SPECIFICATION FOR REPEATED LOAD TRIAXIAL (RLT) TESTING FOR PAVEMENT MATERIALS

1. SCOPE

This specification details the six (6) stage permanent strain Repeated Load Triaxial (RLT) test for unbound and modified aggregates to assess rutting performance, dry and wet.

NZTA T/15 Notes should be referred to for a more detailed explanation of the RLT test.

2. GENERAL

All sampling must be performed in accordance with the methods detailed in NZS 4407:1991 Part 2 and by a laboratory that has accreditation under NZS ISO/IEC 17025:2005 General Requirement of Testing Laboratories. Instruments on the Repeated Load Triaxial apparatus require calibrating at a minimum frequency of once every 2 years as per the IANZ requirements for calibration for mechanical testing laboratories in New Zealand (Appendix 3 – IANZ Mechanic Testing – AS LAB C 4).

3. REPEATED LOAD TRIAXIAL TEST

3.1 Repeated Load Triaxial Apparatus

The Repeated Load Triaxial apparatus shall be of the type capable of testing 150 mm diameter by 300 mm high unbound granular materials in a constant confining test as per the European Standard EN 13286-7 *Unbound and hydraulically bound mixtures – Part 7: Cyclic load triaxial test for unbound mixtures,* with the exception that external displacement transducers are used. RLT testing shall be conducted by suitably skilled and experienced organisations knowledgeable in Repeated Load Triaxial testing and who participate in round robin testing. Prior to testing please refer to the list of acceptable organisations that are suitable to conduct the testing. A minimum of once every two years, round robin testing is required for all RLT apparatuses using the same aggregate, refer to the notes for details.

3.2 Sampling

Representative samples of the basecourse or subbase shall be taken from the conveyor belt, bin, stockpile or truck. Alternative samples can be remanufactured in the laboratory to the target grading. Representative samples of the basecourse or subbase shall be obtained in accordance with NZS 4407:1991. This sample shall be split to enable an RLT test and, if required, the aggregate source and property tests as per (NZTA M/4) to be conducted effectively from the same sample.

3.3 Repeated Load Triaxial (RLT) Test

Dry/Drained or Soaked/Undrained materials shall be prepared according to Table 1 and Table 2 respectively. The sample shall be RLT tested according to the procedure described in Table 3 with the definitions in Table 4 applying.

Table 1: RLT Sample Preparation for Dry/Drained Test (see Appendix A for reporting requirements)

Material Type	Maximum particle size 37.5 mm – remove all materials retained on a 37.5 mm sieve and do not replace unless grading is adjusted to obtain the same grading exponent (NZTA M4 Notes: 2012).
Dry Material	Air dry material if necessary to at or below optimum moisture content and take a sample and oven dry to determine moisture content.
Split and Re-mix Material to the Correct Grading	Split the sample received to enable one sample to be used for RLT testing and the other sent for sieve analysis as per *NZS 4407:1991 Test 3.8.1* and other production tests in NZTA M/4 to establish production limits for specifying the material in NZTA M/4. Otherwise, if target grading is known *and there is no chemical binder present in the sample* then split the sample using dry sieving into the following sieve sizes (mm): 19.0 – 37.5; 9.5 – 19.0; 4.75 – 9.5; < 4.75. Then remix at least 1 RLT sample weight to the correct target grading.
Sample Size	150 ± 2 mm diameter and 290 ± 2 mm or to 300 ± 2 mm high. *(Tolerances are for manufacturing split mould and sample size must be accurately recorded to nearest 0.5mm for the purpose of determining density and stress applied to sample).*
Target Density- and Moisture Content at Time of Sample Preparation	Vibrating compactive effort shall be used to achieve a dry density that is either the minimum dry density achieved in the field or is 95% to 96% MDD at 100% OMC (Maximum Dry Density and Optimum Moisture Content found from vibrating hammer compaction test NZS 4402 Test 4.1.3) on the same material tested in the RLT apparatus using the same grading and binder content with associated curing conditions if applicable. *These target conditions may be altered provided they are typical minimum field density and maximum moisture conditions and/or relate to a standard commonly used compacted effort. All RLT results relate to an achieved dry density and moisture content and thus dry density and moisture content must be reported next to an RLT result in the report. Also there are often errors with the MDD or the MDD is not known and thus a standard compactive effort ranging from 10 seconds to 30 seconds of vibrating compaction should be applied dependent on hammer model and experience to achieve 95 to 96% of MDD. The achieved DD and %MDD shall be clearly recorded on the RLT test report. Any unusually low MDD shall be identified and the client notified.*
Binder Content and Curing	Binder content (*if applicable*) should be specified/recorded based on a percentage of dry aggregate weight, curing conditions, times in stockpile and time left as compacted specimen before RLT test shall be recorded. Curing method used should be the same as recommended in NZTA T19 specification. Another curing method can be used if agreed with the client/engineer. The curing method used needs to be recorded with the RLT test result.

Sample Preparation	Prepare the correct loose sample size required to achieve the target density and moisture content and binder content/curing (*if applicable*) for the sample size to be compacted. Cure as required if binder is added. Use a Vibratory Hammer for sample compaction to the same specifications used in NZS 4402 Test 4.1.3. The sample shall be compacted at OMC but it is expected that some water will be lost during compaction and testing. This is acceptable provided the moisture content and dry density at the end of the test is recorded along with the RLT test result. Place filter paper at the top and bottom of the sample between the bottom and top platens. Place one membrane (optional) in a split mould for compaction and then place a second membrane over the sample after the sample is compacted. Compact in five (5) layers (Measure five equal portions of aggregate and measure the height of compaction for each layer to achieve uniform density at the target density). Document all these measurements. Scarify the top of each layer following compaction with a screwdriver to ensure bonding between the layers. Place sample in the triaxial cell with the valves open and increase cell pressure to 150 kPa and check for any leaks in the membrane. For air confinement, release pressure quickly and check if membrane balloons out. If ballooning occurs then there is a leak in the membrane. If there is a leak then remove the sample to repair the leak and repeat the checking process again. Do not start the test until there are no further leaks. After any leaks have been repaired, record the exact sample height and mass before starting the test (keep valves open). Apply a seating stress of 5 kPa and maintain for the duration of the test. After testing determine the moisture content and dry weight of the sample and calculate the dry density and calculate the degree of saturation (% saturation or DOS) as defined in NZS 4402:1986 and calculated using the formula below. $$\%\ saturation = \frac{dry\ density \times \%\ water}{1 - \dfrac{dry\ density}{solid\ density\ of\ the\ particles}}$$

Table 2 – Sample Preparation for Soaked/Undrained Test

Sample Preparation	Same as Table 1 preparation for Dry/Drained test with the following undertaken prior to testing in the soaked/undrained RLT test. Place the bottom platen on the specimen and seal with an O-ring and two membranes (or one waterproof membrane) and record the total weight. With the bottom base plate valve open, place the sample in a water bath (large rubbish bin) where the water level is approximately 20 mm higher than the sample. Leave in water bath for 1 hour plus or minus 10 minutes (or longer for more severe environmental loading and 24 hours for stabilised samples). Observe bubbles on top of the specimen indicating water penetration. Prior to removing specimen from water bath, plug the valve on the bottom base plate. Remove water in the water bath so that the water level is the same as the top of the specimen then place top platen on specimen and seal with membrane and O-ring. Carefully remove sealed specimen and record total mass to determine the volume of water soaked into the specimen and place in triaxial cell for testing, block air opening in triaxial cell and leave bottom platen valve blocked. Calculate the dry density and calculate the degree of saturation (% saturation or DOS) as defined in NZS 4402:1986 and calculated using the formula below. $\%\ saturation = \dfrac{dry\ density \times \%\ water}{1 - \dfrac{dry\ density}{solid\ density\ of\ the\ particles}}$ Place sample in the triaxial cell with the valves closed and increase cell pressure to 150 kPa and check for any leaks in the membrane. For air confinement release pressure quickly and check if membrane balloons out. If ballooning occurs then there is a leak in the membrane. If there is a leak remove the sample to repair the leak and re-soak and repeat the checking process again. Do not start the test until there are no further leaks. After any leaks have been repaired, measure the exact sample height and mass inclusive of the water before starting the test (keep valves closed). Apply a seating stress of 5 kPa and maintain for the duration of the test.

Table 3: Six Stage RLT Test

RLT Testing Stress Stage	A	B	C	D	E	F
Deviator Stress – q_{max} (kPa) (Cyclic Vertical Stress)	90.0	100.0	180.0	330.0	420.0	550.0
Mean Stress - p_{max} (kPa)	150.0	75.0	150.0	250.0	250.0	233.3
Cell Pressure, σ_{3max} (kPa)	120.0	41.7	90.0	140.0	110.0	50.0
Major Principal Vertical Stress, σ_{1max} (kPa)	210.0	141.7	270.0	470.0	530.0	600.0
Cyclic Vertical Loading Speed	Haversine at 4Hz					
Number of Loads (*N*)	50,000 *for each test stage*					
RLT Test Apparatus (Vertical Loading Pulse)	To suit available RLT pneumatic or hydraulic equipment and control software in New Zealand Haversine pulse at 4 times a second (4Hz) using pneumatic or hydraulic equipment*					
Triaxial Cell and Instrumentation	External load cell and 2 external displacement transducers mounted between loading caps to measure whole-sample strain Use air, water or silicon in the cell to apply confining pressure					
Drainage Condition	Drained condition (no pore pressure measurement), leave valves open during testing					
Record and Report Data Electronically in Microsoft Excel (see Table 3 for definitions)	Items to record and/or calculate are those listed in Table 3 which include: permanent strain, elastic/resilient strain, resilient modulus, specimen height, cell pressure, maximum and minimum cyclic vertical/deviatoric stress at the following load intervals for each RLT testing stage: 1-50; 91-100; 191-200; 391-400; 991-1000; 2491-2500; 4991-5000; 7491-7500; 9991-10000; 12491-12500; 14991-15000; 17491-17500; 19991-20000; 22491-22500; 24991-25000; 27491-27500; 29991-30000; 32491-32500; 34991-35000; 37491-37500; 39991-40000; 42491-42500; 44991-45000; 47491-47500; 49991-50000					

Notes: 1. The sample shall be prepared as per Table 1 in this specification;

2. If a binder is added for modification/stabilisation then tests must be conducted within 7 days after sample compaction;

3. RLT testing can skip to the next stage if the permanent strain from any particular stage reaches 1% being the differential value for that stage and not the cumulative permanent strain *(IPC control systems can be automatically set to skip stages).*

4. See Section 4.0 for interpreting the RLT results to compute the permanent strain slopes for determining the traffic loading limit and resilient modulus for the basecourse aggregate.

Table 4: Definitions and Equations used to Interpret RLT Test Results

Symbol	Definition	Units
N	Number of load cycles	M, Millions
q_{max} *or* σ_{d_max}	Maximum deviator stress or maximum cyclic vertical stress, = $\sigma_{1max} - \sigma_3$	MPa
q_{min} *or* σ_{d_min}	Minimum deviator stress or minimum cyclic vertical stress, = $\sigma_{1min} - \sigma_3$ (*minimum stress due to seating load and static weight of platen and loading rod*)	MPa
σ_{1max}	Maximum major principal vertical stress, = $q_{max} + \sigma_3$	MPa
σ_{1min}	Minimum major principal vertical stress, = $q_{min} + \sigma_3$	MPa
σ_3	Constant confining cell pressure	MPa
L_0	Original length of specimen prior to testing, at N=0	mm
$L_{N\_unloaded}$	Length of specimen in the unloaded portion of the N_{th} loading cycle	mm
L_{N_loaded}	Length of specimen in the fully loaded portion of the N_{th} loading cycle	mm
$L_r(N)$	Resilient axial displacement at load cycle N, defined as the displacement during the application of a single load cycle, from the unloaded state to the fully loaded state for the N_{th} load cycle $L_r(N) = L_{N\_unloaded} - L_{N\_loaded}$	mm
$\varepsilon_1{}^r(N)$	Resilient or recovered axial strain, at load cycle N, $\varepsilon_1{}^r(N) = L_r(N)/L_0$	μm
$E_r(N)$	Resilient modulus at load cycle, N associated with a particular loading stress $E_r(N) = (q_{max} - q_{min})/\varepsilon_1{}^r(N)$	MPa
P_N	Cumulative Permanent Strain, (%) at load cycle N $P_N = (L_0 - L_{N\_unloaded})/L_0$	%

3.4 Reporting

All RLT test results including sample preparation shall be recorded as per Section 5.0.

4. AVERAGE PERMANENT STRAIN SLOPE CALCULATION

4.1 General

Pass and fail limits have been developed based on permanent strain slope as this simple parameter from the RLT test could be related to life found from rut depth modelling and finite element analysis of pavements (Arnold 2010a, 2010b). Permanent strain slope limits are detailed in NZTA M4 (2012). The method to calculate average slope is outline in Section 4.2.

4.2 Average Permanent Strain Slope Determination

Determine the average slope (%/1M) for the first 5 and for all 6 stages as per Table 5 using permanent strains measured in the RLT test.

Table 5: Calculation of average permanent strain slope from RLT test (if test does not complete full 50k cycles per stage due to high permanent strain, refer to Table 6 for calculation)

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}	$=(P_{100k}-P_{75k})/0.025M$
	P_{100k}	
Stage C	P_{125k}	$=(P_{150k}-P_{125k})/0.025M$
	P_{150k}	
Stage D	P_{175k}	$=(P_{200k}-P_{175k})/0.025M$
	P_{200k}	
Stage E	P_{225k}	$=(P_{250k}-P_{225k})/0.025M$
	P_{250k}	
Stage F	P_{275k}	$=(P_{300k}-P_{275k})/0.025M$
	P_{300k}	
Average (first 5 stages)		$= P_{avg(5stages)}$ $= \sum$Slopes(stages A to E)/5
Average (all 6 stages)		$= P_{avg(6stages)}$ $= \sum$Slopes(stages A to F)/6

Notes: 1. If any of the loading stages do not complete the full amount of loading cycles because the deformation limit of 1.0% was achieved then Table 5 calculations will not apply. In this situation the average tangential permanent strain slope achieved is used in place of the value from 25k to 50k load cycles.

2. Permanent strain values for any given load cycle are the average of the previous ten readings in the Repeated Load Triaxial Test to account for any noise in the data.

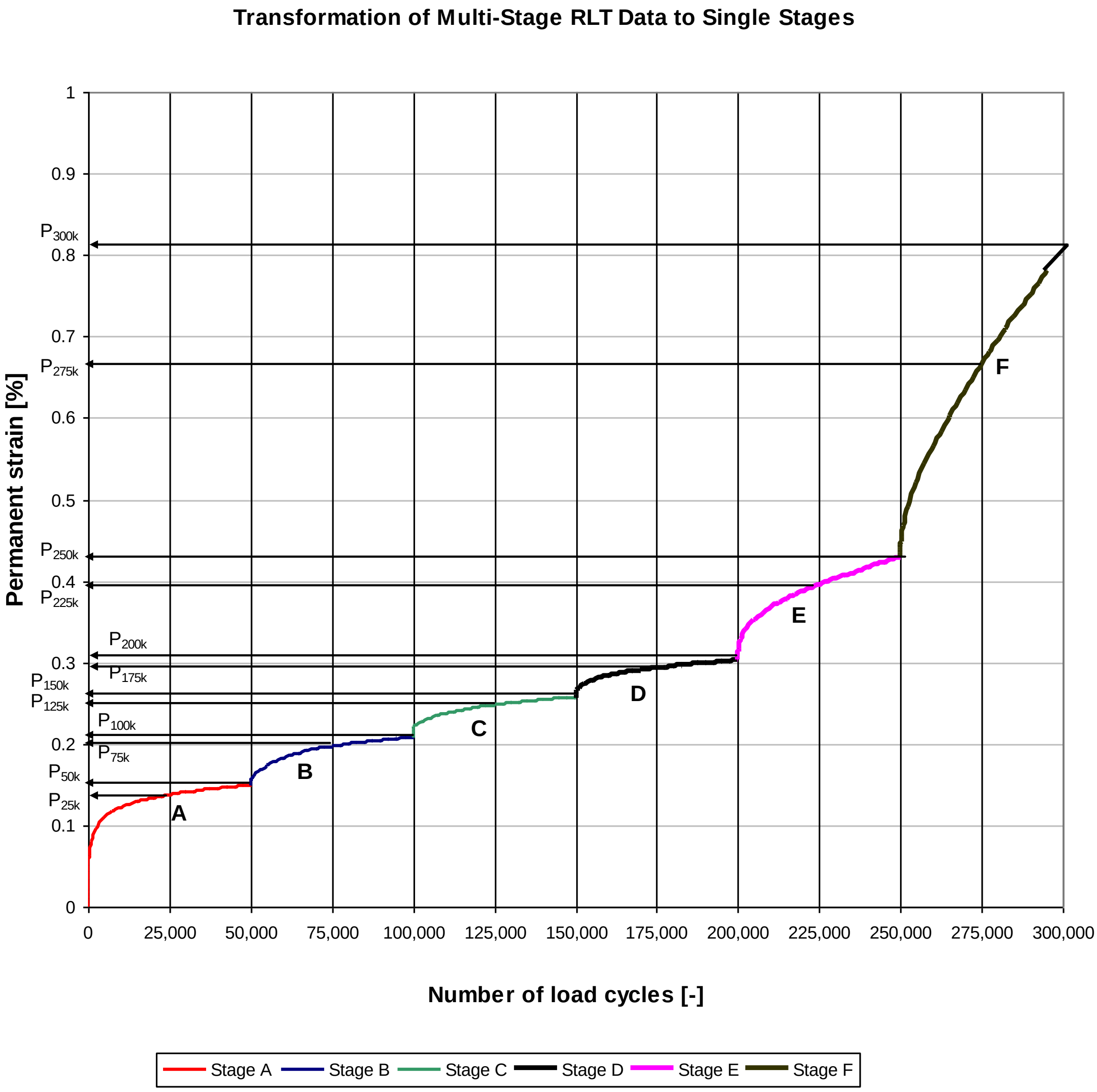

Figure 1: Permanent Strain Points for Determination of Permanent Strain Slopes

Table 6: Calculation of average permanent strain slope from RLT test if test does not complete full 50k cycles per stage due to high permanent strain

RLT Test Stage (Table 2)	[2]Permanent Strain (%) (see Figure 1)	[1]Permanent Strain Slope (%/1M) (Slopes)
Stage A, B, C, D, E, F	P = lesser of $P_{Final\ minus\ 5k}$ Or P_{25k} P_{Final} = the final permanent strain achieved for that particular stage	$=(P_{Final}-P)$/(Number of load cycles between P_{Final} and P) If number of load cycles for the stage is less than 5k then report “fail”
Average (first 5 stages)		$= P_{avg(5stages)}$ = (∑Slopes(stages A to E)/5 If any stages A to E are reported to “fail” then report “fail”
Average (all 6 stages)		$= P_{avg(6stages)}$ = (∑Slopes(stages A to F)/6 If any stages A to F are reported to “fail” then report “fail”

Note: 1. If any of the loading stages do not complete the full amount of loading cycles because the deformation limit of 1.0% was achieved then Table 5 calculations will not apply. In this situation the average tangential permanent strain slope achieved is used in place of the value from 25k to 50k load cycles.

2. Permanent strain values for any given load cycle are the average of the previous ten readings in the Repeated Load Triaxial Test to account for any noise in the data.

5. REPORTING

Appendix A in the notes gives an example of the detail to be recorded with the RLT test result. Minimum recording requirements are listed below:

- Date tested
- Laboratory report number and contact details to enable raw electronic test results to be supplied if requested
- Material description and identifier
- Average Slope first 5 stages
- Average Slope all 6 stages
- Resilient Modulus for all stages
- Dry/drained or soaked/undrained test
- Dry Density
- Moisture content at end of test and, if applicable, the moisture content before and after soaking shall be reported
- Degree of Saturation at end of test
- Solid density (state whether assumed or measured)