm rut in aggregate.**	**Long term rate of rutting within aggregate**	**Resilient Modulus**	**Average RLT Slope**
			Million ESAs	*mm per 1 Million ESAs*	*MPa*	*%/1M*
15	**GAP65 scalped to a GAP40 Sub-base aggregate (typical/good result for sub-base)**	Dry/Drained	4.4	1.9	510	1.35
16		Saturated	0.02	96	310	126

Table 6 - Typical result for a Sub-base aggregate GAP65 scalped to a GAP40 – Analysed if used as a Sub-Base (ie. depth of 150mm below surface).

			Analysed as a sub-base			
#	**Material (unless otherwise stated sample was compacted at 95%MDD and 100%OMC)**	**RLT Test**	**N, ESAs to get 10mm rut in aggregate.**	**Long term rate of rutting within aggregate**	**Resilient Modulus**	**Average RLT Slope**
			Million ESAs	*mm per 1 Million ESAs*	*MPa*	*%/1M*
15	**GAP65 scalped to a GAP40 Sub-base aggregate (typical/good result for sub-base)**	Dry/Drained	17.9	0.53	285	1.35
16		Saturated	0.04	71	195	126

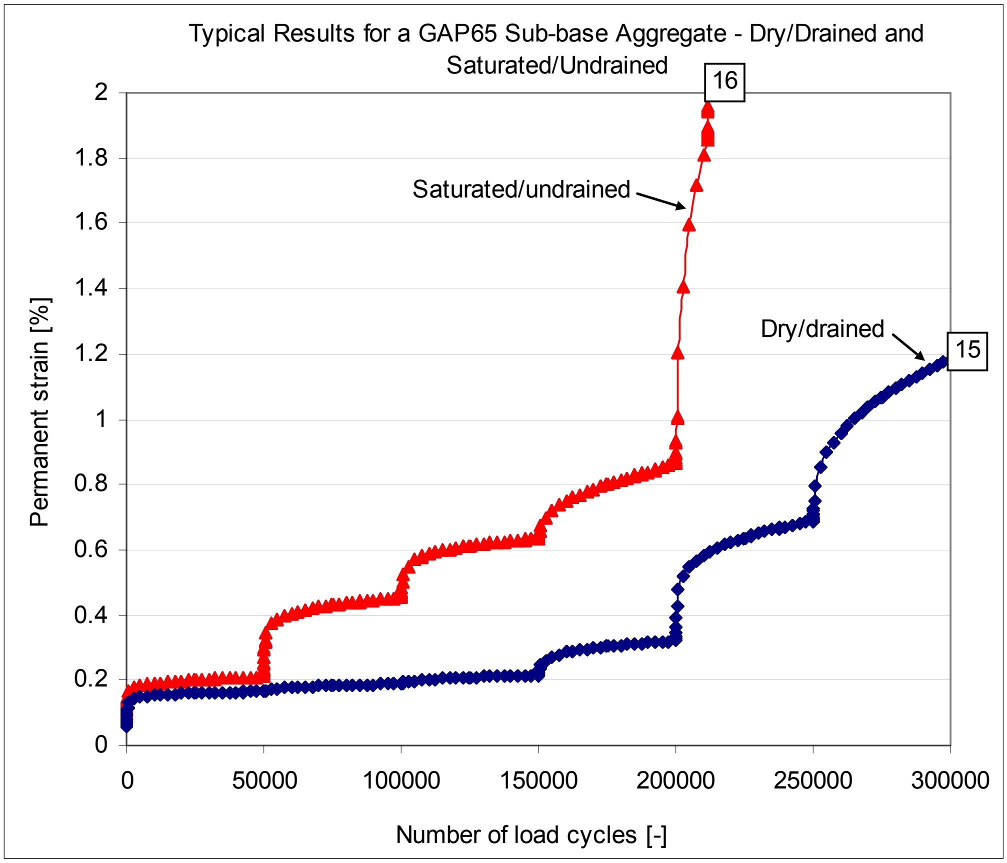

Figure 7 – Typical RLT Results for GAP65 Sub-base Aggregate – Dry/Drained and Saturated/Undrained Test Conditions.

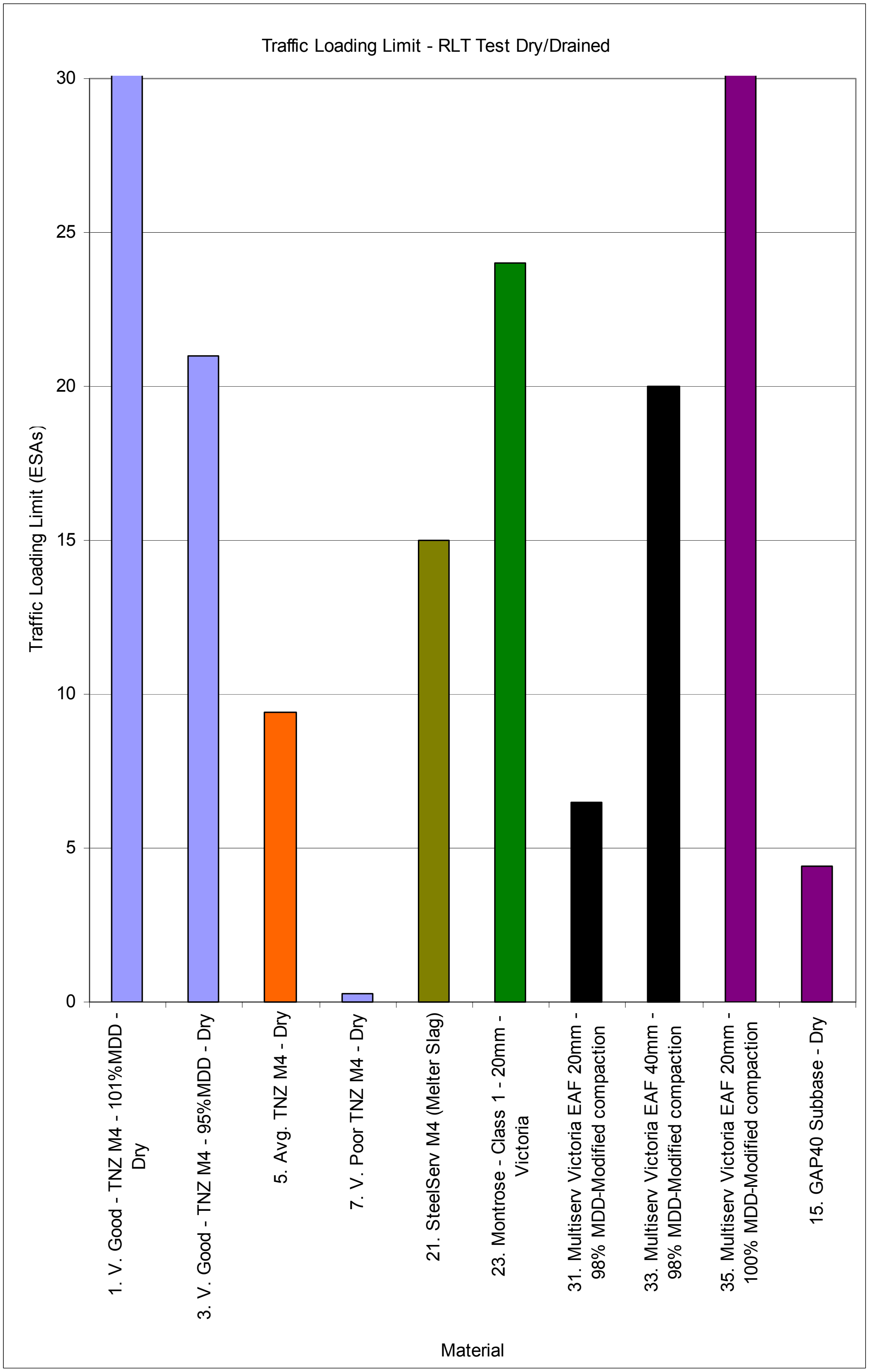

Figure 8. Typical Traffic Loading Limits (ESAs) For Various Unbound Aggregates found from RLT Testing in Dry/Drained conditions.

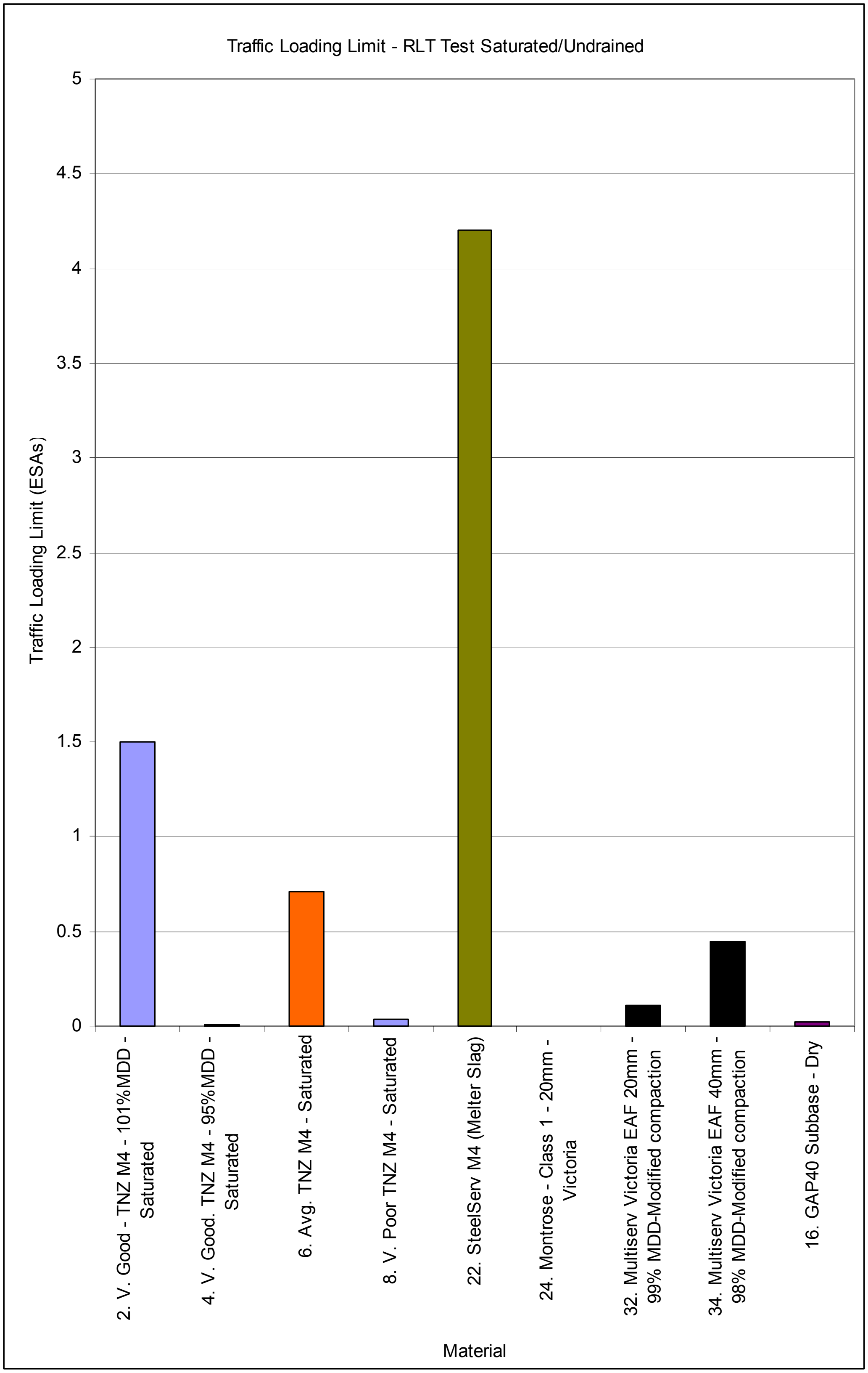

Figure 9. Typical Traffic Loading Limits (ESAs) For Various Unbound Aggregates found from RLT Testing in Saturated/Undrained conditions.

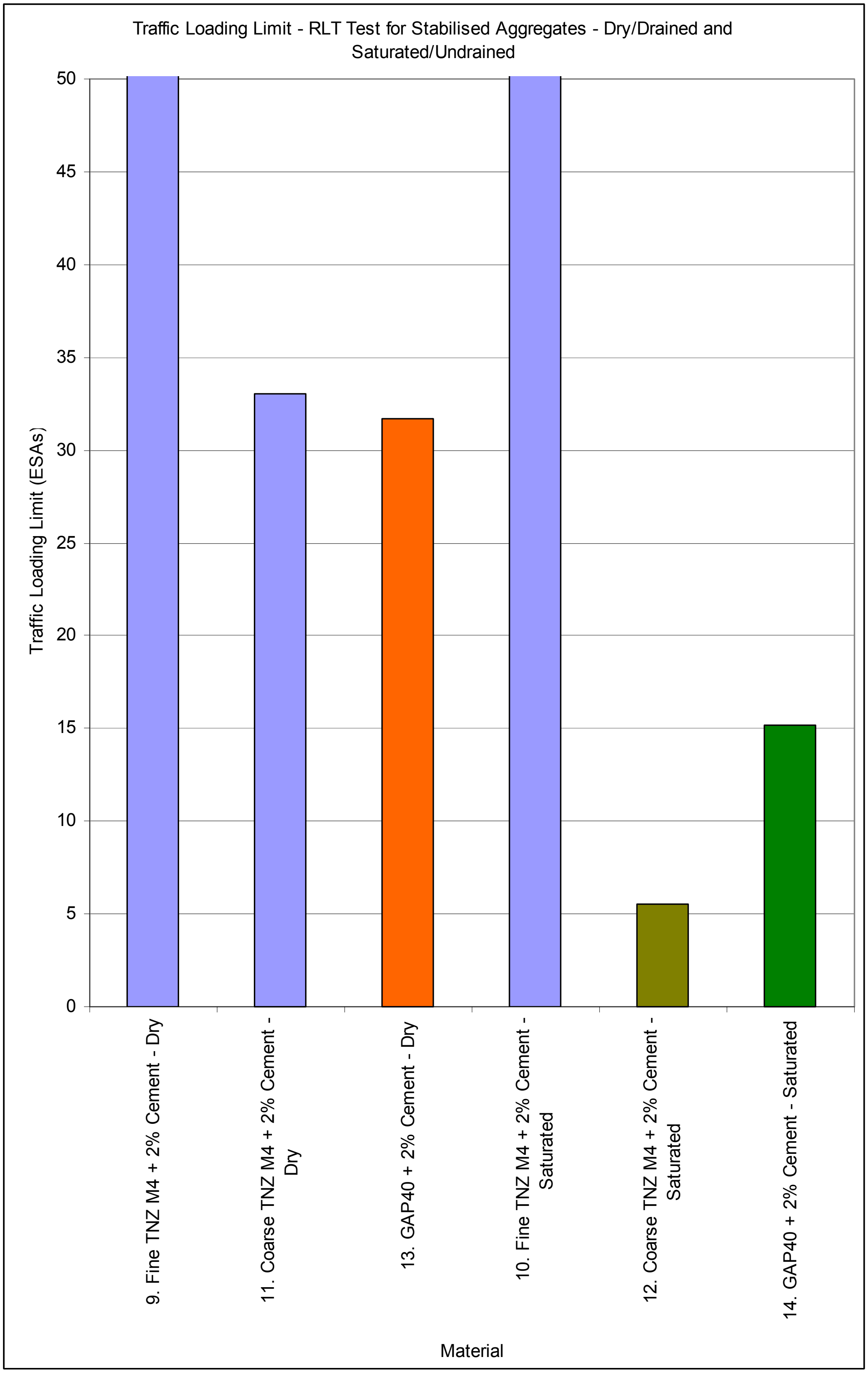

Figure 10. Typical Traffic Loading Limits (ESAs) For Various Stabilised Aggregates found from RLT Testing.

4. 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	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. 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.
Montrose Class 1 20mm Aggregate from Victoria Australia	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.
Multiserv Melter Slag and EAF aggregate from New Zealand and Australia	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.
Cement Stabilised Aggregates	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. 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.
Sub-base	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.

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.

5. FLEXURAL BEAM TESTING

5.1 Background

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 11) 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.

Potential methods that can be used for determining the modulus of cemented materials include the flexural test, direct tension test, indirect tensile test, longitudinal vibration test and the direct compression test (Austroads 2004), however, the last two tests (longitudinal vibration test and the direct compression test) are not suitable for determining the fatigue properties of cemented materials (Austroads 2008). The indirect tensile test (IDT) and the flexural beam test (FBT) have been used in various past research studies (Otte, 1978; Litwinowicz and Brandon, 1994; Bullen, 1994; Andrews *et al*, 1998).

From a review by Yeo *et al* (2002) of potential methods for routine testing of cemented materials for strength, modulus and fatigue, and the method recommended in Austroads (2004), *it was noted that both the indirect tensile test and the flexural beam test were suitable for estimation of the strength, modulus and fatigue life of cemented materials* (Austroads 2008).

Because of the lack of established test protocols in Australia to determine the modulus and fatigue properties of cemented materials, Autroads commissioned a significant development project which is reported in Austroads Technical Report AP-T101/08 (Austroads 2008).

While beam fatigue tests can be used but there is currently no test suitable for aggregates bound by stabilising agents that are typically used in New Zealand for measuring the tensile fatigue characteristics. This is because the current standard tensile fatigue test requires 25mm square long beams usually for asphalt materials as these very small beams can not be manufactured from stabilised aggregates as the small beam will not stay together because of the low cement (or stabilising agent) contents typically used in New Zealand. An alternative is indirect tensile testing with a circular cylinder tested on its side and repetitive loading to split the sample but the literature and Austroad researchers at Arrb TR Ltd report that this method is inaccurate (due to the very small lateral measurements) and does not reflect the beam bending behaviour that occurs in real pavements. This project will aim to use beams of compacted stabilised aggregates (100mm by 100mm by 450mm long) placed under 4 point loading (Figure 1.2). The test configuration is the same as is currently used by Arrb Tr Ltd for an Austroads project studying the fatigue characteristics of Australian cemented aggregates.

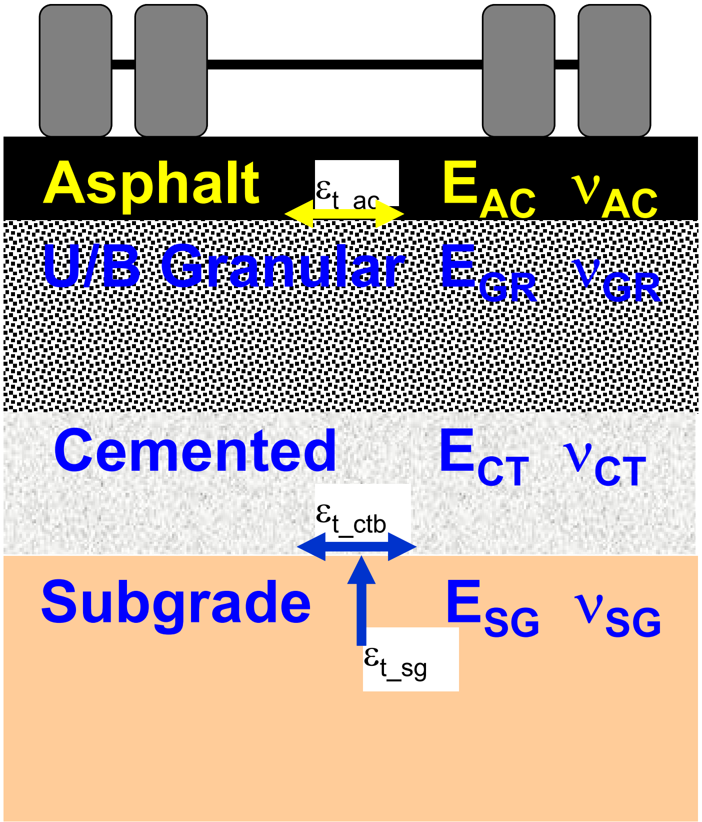

Figure 11 – Inputs required for mechanistic pavement design.

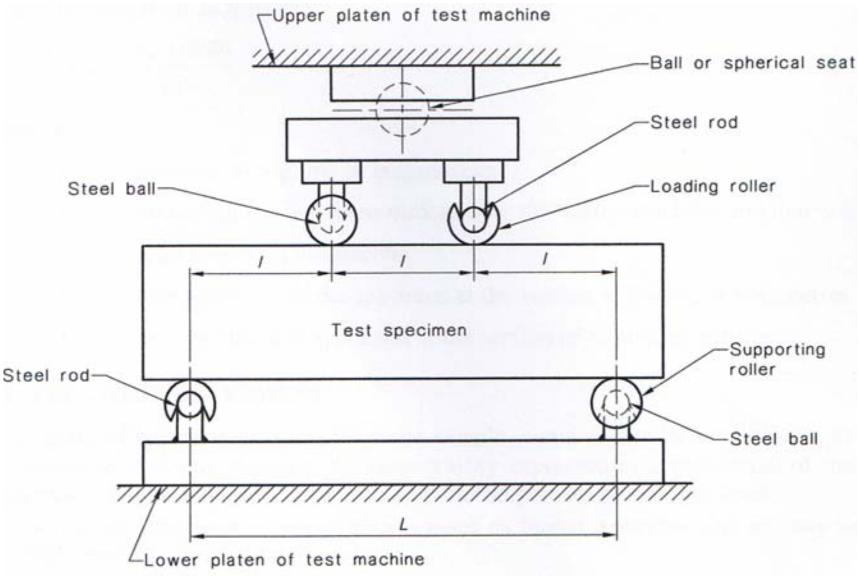

Figure 12 - Four point beam testing apparatus

A fatigue test 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.

5.2 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 13) 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 14.

Figure 13 – Compaction frame with vibrating hammer and foot for beam manufacture.

Figure 14 – 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 15 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 15 – Compacted and cured beam ready for testing.

5.3 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 16, 17 and 18. 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 16 – Test setup for measuring flexural beam properties.

Figure 17 – Result after breakage or fatigue test.

Figure 18 – Measuring deflection during the flexural beam test using LVDT's (Linear Variable Displacement Transducers)

5.4 Initial Flexural Beam Test Results

The following Tables detail the initial results of an ongoing study on stabilised materials using flexural beam tests. The next stage of the research is to replicate testing using Pavespec compaction moulds on the same materials used in a similar Austroads/Arrb study where they used smaller beams cut from a slab. Results of the initial study do show higher tensile stresses and strains at break than would be expected, while the flexural modulus is lower than expected. However, the results are supported by flexural beam tests on beams cut from the CAPTIF test track (Table 8).

Table 6 – Flexural Beam Strength Test Results.

PS0839 Test #	All cured in oven at 40 degrees for 7 days	Max. Vert. Load (kN) and Defln at *Break (mm)	Max. Tensile Stress (kPa)	Tensile Strain at break (μm)	***Flexural Modulus (MPa)
2	CAPTIF ISAACS + 4% Cement	14.5kN @ 0.42 mm	1928 kPa	1450	1330 MPa
4	CAPTIF ISAACS + 4% Cement	13.1kN @ 0.42mm	1741 kPa	1447	1203 MPa
5	CAPTIF ISAACS + 4% Cement	14.2kN @ 0.37mm	1892 kPa	1288	1468 MPa
6	CAPTIF ISAACS + 4% Cement	11.7kN @ 0.33mm	1562 kPa	1145	1364 MPa
8	CAPTIF ISAACS + 4% Cement - *Under compacted:*	Sample Failed with Seating Load of 0.1kN as compacted to only 1.93 t/m^3 while target was 2.19 t/m^3. *Knew of poor compaction but tested anyway for interest.*			
15	CAPTIF ISAACS + 2% Cement	4.75kN @ 0.19mm	633 kPa	680	885 MPa
16b	CAPTIF ISAACS + 2% Cement	4.19kN @ 0.14mm	558 kPa	443	1481 MPa

Table 7 – Flexural Beam Fatigue Test Results.

PS0839 Test #	All cured in oven at 40 degrees for 7 days	Applied Load	Number of load cycles until failure	Tensile Stress (kPa)	Tensile Strain (μm)	Flexural Modulus (MPa)
3b	CAPTIF ISAACS + 4% Cement	10.44kN (75%)	7491	1391	668 - 726	2079 - 1916
7b	CAPTIF ISAACS + 4% Cement	8.34kN (60%)	600	1112	678 – 715	1641 – 1556
9a…9e	CAPTIF ISAACS + 4% Cement	5.57kN (40%)	> 2 Million (did not fail)	742	384	1932
10c	CAPTIF ISAACS + 4% Cement	8.34kN (60%)	110,000	1112	511	2176
11c	CAPTIF ISAACS + 4% Cement	9.75kN (70%)	330	1299	666	1926
13b	CAPTIF ISAACS + 4% Cement	6.10kN (44%)	44,000	813	429	1897
14j	CAPTIF ISAACS + 4% Cement	8.48kN (61%)	490,000	1131	548	2064
17c	CAPTIF ISAACS + 2% Cement	2.86kN (60%)	21,180	382	259	1474
18c	CAPTIF ISAACS + 2% Cement	3.82kN (80%)	2,801	509	306	1664
19b	CAPTIF ISAACS + 2% Cement	3.82kN (80%)	1000	509	290	1700

Table 8 – Flexural Beam Results from Beams Cut from CAPTIF Test Track in the 4% Cement Un-trafficked Section

		*Tensile		Modulus MPa	Cycles o failure
#		Stress kPa	Strain μm/m		
E5U	Initial	136	187	728	First 100
	Start	387	431	899	**2Million
	End	387	435	890	
E4U	Initial	362	532	680	First 100
	Start	487	622	783	341k
	End	487	636	766	
E3U	Mod.	362	483	749	First 100
	Start	452	624	725	546
	End	452	624	725	

* haversine loading at 4Hz values are maximum.
** did not fail

Flexural beam fatigue tests results were plotted in Figure 19 to compare with the Austroads tensile fatigue criteria. As can be seen in the plot the Austroads criteria is more conservative compared to the lab test results. For a tensile micro-strain of 300 Austroads 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 Austroads fatigue criterion predicted fatigue cracking failure usually less than 1 load cycle.

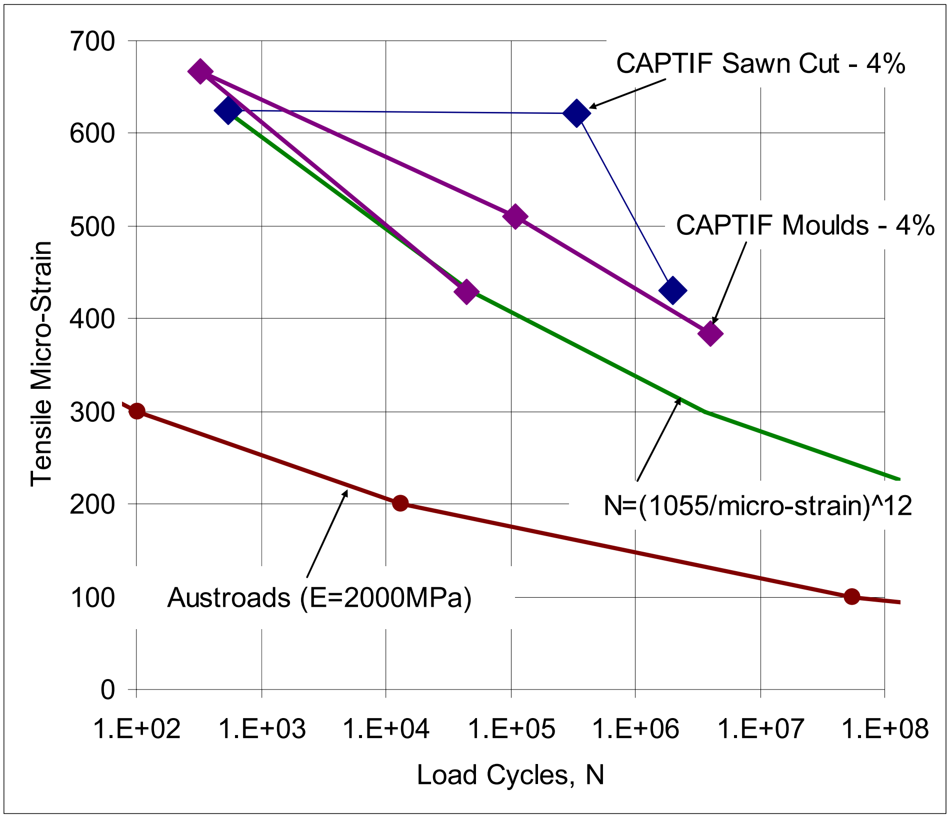

Figure 19 – Fatigue criteria for a 4% Cement Stabilised Aggregate Found from Flexural Beam Tests Compared with Austroads.

6. REDUCING RISK OF PAVEMENT FAILURE

Table 9 – 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.	• 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 my multiplying the traffic up, but research on granular pavements found that increasing depth does not necessarily increase life.	• 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 Repated Load Triaxial testing a range of performace/rut resisistance is obtained.	• 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	• 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.	• 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.	• 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 it's 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.	• 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).	• 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.

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