The performance of New Zealand basecourse aggregates and glass aggregate mixtures found from Repeated Load Triaxial testing

Dr Greg Arnold
Pavespec Ltd

David Alabaster
Transit New Zealand

Jayden Ellis
Stevenson Laboratory Ltd

Jason Lowe
Winstone Aggregates Ltd

ABSTRACT

Repeated Load Triaxial (RLT) tests at many different combinations of confining stress and vertical cyclic stress for 50,000 loading cycles were conducted on a range of granular and glass aggregate mixtures. Results are analysed to predict the number heavy axle passes to achieve a rut depth limit that denotes failure. In the last 2 years at least 100 RLT tests have been conducted on TNZ M4 compliant and non compliant aggregates. This paper reports trends in results with observations on why some basecourse aggregates perform better than others. Different percentages of crushed glass and aggregate were also tested and results are reported. Results from RLT tests in some cases are surprising and early established theories of what makes a good basecourse do not always apply. Overall the Repeated Load Triaxial test has proven ability to rank and predict the performance non traditional aggregates including waste and recycled materials. The introduction of the RLT test into Transit New Zealand specifications will allow more use of these non traditional materials in road construction.

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. Transit New Zealand 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). 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 .

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.

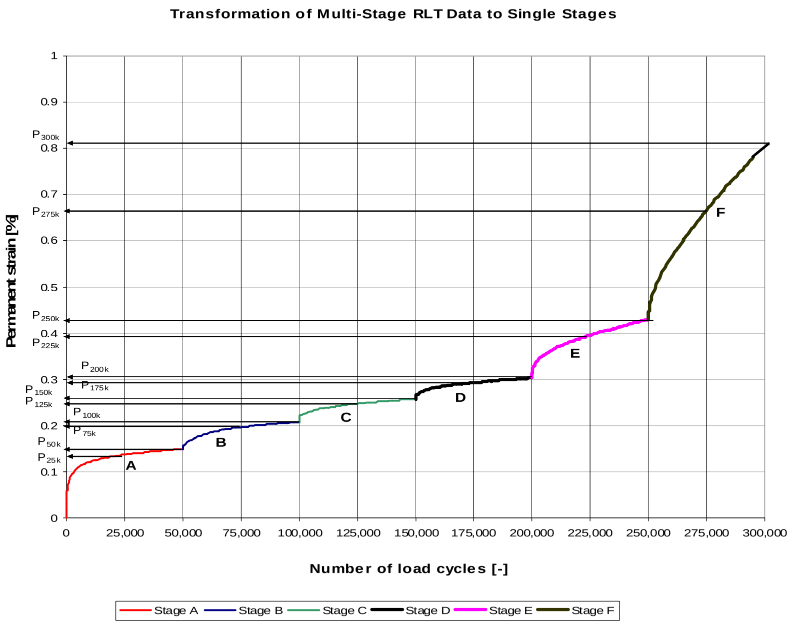

Table 5: Calculation of average permanent strain slope from 6 stage RLT test.

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.

3. REPEATED LOAD TRIAXIAL TESTING RESULTS

3.1 INTRODUCTION

In the last two years a significant amount of RLT tests from research projects and predominantly commercial tests have been undertaken. A selection of these tests are reported below including: results of different percentages of crushed glass; good and poor performing TNZ M4 basecourse aggregates; sub-base aggregates and cement modified aggregates.

3.2 THE EFFECT OF CRUSHED GLASS ON AGGREGATE PERFORMANCE

Glass bottles collected by councils are forming large stockpiles particularly in the South Island as it is uneconomic to transport the glass to the Auckland plant where it is reused into glass bottles. An alternative method of disposal is to crush the glass and mix it into basecourse aggregate. Transit New Zealand currently allows up to 5% by mass of crushed glass to be mixed in the aggregate. This study investigated the effect on aggregate performance of percentages of crushed glass up to 50% by mass of aggregate or a third of the total mass. Performance was measured using the Repeated Load Triaxial apparatus and associated rut depth modelling (Arnold, 2004) to determine the number of heavy axles until 10mm of rutting occurs within the aggregate layer. RLT test results for tests at 100% Optimum

Moisture Content (OMC)[1] and 95% of Maximum Dry Density (MDD)[1] at drained conditions were conducted.

Glass was added directly to the source aggregate (Material #1) which had an original grading in the middle of TNZ M/4 (Transit, 2006) with a Talbot exponent n value of 0.55. Using the actual grading for the glass detailed in Table 2 the new resulting grading curves were determined for the glass aggregate mixtures (Figure 2). As can be seen the 30% and 50% glass aggregate mixture has a grading being outside the limits of TNZ M/4 (Transit, 2006).

Table 2. Grading of crushed glass as received and used in RLT tests compared with TNZ M/4 *Specification for Basecourse Aggregate* (Transit, 2006) requirements.

Particle Size Distribution from Dry Sieve Analaysis		
	Percent Passing	
Sieve Size (mm)	**Actual for Glass as recieved**	**TNZ M4 (2006) PSD range for Glass *(current limits)***
9.5	100	100
6.7	76.1	-
4.75	46.6	70 - 100
2.36	26.1	35 - 88
1.18	14.0	15 - 45
0.30	4.6	4 - 12
0.075	1.5	0 - 5

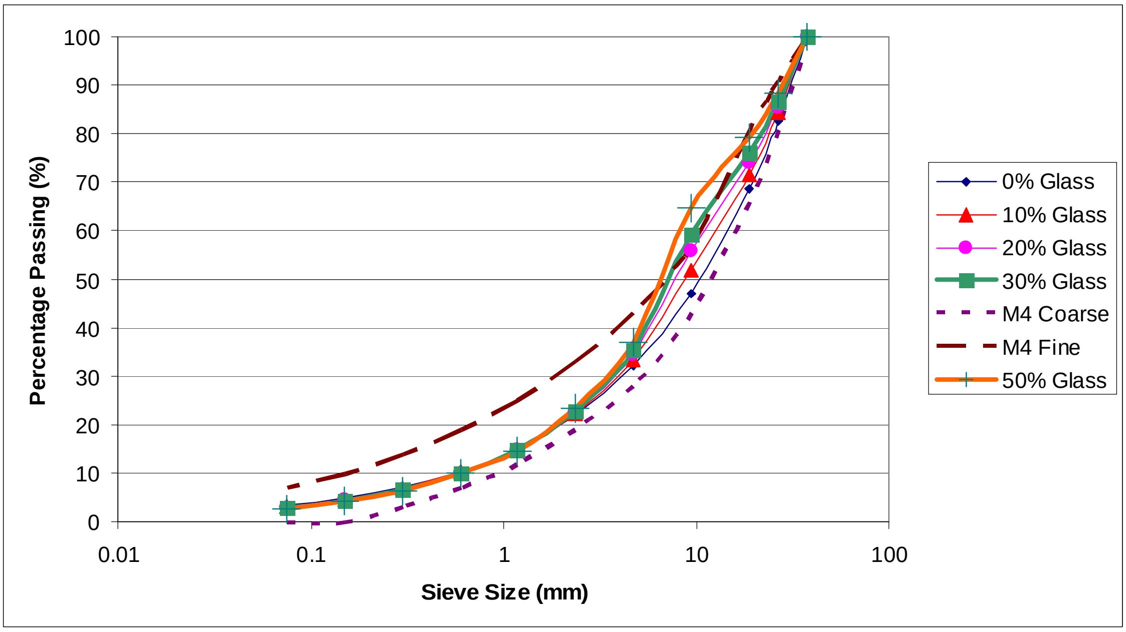

Figure 2 – Aggregate and glass mixtures grading curves.

Details of the RLT tests conducted in accordance with the 2007 draft TNZ T/15 Specification for Repeated Load Triaxial Testing is summarised in Table 3. The

---

[1] OMC = Optimum Moisture Content and MDD = Maximum Dry Density (NZS 4402 : 1986 Test 4.13 NZ VH)

raw RLT results plotting permanent strain with number of load cycles is shown in Figure 3. Rut depth modelling was undertaken using the RLT results to predict the number of heavy axle passes until a certain rut depth is obtained if the material was used at Transit New Zealand's CAPTIF test track.

Table 3 – RLT tests conducted and details of sample preparation.

Pavespec Test #	% Glass by Mass of Aggregate	% of Glass to Total Mass of RLT Sample	[1]Final Achieved Density and Moisture Content	[2]MDD	[2]OMC
PS0022 Test # 1 CAPTIF1 - 0% Glass	0	0	96.3%MDD (DD=2.253 t/m3) ; 89.2%OMC (MC=4.5%)	2.34	5.0
PS0022 Test # 2 CAPTIF1 - 10% Glass	10	9.09	97.6%MDD (DD=2.256 t/m3) ; 64.7%OMC (MC=3.2%)	2.31	5.0
PS0022 Test # 3 CAPTIF1 - 20% Glass	20	16.67	96.8%MDD (DD=2.216 t/m3) ; 81%OMC (MC=4.1%)	2.29	5.0
PS0022 Test # 4 CAPTIF1 - 30% Glass	30	23.08	96.9%MDD (DD=2.19 t/m3) ; 81%OMC (MC=4.1%)	2.26	5.0
PS0022 Test # 5 CAPTIF1 - 50% Glass	50	33.33	97.2%MDD (DD=2.144 t/m3) ; 82.2%OMC (MC=4.1%)	2.21	5.0

Note 1: Density and moisture content targeted at the time of sample compaction was 97%MDD and 100%OMC.
Note 2: MDD (Maximum Dry Density) was interpolated from values obtained for 0 and 30% glass compaction tests while OMC (Optimum Moisture Content) was kept at 5.0%.

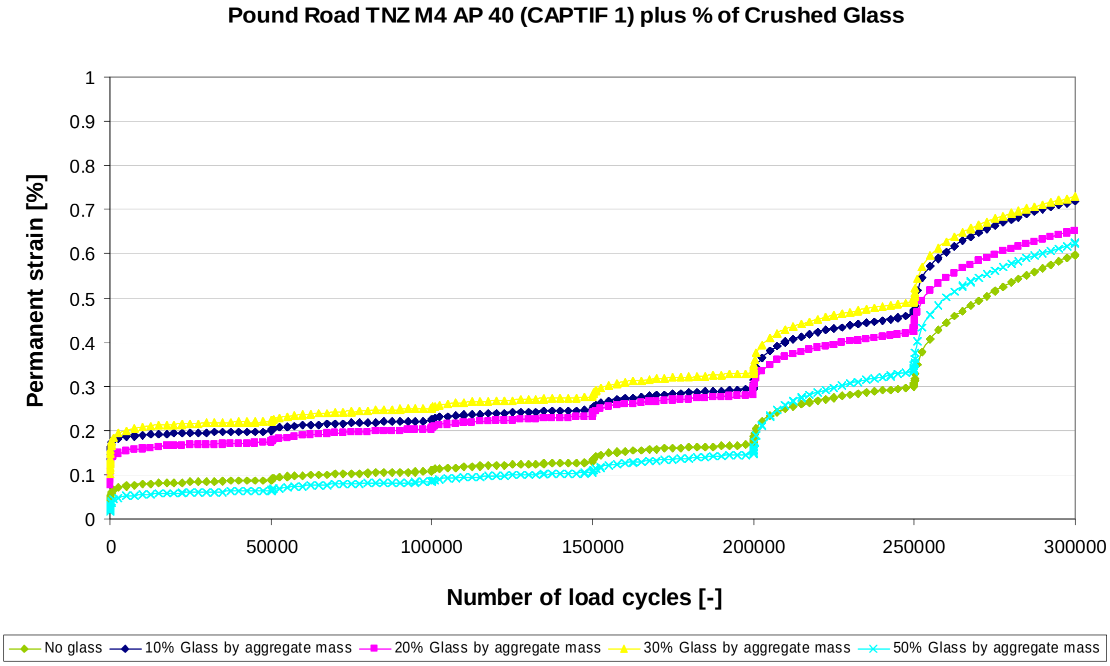

Figure 3 – RLT Results for various percentages of crushed glass.

Table 4 – Rut Depth Predictions from RLT Results of glass aggregate mixtures.

		CAPTIF Pavement 300mm Aggregate over 10CBR Subgrade					
		Total Pavement	**Aggregate only**	**Aggregate only**			
		N, ESAs to get 25mm rut	**N, ESAs to get 10mm rut in aggregate.**	**Long term rate of rutting within aggregate**	**Resilient Modulus**	**Average RLT Slope**	**Maximum Slope**
#	**Material #**	*Million ESAs*	*Million ESAs*	*mm per 1 Million ESAs*	*MPa*	*%/1M*	*%/1M*
1	**PS0022 Test # 1 CAPTIF1 - 0% Glass**	2.88	7.12	1.3	**483**	**0.855**	3.2542
2	**PS0022 Test # 2 CAPTIF1 - 10% Glass**	3.12	10.47	0.9	**517**	**0.746**	2.2174
3	**PS0022 Test # 3 CAPTIF1 - 20% Glass**	3.15	11.73	0.8	**529**	**0.736**	2.0972
4	**PS0022 Test # 4 CAPTIF1 - 30% Glass**	3.19	13.51	0.7	**527**	**0.722**	2.009
5	**PS0022 Test # 5 CAPTIF1 - 50% Glass**	3.00	9.13	1.0	**535**	**0.814**	2.4406

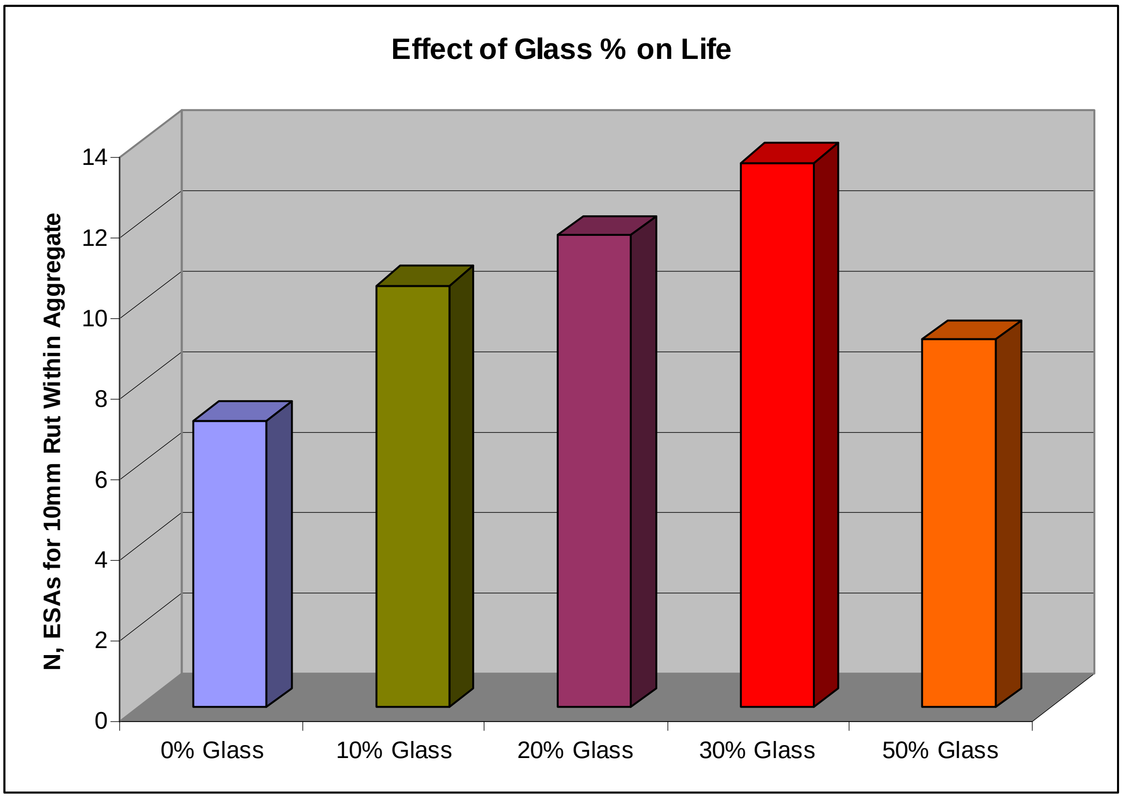

Figure 13 – Effect of Glass Content on Number of Load Cycles to Achieve a 10mm Rut Within Aggregate Layer for the Pavespec RLT test results.

Based on the Repeated Load Triaxial test results for aggregate glass mixtures it appears that adding crushed glass in quantities of up to 30% by mass has little or no effect on aggregate rut depth performance. This is the case for an already high rut resistance aggregate from Pounds Road Quarry in Christchurch. The result is surprising considering 23% of the aggregate is crushed glass of less than 9.5mm in size. The RLT tests conducted by the University of Canterbury confirm this result.

Given that the literature generally shows crushed glass up to 15% by mass is acceptable for basecourse aggregates and the triaxial study conducted shows little effect to aggregate performance, it is proposed that 15% be used as the new limit for crushed glass in basecourse. Further, the grading envelope for the glass cullet should be expanded to reflect what was used in this study (Table 2), being typical of what is crushed. Higher, percentages may be accepted if proven through RLT testing.

3.3 TYPICAL RLT TEST RESULTS

In the past 2 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 was 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.

RLT tests were conducted at both saturated/undrained and dry/drained conditions. Typical results are listed in the Tables 5 to 8 and Figures 14 to 18 shown below.

Table 5 - Typical results for TNZ M4 Basecourse Aggregates (note: ranked in terms of performance in dry/drained RLT Test).

#	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

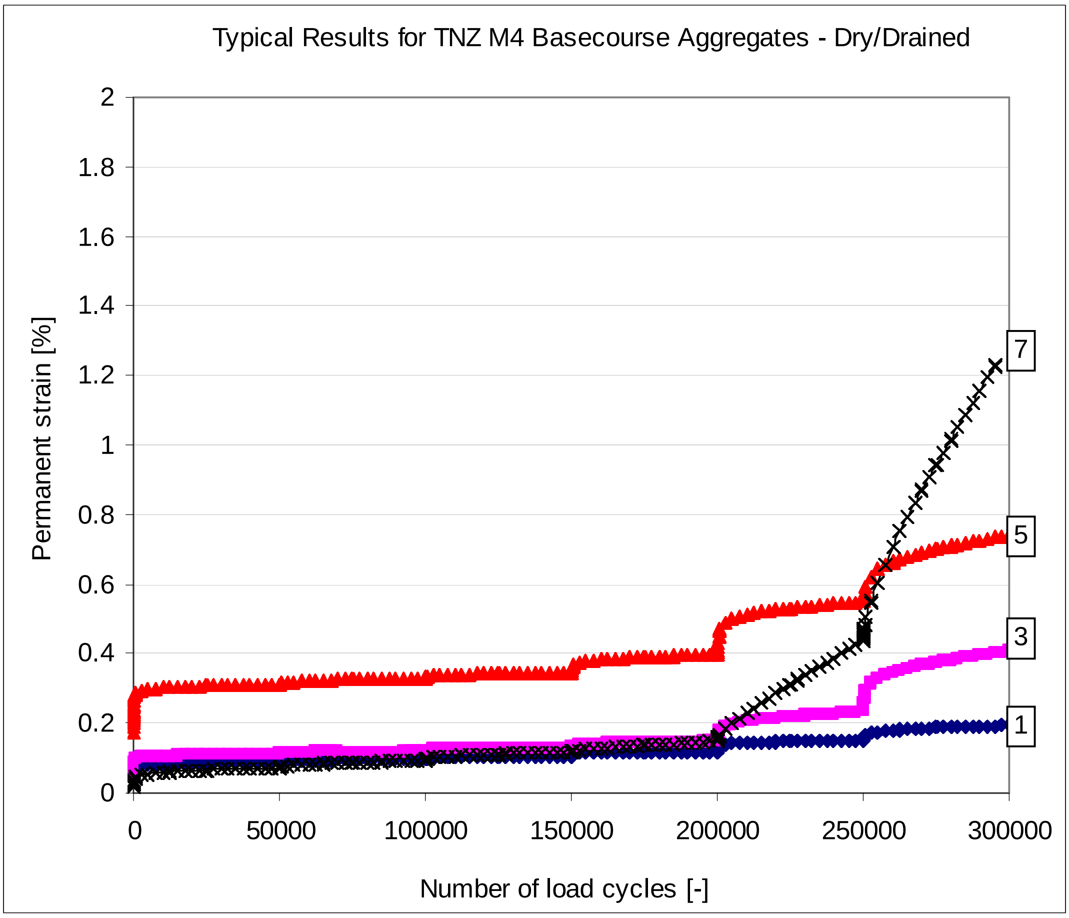

Figure 14 – Typical RLT Results for TNZ M4 Basecourse in Dry/Drained conditions.

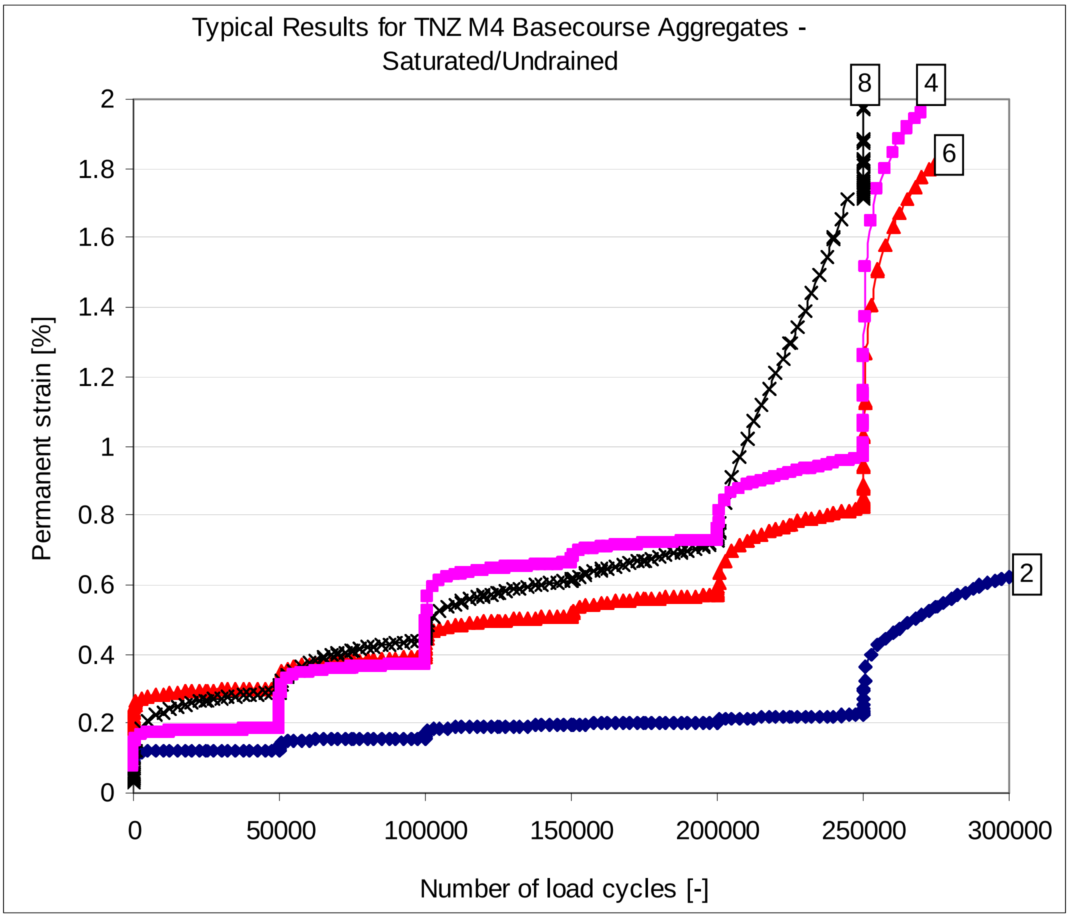

Figure 15 – Typical RLT Results for TNZ M4 Basecourse in Saturated/Undrained conditions.

Table 6 - Typical results for Stabilised Aggregates (note: ranked in terms of performance in dry/drained RLT Test).

#	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	31.68	0.3	805	0.160
14		Saturated	15.20	0.6	684	0.353

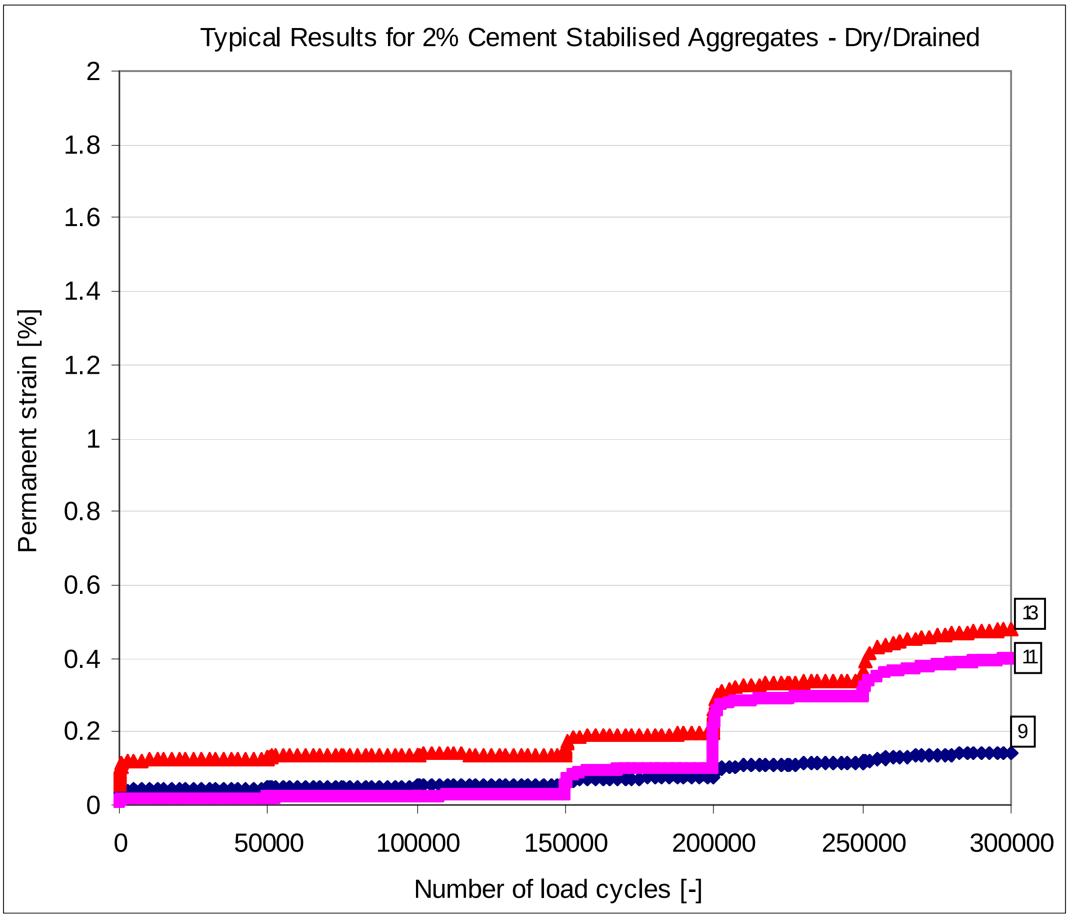

Figure 16 – Typical RLT Results for 2% Cement Stabilised Aggregates – Dry/Drained Test Conditions.

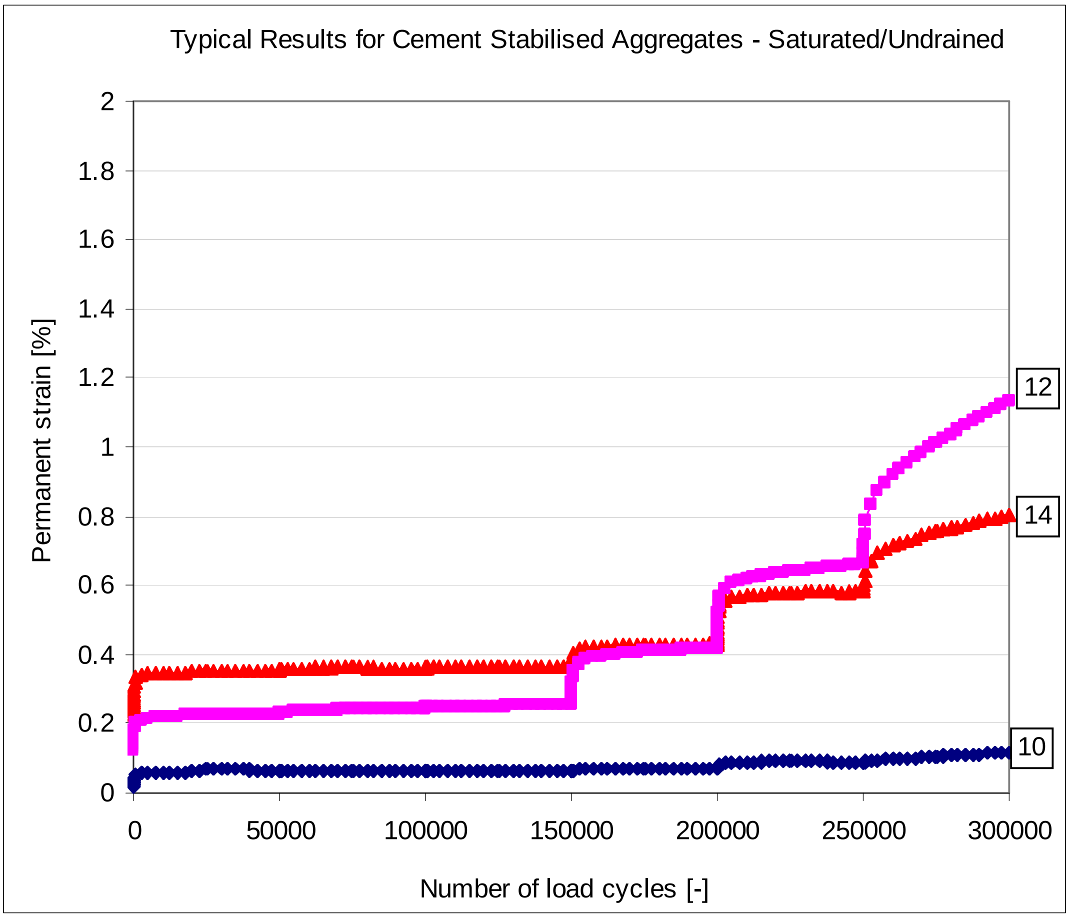

Figure 17 – Typical RLT Results for 2% Cement Stabilised Aggregates – Saturated/Undrained Test Conditions.

Table 7 - Typical result for a Sub-base aggregate GAP65 scalped to a GAP40 – Analysed if used as a basecourse.

			Analysed as a basecourse			
			N, ESAs to get 10mm rut in aggregate.	**Long term rate of rutting within aggregate**	**Resilient Modulus**	**Average RLT Slope**
#	**Material (unless otherwise stated sample was compacted at 95%MDD and 100%OMC)**	**RLT Test**	*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 8 - Typical result for a Sub-base aggregate GAP65 scalped to a GAP40 – Analysed if used as a Sub-Base.

			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

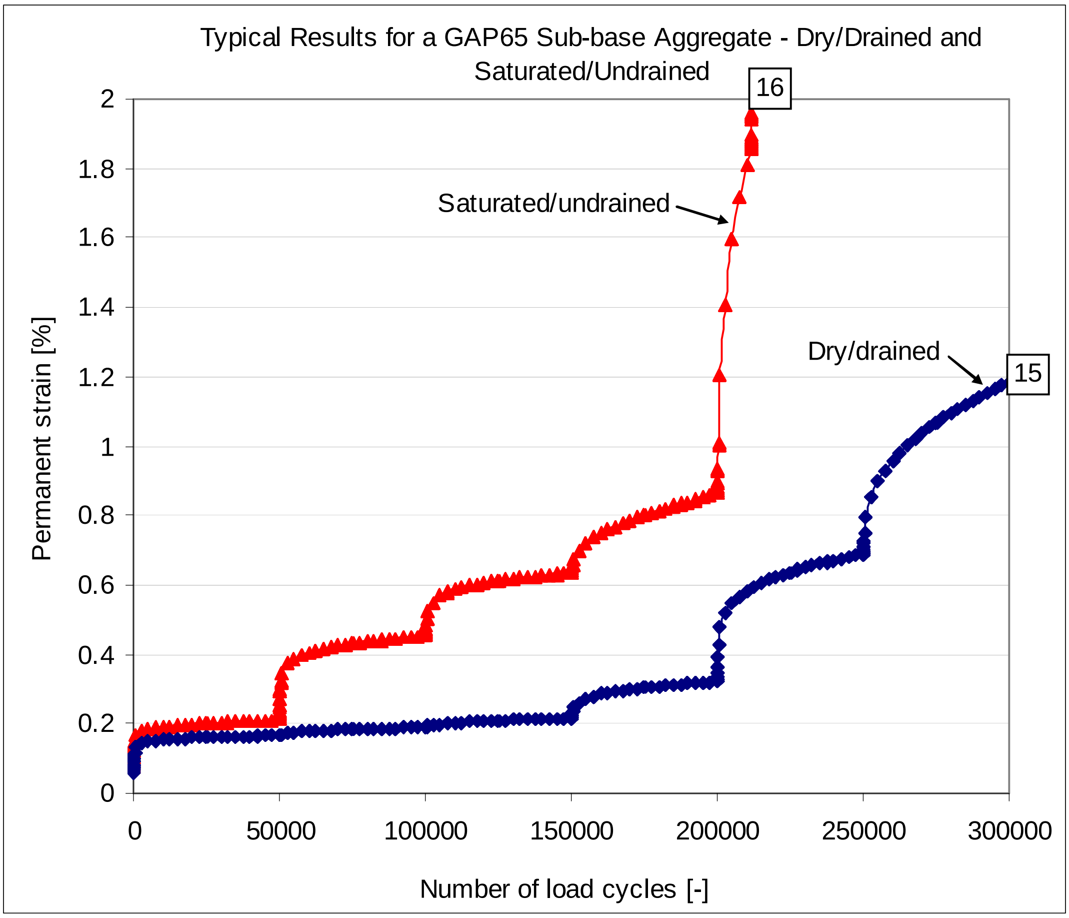

Figure 18 – Typical RLT Results for GAP65 Sub-base Aggregate – Dry/Drained and Saturated/Undrained Test Conditions.

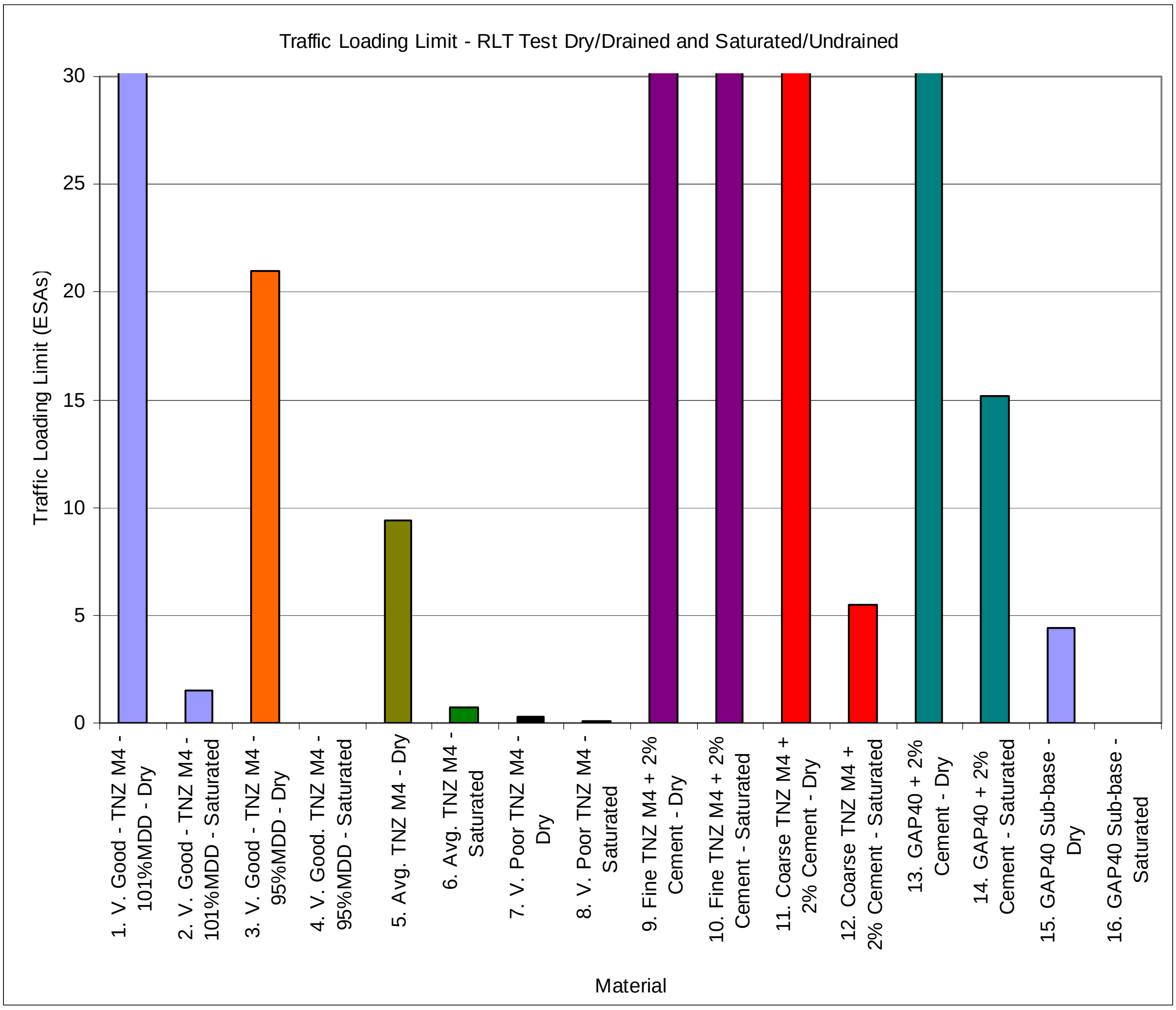

Figure 19. Typical Traffic Loading Limits (ESAs) For Various Aggregates found from RLT Testing.

4. CONCLUSIONS

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 9.

Table 9 – RLT Result Summary.

Material	**Repeated Load Triaxial Test Result and Rut Depth Prediction**
TNZ M4 Basecourse + glass.	Adding crushed glass in quantities of up to 30% by mass has little or no effect on aggregate rut depth performance.
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.
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.

4. REFERENCES

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 pave-ment performance from repeat load triaxial tests on granular materials. Transfund New Zealand Research Report, Wellington, New Zealand.

Chan, FWK. 1990. Permanent deformation resistance of granu-lar layers in pavements, Ph.D. Thesis, University of Not-tingham, Nottingham, UK.

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 Ad-ministration. Finnra Reports 22/2003. 39 p. + app. ISSN 1457-9871, ISBN 951-803-052-9, TIEH 3200810E.

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

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

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 As-phalt Pavements, August, Seattle, Washington, USA.

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

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.