

# **COMMENTARY TO AG:PT/T053 - DETERMINATION OF PERMANENT DEFORMATION AND RESILIENT MODULUS CHARACTERISTICS OF UNBOUND GRANULAR MATERIALS UNDER DRAINED CONDITIONS**

## **PREFACE**

This repeat load triaxial (RLT) test method was prepared by an Austroads Working Group on behalf of Austroads under the Austroads Projects N&T 9529 during 1999/2000. Representatives of Austroads, ARRB Group and industry have been involved in the development and review of this method.

## **FOREWORD**

This test method was developed in response to a need for performance characterisation indices and performance-based specifications for unbound materials. In addition, there was a need to address issues associated with the non-uniformity of current empirical specifications adopted by different Austroads Member Authorities, with a view to developing more uniform national performance-based specifications using a framework based on mechanistic design procedures.

## **SCOPE**

This method covers the determination of both the permanent deformation and resilient modulus of unbound pavement materials with a maximum particle size not exceeding 19 mm using repeated load triaxial equipment incorporating, static confining pressures and external vertical displacement measuring devices, under drained conditions, without pore pressure measurement. The same sample preparation procedure and loading apparatus are utilised to determine both the permanent deformation and resilient modulus properties from a single specimen prepared to a specified density and moisture condition. The permanent deformation determination characterises the vertical permanent strain at three stress conditions using three levels of repeated vertical stress and a static lateral stress. Each stress condition consists of 10,000 repetitions of vertical stress application. The resilient modulus determination characterises the vertical resilient strain response over 66 stress conditions using combinations of applied repeated vertical and static lateral stresses. Based on the test results, stress-dependent characteristics of both permanent strain and resilient modulus for the specimen can be determined.

## **Further Development**

As both permanent deformation and resilient modulus tests results are significantly dependent on the compaction method used, it was decided that only one sample preparation procedure, namely dynamic compaction method, be used in this Standard, with the possibility of including other compaction methods when more reliable field data became available. However, the dynamic compaction method has been found to produce significant differences in the distribution of test specimen density, particularly with the use of a split mould. A future plan is to review the Gyrotory compaction method, which employs a one piece mould, to improve the production of consistent specimens.

Other future plans include further development of the RLT test method to cover special test conditions (e.g. undrained condition with pore pressure measurement) and material conditions (e.g. oversize materials).

# DETERMINATION OF PERMANENT DEFORMATION AND RESILIENT MODULUS CHARACTERISTICS OF UNBOUND GRANULAR MATERIALS UNDER DRAINED CONDITIONS

## 1 REFERENCED DOCUMENTS

The following documents are referred to in this method:

### AS /NZS

1141	Methods for sampling and testing aggregates
1141.3	Part 3: Sampling of aggregates
1152	Specification for test sieves
1289	Methods of testing soils for engineering purposes.
1289.1	Method 1 Preparation of disturbed samples for testing.
1289.2.1.1	Method 2.1.1 Soil moisture content tests—Determination of the moisture content of a soil—Oven drying method (standard method).
1289.5.1.1	Method 5.1.1 Soil compaction and density tests—Determination of the dry density/moisture content relation of a soil using standard compactive effort.
1289.5.2.1	Method 5.2.1 Soil compaction and density tests—Determination of the dry density/moisture content relation of a soil using modified compactive effort.
1289.5.5.1	Method 5.5.1 Soil compaction and density tests—Determination of the minimum and maximum dry density of a cohesionless material – Standard method.
1289.6.4.1	Method 6.4.1 Soil strength and consolidation tests – Determination of compressive strength of a soil. Compressive strength of a specimen tested in undrained triaxial compression without measurement of pore water pressure.
1349	Bourdon tube pressure and vacuum gauges
1545	Methods for the calibration and grading of extensometers
2193	Methods for calibration and grading of force-measuring

## 2 DEFINITIONS

For the purpose of this standard, the following definitions apply:

- a. Laboratory moisture ratio—The ratio of the moisture content of the specimen to the optimum moisture content of the material, as determined by AS 1289.5.1.1, AS 1289.5.2.1 or AS 1289.5.5.1 expressed as a percentage.
- b. Laboratory density ratio—The ratio of the dry density of the specimen to the maximum dry density of the material, as determined by AS 1289.5.1.1, AS 1289.5.2.1, or AS 1289.5.5.1, expressed as a percentage.
- c. Repeated vertical force ( $F_d$ )—The measured vertical force repetitively applied to the specimen via the loading ram, expressed in kilonewtons (kN).
- d. Repeated deviator stress ( $\sigma_d$ ) —The ratio of the applied repeated vertical force to the cross-sectional area of the specimen, expressed in kilopascals (kPa).
- e. Static confining stress ( $\sigma_3$ )—The static pressure applied to the specimen in the triaxial cell, via air/liquid medium, expressed in kilopascals (kPa).
- f. Static vertical stress ( $\sigma_{1s}$ )—The total static stress applied to the top cap of the specimen, including the static confining pressure and other static stresses applied to the loading ram, expressed in kilopascals (kPa).
- g. Vertical permanent displacement ( $\delta_p$ )—The difference between the initial specimen length and the specimen length after a given number of loading cycles measured with no vertical stress and no confining stress, expressed in millimetres.
- h. Vertical permanent strain ( $\epsilon_p$ )—The ratio of the vertical permanent deformation of the specimen to the initial specimen length, expressed as a percentage.
- i. Vertical resilient displacement ( $\delta_r$ )—The maximum difference in specimen length measured during the unloading phase of the applied repeated vertical stress for any given cycle ( $n$ ), viz between the maximum displacement under the applied repeated vertical stress and the minimum displacement during the unloading phase, expressed in millimetres.
- j. Vertical resilient strain ( $\epsilon_r$ )—The ratio of the vertical resilient displacement of the specimen to the current specimen length, expressed as a percentage.
- k. Vertical resilient modulus ( $E_r$ ) —The ratio of the applied repeated vertical stress (in kilopascals) and 10 times the vertical resilient strain (in percentage), expressed in megapascals (MPa).

### 3 APPARATUS

The following apparatus is required:

- a. Repeated loading equipment capable of applying a repeated vertical force of up to 5 kN to the specimen via loading ram/top cap connection of the triaxial cell (see Note 1) and a static confining pressure of up to 500 kPa to the specimen via air/liquid interface in the triaxial cell (see Note 2). A general arrangement of the loading cell is shown in Figure 1. The loading equipment can be fully automated (see Note 3), viz using a computer, control and data acquisition hardware and software to control the application and sequencing of applied stresses to the specimen. The equipment shall meet the following requirements:

- i. The repeated vertical force loading cycle shall have a period of 3 s with rise and fall times of up to 0.3 s and load pulse width of 1 s (see Figure 2).
- ii. The applied repeated vertical stress (which is equal to the repeated vertical force divided by the specimen cross-sectional area) shall be controllable to  $\pm 5$  kPa of the required repeated vertical stress and shall be measured with a device that meets the accuracy requirements of AS 2193 for Grade A testing machines (see Note 3). The device can be located either inside the triaxial cell (internal) or outside the triaxial cell (external), depending on the loading friction specification of the triaxial cell (see Clause 3b and Note 4). If the device is placed internally, its output shall not be affected by the application of confining pressure or the confining pressure medium itself.
- iii. The loading equipment shall be capable of providing at least 40,000 continuous vertical load cycles.
- iv. The static confining pressure shall be controllable to  $\pm 2.5$  kPa of the required applied pressure and shall be measured at the base of the triaxial cell using a device that meets the accuracy requirements of AS 1349 for electronic pressure transducers. There shall be no rippling or upsurge of confining pressure during both loading and unloading periods (see Note 3).
- v. If the loading equipment cannot provide the secondary vertical static force to prevent the lifting up of the loading piston under confining pressure (see Note 1), a rigid cell loading ram/top cap connection in the triaxial cell, in which the cell loading ram is screwed directly into the top loading cap, must be used.
- vi. If the loading equipment can provide the secondary vertical static force to prevent lifting up of the loading piston under the action of confining pressure (see Note 1), a flexible loading ram/top cap connection in the triaxial cell, in which the ball end of the cell loading ram rests in the vee notched top surface of the loading top cap, can be used.

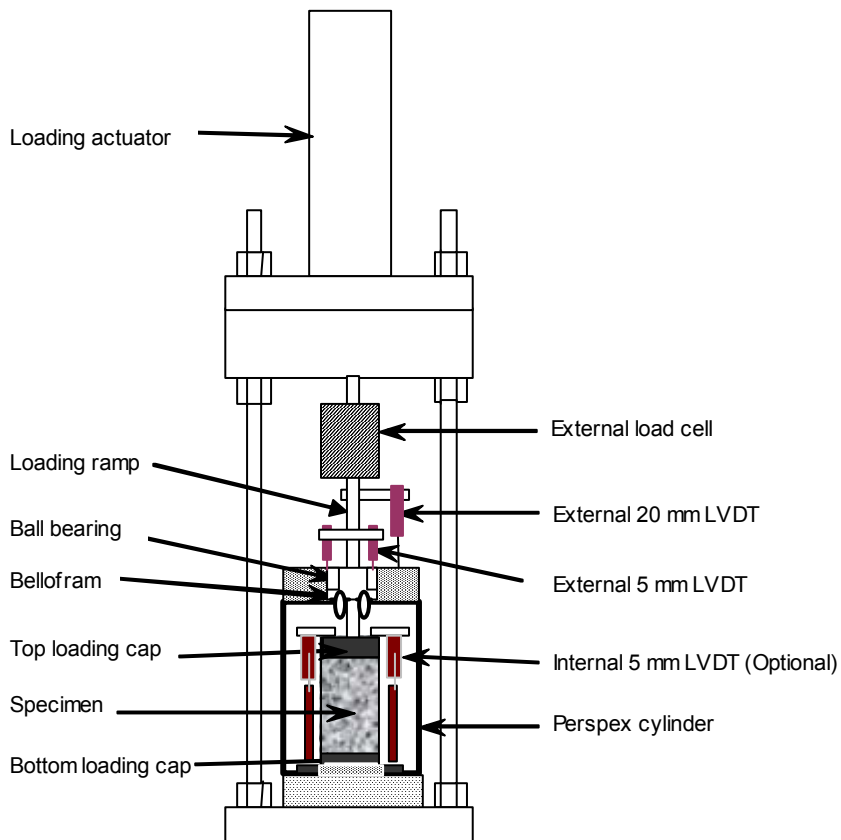


Figure 1 - Schematic of typical repeated load triaxial test apparatus

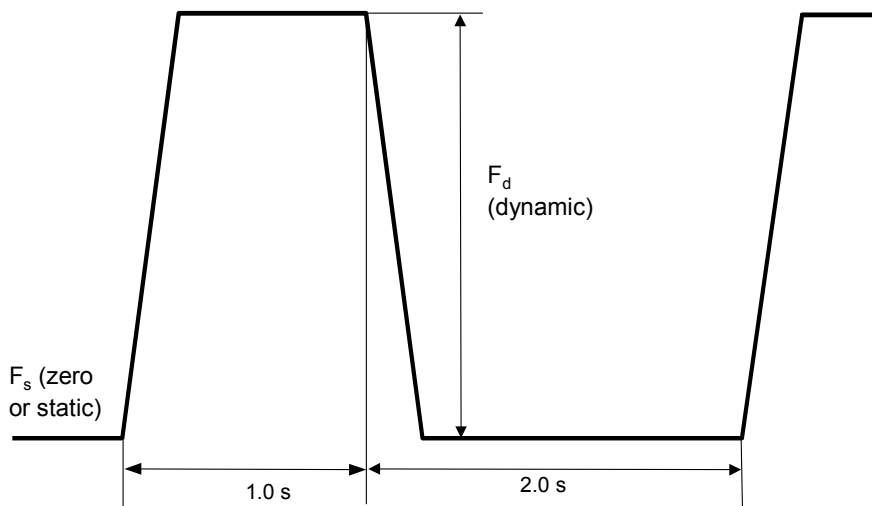


Figure 2 - Illustration of the vertical force waveform

- b. Standard triaxial cell suitable for 100 mm diameter and 200 mm high specimens and with a working pressure of at least 500 kPa shall be used. The cell specifications are dependent on stress and strain measurement methods used. It shall meet the following requirements:
- i. If an external load measurement device is used to measure the applied repeated vertical load, the value of friction for the cell loading ram and guide shall be less than 2% of the applied repeated vertical load (see Clause 3(a)(ii) and Note 4).
  - ii. If an internal load measurement device is used to measure the repeated vertical force, the friction value for the cell loading ram and guide shall be less than 15 kPa or 3% of the applied repeated force, whichever is the lesser (see Clause 3(a)(ii) and Note 4).
  - iii. If an external displacement measurement device is used to measure the vertical resilient displacement under an applied repeated vertical force rather than an internal displacement measurement device (see Clause 3(c)), the displacement of the cell loading assembly under the repeated vertical force shall be less than 30% of the measured external vertical resilient displacement. The displacement of the cell loading assembly shall be measured and reported for correction of the vertical resilient displacement prior to the calculation of vertical resilient strain and vertical resilient modulus (see Note 5 and Clause 11(f)).
- c. Vertical permanent displacement ( $\delta_p$ ) shall be measured using an external displacement measuring device attached to the loading piston and cell cap outside the cell. The device shall have a range of 20 mm and meet the accuracy and repeatability requirements for a Grade B extensometer as defined in AS 1545 (see Note 3).
- d. Vertical resilient displacement ( $\delta_r$ ) shall be measured with two displacement measurement devices each having a working range of 5 mm and meet the accuracy and repeatability requirements for a Grade B extensometer as defined in AS 1545 (see Note 3). The devices shall be attached to the specimen loading cap and cell base pedestal at 180° interval (internal displacement measurement) or to the cell loading ram and cell top outside the cell at 180-degree interval (external displacement measurement). In the case of internal displacement measurement, there is no correction required for the measured vertical resilient displacement. However, in the case of external displacement measurement, the measured vertical resilient displacement is dependent on the displacement of the cell loading assembly used, and therefore a correction factor ( $K_{\text{system}}$ ) is required to account for displacement of the cell loading assembly (see Clause 11f and Note 5).
- e. If the automatic data acquisition system and software are used to record the data and perform calculation of stresses and strains at any loading cycle required during the test (see Clauses 11, 12 and 13), the data acquisition system and software shall be capable of filtering the electrical and mechanical noise levels in the recorded data to less than (i)  $\pm 2$  kPa for vertical stress, (ii)  $\pm 2$  kPa for confining pressure, (iii)  $\pm 5$  micrometres for vertical resilient displacement, and (iv)  $\pm 10$  micrometres for vertical permanent displacement. (see Note 3).

- f. Vernier callipers for measuring the length and diameter of the specimen to an accuracy of  $\pm 0.2\%$ .
- g. Compaction apparatus meeting the requirements of AS 1289.5.1.1, AS 1289.5.2.1, or AS 1289.5.5.1 as applicable (see Note 7).
- h. A cylindrical split metal mould and baseplate capable of producing a specimen  $100 \pm 0.5$  mm diameter and  $200 \pm 0.5$  mm high with a collar of sufficient height to permit the filling of the mould in layers with loose soil prior to compaction.
- i. Seamless rubber membrane(s) in the form of a tube, open at both ends, of internal diameter equal to that of the specimen and length about 50 mm greater than that of the specimen and of 0.25 mm to 0.60 mm thickness.
- j. Membrane stretcher to suit the size of specimen.
- k. Rubber rings of circular cross-section to suit the diameter of the end caps (see also AS 1289.6.4.1).
- l. A balance of at least 10 kg capacity with a limit of performance not exceeding  $\pm 0.5$  g.
- m. Sieves 1.18 mm and 19 mm complying with AS1152.
- n. Sealable containers suitable for curing moist samples.

## 4 TEST CONDITIONS

The following test conditions shall be specified:

- a. The optimum moisture content and the maximum dry density of the material, as determined by AS 129.5.1.1, AS 1289.5.2.1 or AS 1289.5.5.1 and relevant test method by which they are determined.
- b. The moisture ratio of the specimen at the start of the test (see Note 6).
- c. The density ratio of the specimen at the end of the test (see Note 6).
- d. The compaction apparatus, moisture condition, number of layers and compactive effort used to compact the specimen (see Notes 7 and 8).
- e. The confining and vertical deviator stresses to be applied to the specimen for permanent deformation and resilient modulus testing (see Tables 1 and 2, Clauses 8.1 and 9.1 and Note 13)

## 5 SAMPLE

The sample shall be obtained and prepared as follows:

- a. Obtain a bulk sample of the material to be tested in accordance with AS 1141.3.
- b. Prepare the sample in accordance with the appropriate Section of AS 1289.1. Sieve the sample over the 19 mm sieve and discard the material retained on the 19 mm sieve (see Note 9). Report the percentage by mass of the discarded material.

- c. From the sample prepared in Step (b) obtain, by riffing or splitting, a representative subsample of about 5 kg for the compaction of the triaxial specimen. Place the subsample in a sealed container.
- d. If required, obtain at least 300 g from the subsample obtained in Step (c) above for the determination of the subsample moisture content in accordance with AS 1289.2.1.1.
- e. Bring the moisture of the subsample in Step (c) above to the moisture ratio condition at which compaction is to be performed (see Clause 4(b)). Thoroughly mix the subsample and place in a sealed container.
- f. Allow the subsample to cure for an appropriate time for the soil type (see Note 10).

## 6 Preparation of test specimens

Test specimens shall be prepared as follows:

- a. Using the compaction subsample obtained in Step 5(f), compact the soil in the mould to the required density. Unless otherwise specified, the material is to be compacted in 5 layers when using a hammer as described in AS 1289.5.1.1 or 8 layers when using a hammer as described in AS 1289.5.2.1 (see Notes 7 and 8). Proceed as follows:
  - i. Clean the mould and place the collar on its top.
  - ii. Determine the mass ( $m_1$ ) of the mould and collar (with baseplate, if appropriate).
  - iii. Assemble the mould, collar and baseplate and place the assembly on a rigid foundation.
  - iv. Determine the mass of material for each layer to be compacted.
  - v. Check for moisture loss in the compaction subsample prepared in Step 5(f) during curing, before compaction (see Notes 6 and 10). If required, bring the subsample to the moisture ratio condition at which compaction is to be performed (see Clause 4(b)). Thoroughly mix the subsample and place it in a covered tray.(see Note 11)
  - vi. Split sufficient material from the cured compaction subsample to fill the compaction mould and, if required at least another 300 g for moisture content determination.
  - vii. If required, determine the moisture content ( $w_1$ ) of the moisture subsample prepared in Step (iv).
  - viii. For each layer add the mass of soil, as determined in Step (iv), in the mould and compact to the required density level. Compact each layer by uniformly distributed blows of the rammer falling freely from the specified height (300 mm for standard compactive effort or 450 mm for modified compactive effort) (see Note 7). After compaction of each layer, check the accumulated layer thickness to ensure that it does not vary by more than 2 mm from the target accumulative

layer thickness. It is recommended that the top 5 mm of each layer be scarified prior to placing the material for the next layer in the mould.

- ix. The total number of blows will depend on the density and moisture content levels required and the number of layers (see Notes 7 and 8). Specimens that do not meet the requirements of minimum number of blows per layer of 24 blows and minimum layer thickness of 22 mm must be discarded (see Notes 7 and 8).
  - x. Level the material to the top of the mould by means of a straight-edge; smooth the top of the specimen by adding a small amount of fines obtained from the spare material to fill surface irregularities. The fines shall pass a 1.18 mm aperture size sieve complying with AS 1152.
- b. Determine the mass ( $m_2$ ) of the mould, collar and wet specimen, with baseplate if appropriate.
  - c. Remove the specimen from the mould by disassembling the split mould. During the demoulding process ensure that the side and ends of the specimen are not damaged. (see Note 12).
  - d. Measure the length ( $h_s$ ) and three diameters ( $d_s$ ) of the specimen to the nearest 0.5 mm.

## 7 SPECIMEN ASSEMBLY

Proceed with the specimen assembly as follows:

- a. Place the triaxial cell base on the platform of the loading machine.
- b. Open the valve connected to the base pedestal to atmospheric pressure.
- c. Place the specimen centrally on the base pedestal and place the loading cap on top of the specimen. Using the membrane stretcher, place the rubber membrane around the specimen and seal the membrane at both end platens by means of rubber O rings.
- d. For internal displacement measurement, attach the displacement measuring devices to the specimen load cap and base pedestal, so that they operate within their calibrated range and provide optimum displacement (see Note 5).
- e. Assemble the triaxial cell into position ensuring that the cell loading ram is seated centrally in the load cap. For a rigid cell loading ram to top cap assembly, ensure the connecting pin is secure.
- f. For external displacement measurement, attach the displacement measuring devices to the cell loading ram so that they operate within their calibrated range and provide optimum displacement (see Note 5).
- g. Fill the cell, to just above the top loading cap on the test specimen, with the liquid to be used as the confining medium. (For internally mounted displacement measurement devices silicon oil must be used. For externally mounted displacement measurement devices water can be used).

- h. Close the cell base port used to apply the liquid confining medium to the cell.
- i. Open the valve at the top of the cell used to apply static air pressures, to the air void above the liquid confining medium in the cell (see Note 2).

## 8 PERMANENT DEFORMATION TESTING

Unless otherwise specified (see Note 13), the specimen is to be loaded with three stress stages, each involving 10,000 cycles at a stress condition of specified repeated deviator stress and static confining stress. Proceed as follows:

### 8.1 Selection of stress levels for permanent deformation tests

The required values of the repeated deviator stress and static confining stress for the stress stages 1, 2 and 3 are obtained from Table 1 for the following types of materials.

- a. Base materials (0 to 150 mm below the pavement surface)
- b. Upper sub-base materials (150 to 250 mm below the pavement surface); and
- c. Lower sub-base materials (>250 mm below the pavement surface).

Table 1: Stress levels for permanent deformation

Permanent Deformation Stress Levels						
Stress Stage Number	Base		Upper Subbase		Lower Subbase	
	$\sigma_3$ (kPa)	$\sigma_d$ (kPa)	$\sigma_3$ (kPa)	$\sigma_d$ (kPa)	$\sigma_3$ (kPa)	$\sigma_d$ (kPa)
1	50	350	50	250	50	150
2	50	450	50	350	50	250
3	50	550	50	450	50	350

The stress levels in Table 1 cover typical ranges of repeated deviator stress and static confining stress for the purpose of examining the stress dependent permanent strain characteristics of the material to be tested.

NOTE: Other stress levels may be specified for other purposes if required. It should be noted that stress conditions in actual granular pavement layers under rolling wheel loads are very complicated. If the test is to characterise the permanent deformation of a specified pavement layer for the purpose of pavement design, the representative repeated deviator stress ( $\sigma_d$ ) and static confining stress ( $\sigma_3$ ) for laboratory testing condition can be selected to reflect the critical repeated deviator and repeated lateral stresses that cause the maximum permanent deformation rate in the pavement layer concerned under the applied field load. However, the laboratory determined permanent strain must be corrected for the differences between the laboratory static confining stress ( $\sigma_3$ ) and field lateral repeated stress (see Note 13).

### 8.2 Permanent deformation testing

Proceed as follows:

- a. In sequential order, for each of the three stress stages selected, apply and hold the static confining pressure to the specimen, then apply cycles of loading and unloading of the respective repeated vertical stress (see Figure 2) for 10,000 repetitions.

- b. For the first stress stage, record at least 13 reading sets of applied stresses, vertical resilient displacements and vertical permanent displacements at approximately 1, 5, 10, 20, 50, 100, 200, 250, 500, 1000, 2000, 5000, and 10,000 repetitions.
- c. For the second stress stage, record at least 10 reading sets of applied stresses, vertical resilient displacements and vertical permanent displacements at approximately 10,500, 11,000, 12,500, 13,500, 14,500, 15,500, 16,500, 17,500, 18,500 and 20,000 repetitions.
- d. For the third stress stage, record at least 10 reading sets of applied stresses, vertical resilient displacements and vertical permanent displacements at approximately 21,000, 22,000, 23,000, 24,000, 25,000, 26,000, 27,000, 28,000, 29,000 and 30,000 repetitions.
- e. Calculate and report the vertical resilient strain, vertical permanent strain and resilient modulus from the recorded stresses, vertical resilient displacements and vertical permanent displacements (see Clause 11).

## 9 RESILIENT MODULUS TESTING

Unless otherwise specified (see Note 13), the specimen is to be tested under 66 stress stages, each involving at least 50 cycles at the stress condition of specified repeated deviator stress and static confining stress (see Table 2). Proceed as follows:

### 9.1 *Specimen elastic condition*

The specimen shall be in elastic condition prior to each resilient modulus testing stage as follows.

- a. When using the same specimen as used for determination of permanent strain testing, the following conditions shall be met prior to any resilient modulus testing stage:
  - i. the specimen shall have a total permanent strain of less than 1% strain; and
  - ii. the resilient strain shall not substantially increase with increasing loading cycles during any previous permanent strain testing stages, viz the difference between the final and initial resilient strains for each permanent stage shall not be higher than 10% of the initial resilient strain for the stage concerned.

The specimen that does not meet these tolerances must be discarded and a new specimen must be prepared for resilient modulus testing. Do not reuse material from a previously compacted and tested specimen.

- b. During the multiple stress-stage resilient modulus tests, the resilient modulus determined for a repeated stress stage shall not be more than 15% lower than those determined at any previous permanent strain and resilient modulus testing stages with the same stress conditions. The stress stage that does not meet these tolerances must be reported separately and noted as a failure condition. All subsequent stress stages that follow a failure stress stage shall be reported in the same manner.

## 9.2 Selection of stress levels for resilient modulus tests

The required values of repeated deviator stress and static confining stress for the 66 stress stages shall be obtained from Table 2. These stress levels cover ranges of deviator stress, stress ratio and mean stress for the purpose of examining the stress dependent resilient modulus characteristics of the material to be tested. Included within the 66 stress stages, are several duplicate stress states for the purpose of checking the elastic condition of the test specimen throughout the multiple loading stress stages (see Clause 9.1). The loading stages shall be applied in sequential order as shown in Table 2 to reduce the rate of early failure that could occur during the 66-stage testing.

NOTE: Other stress levels may be specified for other purposes if required. It should be noted that stress conditions in actual granular pavement layers under rolling wheel loads are very complicated. If the test is to characterise the resilient modulus of a specified pavement layer for the purpose of pavement design, the representative repeated deviator stress ( $\sigma_d$ ) and static confining stress ( $\sigma_3$ ) for laboratory testing condition can be selected to reflect the average repeated deviator and repeated lateral stresses in the middle of pavement layer under the applied field load. However, the laboratory determined modulus must be corrected for the differences between the laboratory static confining stress ( $\sigma_3$ ) and field lateral repeated stress (see Note 13).

**Table 2: Stress levels for resilient modulus  
(Material ranking and specifications)**

Resilient Modulus Stress Levels					
Stress Stage Number	$\sigma_3$ (kPa)	$\sigma_d$ (kPa)	Stress Level Number	$\sigma_3$ (kPa)	$\sigma_d$ (kPa)
0	50	100	33	40	250
1	75	150	34	30	210
2	100	200	35	40	280
3	125	250	36	50	350
4	150	300	37	75	525
5	100	200	38	40	280
6	50	150	39	20	150
7	75	225	40	30	245
8	100	300	41	40	325
9	125	375	42	50	400
10	150	450	43	30	245
11	75	225	44	20	185
12	40	125	45	30	275
13	30	100	46	40	370
14	40	150	47	50	450
15	50	200	48	30	275
16	75	300	49	20	225
17	100	400	50	30	335
18	125	500	51	40	450
19	75	300	52	50	550
20	30	125	53	20	250
21	20	100	54	30	375
22	30	150	55	40	500
23	40	200	56	20	300
24	50	250	57	30	450
25	75	375	58	40	600
26	100	500	59	30	500
27	50	250	60	20	350
28	30	180	61	30	550
29	50	300	62	20	375
30	75	450	63	30	575
31	50	300	64	20	400
32	30	180	65	20	500

### 9.3 Resilient modulus testing

In sequential order, for each of the 66 stress stages selected, apply and hold the static confining pressure to the specimen, then apply cycles of loading and unloading of the respective deviator stress for pre-conditioning and for the determination of resilient modulus for the stress stage concerned as specified below.

- a. 1000 cycles of pre-conditioning shall be used for the first stress stage applied to a new specimen that has no previous pre-conditioning, and at least 50 cycles pre-conditioning be used for any subsequent loading stage after that first stress stage. When using the same specimen as used for determination of permanent strain (see Clause 9.1.a), at least 50 cycles pre-conditioning be used for any subsequent loading stage after that permanent strain testing.

Note: Pre-conditioning is to be performed for each resilient modulus test to allow the end caps to bed into the specimen and/or to allow the applied stresses and resilient strains to stabilise under the imposed stress condition prior to the measurements of the stresses and strains for the determination of resilient modulus at the stress condition concerned. The number of loading cycles for pre-conditioning to be used for each stress condition will depend on the previous stress history applied to the specimen and the elastic condition of the specimen.

- b. For each cycle after the pre-conditioning stage, record the applied stresses, vertical resilient displacements and vertical permanent displacements for the calculation of resilient modulus (see Clause 11). Continue the application of the loading/unloading cycles until the resilient modulus values determined from the last 'six results' vary by 'less than' 5 percent of the mean value of those six results or until 200 cycles at each stress level have been completed.
- c. Report the last mean values of stresses, vertical resilient strains and vertical permanent strain and resilient modulus.

## 10 SPECIMEN DISASSEMBLY AND POST TESTING

- a. Remove the specimen from the cell.
- b. Determine the moisture content ( $w$ ) of the whole specimen in accordance with AS 1289.2.1.1.
- c. Determine the particle size distribution of the whole specimen in accordance with AS 1141, if required.

## 11 CALCULATIONS

For the specimen, calculate as follows:

- a. The cross-sectional area of the specimen from the following equation:

$$A = \frac{\pi \times d_s^2}{4} \times 10^6 \quad (12.1)$$

where

$A$  cross-sectional area of the specimen, in square millimetres

$d_s$  diameter of the specimen, in millimetres

- b. The dry density ( $\rho_d$ ) of the specimen from the following equation:

$$\rho_d = \frac{(m_2 - m_1)}{A \times h_s} \times \frac{10^5}{(100 + w)} \quad (12.2)$$

where

$\rho_d$	dry density of the specimen, in tonnes per cubic metre
$m_2$	mass of specimen, mould and collar, and baseplate if applicable, in grams
$m_1$	mass of the mould and collar, and baseplate if applicable, in grams
$A$	cross-sectional area of the specimen, in square millimetres
$h_s$	height of the specimen, in millimetres
$w$	moisture content of the specimen, in percent

- c. The measured repeated deviator stress ( $\sigma_d$ ) at the relevant loading cycle, ( $n$ ) from the following equation:

$$\sigma_{d(n)} = \frac{F_{d(n)}}{A} \quad (12.3)$$

where

$\sigma_{d(n)}$	repeated deviator stress for that cycle (see Note 15), in kilopascals
$F_{d(n)}$	measured repeated vertical force applied to the loading ram, in kilonewtons (see Figure 2 for the illustration of the term)
$A$	cross-sectional area of the loading cap or cross-sectional area of the specimen, whichever the lesser, in square metres (see Note 15)

- d. The static vertical stress ( $\sigma_{1s(n)}$ ) at the relevant loading cycle, ( $n$ ) from the following equation:

$$\sigma_{1s(n)} = \frac{F_s}{A} + \sigma_{3s(n)} \times \left[ \frac{(A - a)}{A} \right] \quad (12.4)$$

where

$\sigma_{1s(n)}$	static vertical stress for that cycle (see Notes 14 and 15), in kilopascals
$F_s$	static vertical force applied to the loading ram, including self-weight of the loading ram, friction force in the loading actuator and or secondary force provided by the loading equipment (see Figure 2 for the illustration of the term), in kilonewtons
$\sigma_{3s(n)}$	static confining stress applied to the specimen, in kilopascals (see Note 14)

- A cross-sectional area of the loading cap or cross-sectional area of the specimen, whichever the lesser, in square metres (see Note 15)
- a cross-sectional area of the loading ram or the bellofram seal, whichever the larger, in square metres

e. At the completion of any loading cycle ( $n$ ), the vertical permanent strain ( $\epsilon_p$ ) from:

$$\epsilon_{p(n)} = \frac{(\delta_{4(n)} - \delta_2)}{l_i} \times 100 \quad (12.5)$$

where

- $\epsilon_{p(n)}$  vertical permanent strain at that cycle, in percent
- $\delta_{4(n)}$  vertical displacement with the confining stress ( $\sigma_3$ ) applied and the repeated deviator stress ( $\sigma_d$ ) released, in millimetres (see Figure 3 for the illustration of the term)
- $\delta_2$  vertical displacement when the confining stress ( $\sigma_3$ ) is first applied, in millimetres (see Figure 3 for the illustration of the term)
- $l_i$  initial gauge length, ie. the initial height of the specimen ( $h_s$ ), in millimetres

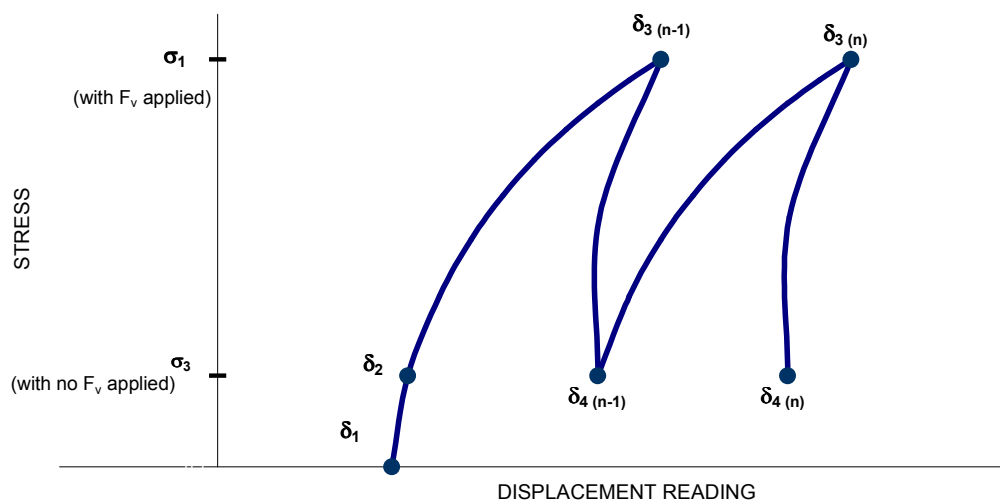


Figure 3 - Illustration of terms

f. The resilient displacement of the specimen at the relevant cycle from the following equation:

$$\delta_{r(n)} = (\delta_{3(n)} - \delta_{4(n)}) - \sigma_{d(n)} \times K_{system} \quad (12.6)$$

where

$\delta_{r(n)}$	vertical resilient displacement of the specimen for cycle $n$ , in millimetres
$\delta_{3(n)}$	measured vertical displacement with the confining stress ( $\sigma_3$ ) applied and the deviator stress ( $\sigma_d$ ) applied, in millimetres (see Figure 3 for the illustration of the term)
$\delta_{4(n)}$	measured vertical displacement with the confining stress ( $\sigma_3$ ) applied and the resilient deviator stress ( $\sigma_d$ ) released, in millimetres (see Figure 3 for the illustration of the term)
$\sigma_{d(n)}$	resilient or repeated deviator stress for that cycle (see Note 15), in kilopascals
$K_{\text{system}}$	constant for correction of system deflection when using external displacement measurement devices ( $K_{\text{system}} = 0$ when using internal displacement measurement devices) (see Clause 3c and Note 5)

- g. The gauge length ( $l_{(n)}$ ) over which the resilient deformation is measured (see Note 16) for the relevant cycle from the following equation:

$$l_{(n)} = l_i - (\delta_{4(n-1)} - \delta_1) \quad (12.7)$$

where

$l_{(n)}$	gauge length over which the deformation is measured for the $n^{\text{th}}$ cycle, in millimetres
$l_i$	initial gauge length, ie. the initial height of the specimen ( $h_s$ ), in millimetres
$\delta_{4(n-1)}$	vertical displacement with the confining stress ( $\sigma_3$ ) applied and the vertical force $F_d$ released for the previous cycle, in millimetres
$\delta_1$	vertical displacement at the commencement of the test with no confining stress ( $\sigma_3$ ) and no vertical force $F_d$ applied, in millimetres (see Figure 3 for the illustration of the term)
$n$	the cycle number

- h. The vertical resilient strain ( $\varepsilon_{r(n)}$ ) of the specimen at the relevant cycle from the following equation:

$$\varepsilon_{r(n)} = \frac{\delta_{r(n)}}{l_{g(n)}} \times 100 \quad (12.8)$$

where

$\varepsilon_{r(n)}$	vertical resilient strain, in percent
$\delta_{r(n)}$	vertical resilient displacement of the specimen for cycle $n$ , in millimetres

$l_{(n)}$  gauge length over which the deformation is measured for that cycle in millimetres

- i. The resilient modulus ( $E_{r(n)}$ ) at the  $n$ th cycle from the following equation:

$$E_{r(n)} = \frac{\sigma_{d(n)}}{10 \times \varepsilon_{r(n)}} \quad (12.9)$$

where

$E_{r(n)}$  resilient modulus at that cycle, in megapascals

$\sigma_{d(n)}$  repeated deviator stress at that cycle, in kilopascals

$\varepsilon_{r(n)}$  vertical resilient strain at that cycle, in percent

## 12 RECORDED INFORMATION AND TEST RESULTS

### 12.1 Raw data

The following raw (unprocessed) data for the outputs of all the measurement devices shall be recorded in a completed test.

- a. One full cycle at the beginning and one full cycle at the end of the test, both with no confining pressure and no repeated deviator stress (to enable checking of the drifts in the outputs of the measurement devices if required).
- b. The loading apparatus, triaxial cell configuration and data acquisition system that meet the requirements as specified in Clauses 3a, 3b, 3c, 3e and 3f.
- c. The calibration factors of all measurement devices and date of the calibration tests (see Clauses 3a, 3b, 3c and 3d).
- d. The correction factors for system stiffness if required (see Clause 3c).

### 12.2 Permanent deformation results

For each reading set required in the permanent strain testing (see Clause 8), the following results shall be recorded:

- a. Cycle number ( $n$ ).
- b. The average measured total vertical and static confining stress values  $\sigma_1$  and  $\sigma_3$  in kilopascals.
  - i. The average measured repeated deviator stress values  $\sigma_d$  in kilopascals.
  - ii. Permanent strain  $\varepsilon_{p(n)}$  in percent.
- c. Resilient strain  $\varepsilon_{r(n)}$  in percent.
- d. Resilient modulus  $E_{r(n)}$  in megapascals.

### 12.3 Resilient modulus results

For each stress level number selected in the resilient modulus testing (see Clause 9), the following results shall be recorded:

- a. The number of cycles ( $n$ ).
  - i. The average measured total vertical and static confining stress values  $\sigma_1$  and  $\sigma_3$  in kilopascals for the last six cycles.
  - ii. The average measured repeated deviator stress  $\sigma_d$  in kilopascals for the last six cycles.
- b. Average resilient strain  $\varepsilon_r$ , in percent, for the last six cycles.
- c. Average resilient modulus  $E_r$  in megapascals, for the last six cycles.
- d. If required, the vertical permanent strain  $\varepsilon_p$ , in percent for the last cycle.

## 13 TEST REPORT

### 13.1 General

The following information shall be reported:

- a. The type and source of the material
- b. The percentage of material larger than 19 mm, if applicable.
- c. Reference to this Standard i.e. AG:PT/T053
- d. The specified and as-tested laboratory density ratio and laboratory moisture ratio to the nearest 0.1%, together with the optimum moisture content and the maximum dry density of the material.
- e. The as tested initial and final moisture contents of the test specimen to the nearest 0.1%.
- f. If a method of compaction or number of layers other than those shown in Clause 6, the method of compaction of the specimen, the number of layers compacted and the number of blows per layer.

### 13.2 Permanent deformation test

The following information and test results shall be reported:

- a. For each applied stress combination,
  - i. the cycle number ( $n$ );
  - ii. the nominal repeated deviator stress ( $\sigma_d$ ) and static stress values  $\sigma_1$  and  $\sigma_3$  applied to the specimen to the nearest 1 kPa;
  - iii. the permanent strain  $\varepsilon_{p(n)}$  to the nearest 0.01%; and

- iv. if required, the resilient modulus  $E_{r(n)}$  to the nearest 1 MPa.
- b. If required, plots of the permanent strain ( $\epsilon_{p(n)}$ ) and resilient modulus ( $E_{r(n)}$ ) as a function of the cycle number (n).

### 13.3 Resilient modulus test

The following information and test results shall be reported:

- a. For each applied stress combination—
  - i. the final loading cycle (n) of the loading stage;
  - ii. the average, static confining stress value  $\sigma_3$  applied to the specimen to the nearest 1 kPa;
  - iii. the average repeated deviator stress ( $\sigma_d$ ) applied to the specimen to the nearest 1 kPa;
  - iv. the average resilient modulus ( $E_r$ ) to the nearest 1 MPa; and
  - v. if required, the final permanent strain of the loading stage to the nearest 0.01%.
- b. If required, plots of the average resilient modulus as a function of the applied stresses.

#### NOTES:

1. **Repeated Loading Equipment:** Repeated loading equipment that can only provide control of the repeated force  $F_d$ , with no control of static vertical force  $F_s$ , is only suitable for a rigid cell loading ram/top cap connection in the triaxial cell, where the cell loading ram is screwed directly into the top loading cap to prevent separation of the cell loading ram/top cap under the action of confining pressure. It should be noted that friction in the vertical load actuator can cause fluctuation in the repeated force and instability in the static vertical force, which in turn can affect the accumulation of permanent strain over numerous loading cycles. A means of checking the repeated force and static force of an actuator is to record the raw (unprocessed) voltage output of the load cell continuously over many loading cycles. The static force at a given cycle is calculated based on the difference between the voltage output of the load cell at the unloading stage of the cycle concerned and the initial voltage output of the load cell at the start of the experiment. Therefore, it is important that, for this type of repeated loading equipment (with no control of vertical static force), the seating stress (= static vertical force/area of loading cap) shall be less than 5 kPa and remain constant throughout the test (see References 1 and 2).

Where a flexible loading ram/top cap connection in the triaxial cell is used, in which the ball end of the cell loading ram rests in the vee notched top surface of the loading top cap, the repeated loading system shall provide, in addition to the applied repeated force, a secondary static force  $F_s$  throughout the duration of the test to ensure the cell loading ram is firmly in contact with the top loading cap at all times.

The contribution of the static cell pressure to the static vertical stress will be dependent on the repeated loading equipment and loading ram/top cap connection used. The

formula given for static vertical stress  $\sigma_{1s}$  (see equation 12.4) is for all repeated loading equipment and loading ram/top cap connections. It takes into account the effective vertical static force applied to the specimen by the static cell pressure and the static force applied by the loading actuator, including the self-weight of the loading ram and the friction force in the loading actuator or the secondary static force provided by the loading equipment. (The effective static vertical force applied on the specimen by the static cell pressure is dependent on the cross sectional area of the cell loading ram and the cross sectional area of the bellofram seal, where fitted).

2. **Confining medium:** A two component medium, air/liquid, is used to apply static confining pressures, with the liquid, either water or silicon oil, level being just above the top loading cap level. The incompressible liquid component prevents air diffusing through the rubber membrane, and acts as a means for checking leakages during the test. The air component of the confining medium acts as a damper to minimising and cushion the pulsing effect of the static confining pressure due to volume displacements caused by movement of the bellofram seal and/or loading ram in and out of the triaxial cell.
3. **Automatic loading apparatus and data acquisition system:** It is recommended that an automatic loading apparatus and data acquisition system be used to simplify the operating procedures, reduce the operating cost and eliminate operator errors. In principle, it requires a computer, control and data acquisition hardware and software, and electrical/electronic measurement devices to:
  - i. control the application and sequencing of applied stresses to the specimen
  - ii. record the data, to the required accuracy, from the load, pressure and displacement measuring devices in a full loading cycle (see Figure 2)
  - iii. calculate stresses, strains and resilient modulus during the test, at any loading cycle required, (see Clauses 11, 12 and 13).

Requirements for automatic loading apparatus and data acquisition systems are specified in References 1 and 2.

The performance of an automatic loading system relies on the quality of all electrical/electronic measurement/control devices. Generally, a loading test can last up to several days; therefore it is important that the electrical/electronic measurement/control devices produce stable and repeatable outputs throughout the test. Temperature drift and electrical noise in the outputs of the load and pressure measuring devices can produce significant errors in the applied stresses. A means of checking the drifts and noise in the outputs of these devices is to record their raw (unprocessed) data continuously over a long period up to several days. Generally, significant initial drifts can be reduced if all electrical and electronic equipment and measurement devices are switched on and allowed to warm up for about 30 minutes prior to commencing a test. Load and pressure measurement devices, which show long-term drifts (>2 kPa/day) and high electrical noise levels (>4 kPa) after the warm-up period shall not be used. It is also recommended that raw data at the beginning and at the end of the test (with no vertical load and no confining pressure) be recorded and used to quantify the drifts and noises in the outputs of the devices (see Clause 12.1).

Filtering techniques can be incorporated in the data acquisition/processing software to filter high-frequency electrical noise in the measurement devices, without distorting the actual the stress and strain pulses. Generally, the noise levels can be significantly reduced, but the wave shape and the peak and base values of the stress and strain pulses can be distorted if they are heavily filtered. A means for checking the effectiveness of the filtering technique is to compare the raw (unprocessed) data with the filtered data (see References 1 and 2). It is desirable that the filtered outputs of the measurement devices with no vertical load and no confining pressure should be within (i)  $\pm 2$  kPa for vertical stress, (ii)  $\pm 2$  kPa for confining pressure, (iii)  $\pm 5$  micrometres for vertical resilient displacement, and (iv)  $\pm 10$  micrometres for vertical permanent displacement.

4. **Loading Friction:** Loading friction at the cell loading ram/triaxial cell top interface prevents unimpeded application and removal of the applied vertical load to the specimen during loading and rebound of the specimen during unloading. It contributes significant errors to the controlled and measured repeated vertical load and can also cause noise and instability in the loading system, which contribute errors to the measured resilient modulus and permanent strain.

Triaxial cells that use a linear bearing and bellofram seal at the interface may produce a coefficient of friction at the cell loading ram/triaxial cell top interface of less than 0.5%. In using this type of cell, the load measurement device can be attached to the cell loading ram outside the cell. Triaxial cells that use a brass bushing and an O-ring seal may produce higher and variable coefficients of friction. In using this type of cell, the load measurement device shall be attached on the cell loading ram inside the triaxial cell. In the latter case, the device output shall not be dependent on confining pressure. Cells with high and variable loading friction shall not be used in a rigid loading system.

Triaxial cells that produce high loading friction at the cell loading ram/cell top interface such as those incorporating a bronze bushing and O-ring seal(s) shall not be used in a rigid loading system (References 1 and 2).

For both rigid and flexible cell loading ram/top loading cap connections (see Figure 1), the ball end of the load actuator shall rest on the flat top surface of the cell loading ram in order to minimise any sideways force applied to the cell loading ram, and hence reducing the loading friction at the cell loading ram/triaxial cell top interface.

5. **Correction for cell displacement under repeated loading:** The formula given for vertical resilient displacement  $\delta_{r(n)}$  at the nth cycle (see equations 12.6) is for both internal and external displacement measurement methods.

For internal displacement measurements, which are independent of the system strain (or cell stiffness), no correction will be required (ie. the correction factor for system displacement  $K_{\text{system}}$  is zero).

For external strain measurement method, the measured vertical resilient displacement under a given applied repeated deviator stress includes both the displacements in the loading system and in the specimen.

$$\delta_{\text{measured}} = \delta_r + \delta_{\text{system}}$$

where

$\delta_r$	vertical displacement of the specimen, in millimetres
$\delta_{\text{measured}}$	measured vertical resilient displacement using external displacement devices, in millimetres
$\delta_{\text{system}}$	vertical resilient displacement of the system under the applied deviator stress, in millimetres

Therefore, the vertical resilient system displacement shall be measured for the correction of the measured vertical resilient displacement to the measured vertical resilient displacement.

A method for measurement of system displacement (or system modulus) under repeated loads is given in References 1 and 2. In this method, three dummy specimens (comprising of proving rings of known stiffness) are tested using the same procedure of resilient modulus testing of actual specimens. It is important that the strain measurement devices are mounted on the cell loading ram at the same fixed distance, from the top surface of the reference specimens, for all three reference specimens, as varying distances may influence the determination of the system displacement (system modulus). From the loading test of each elastic reference specimen, the measured modulus of the reference specimen can be determined (without correction of system deflection) as:

$$E_{\text{measured}} = \sigma_d / \varepsilon_{\text{measured}} = (F_d / A) / (\delta_{\text{measured}} / L)$$

where

$F_d$	repeated deviator force, in kilonewtons
$A$	area of the loading cap, in square millimetres
$L$	specimen gauge length (preferably to be 200 mm), in millimetres
$\sigma_d$	repeated deviator stress ( $F_d / A$ ), in kilopascals
$\delta_{\text{measured}}$	measured resilient vertical displacement
$\varepsilon_{\text{measured}}$	measured vertical resilient strain ( $\delta_{\text{measured}} / L$ )

Each reference elastic specimen has a known vertical elastic modulus,  $E_r$ , which is defined as

$$E_r = \sigma_d / \varepsilon_r = (F_d / A) / (\delta_r / L)$$

where

$\varepsilon_r$	resilient vertical strain of the specimen ( $\delta_r / L$ )
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Similarly, the system modulus,  $E_{\text{system}}$ , can be defined as:

$$E_{\text{system}} = \sigma_d / \varepsilon_{\text{system}} = (F_d / A) / (\delta_{\text{system}} / L)$$

where

$\varepsilon_{\text{system}}$	resilient vertical strain of the system ( $\delta_{\text{system}} / L$ )
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From the measured resilient modulus and the known modulus of the elastic specimen, the system modulus can be determined as:

$$E_{\text{system}} = (E_r \cdot E_{\text{measured}}) / (E_r - E_{\text{measured}})$$

Thus, the system deflection can be calculated as:

$$\delta_{\text{system}} = L / E_{\text{system}} \cdot \sigma_d$$

6. **Specimen moisture and density ratios:** As both permanent deformation and resilient modulus test results are significantly dependent on the density and moisture condition of the specimen (References 1 and 2), it is important that the specimen should have the target moisture and density ratios. It has been found that experienced operators can prepare specimens within the tolerances of  $\pm 0.5\%$  for density ratio and  $\pm 5\%$  for moisture ratio using the dynamic compaction method. Nevertheless, such differences in density and moisture ratios can significantly affect the test results of permanent strain and resilient modulus. Therefore, it is recommended that:

If the test is performed at a single density and moisture combination, at least two specimens prepared to the target density and moisture ratios shall be tested to check the repeatability of the test results. The average values and the maximum differences of density ratio, moisture ratio, permanent strain and resilient modulus between tested specimens shall be reported.

If multiple tests are performed at different density and moisture conditions to obtain a full characterisation of the material for the purpose of material ranking and specifications, one specimen per density and moisture combination is required. (For material characterisation, it is recommended that testing is conducted at a minimum of three (3) moisture and three (3) density conditions)

7. **Compaction apparatus:** As both permanent deformation and resilient modulus tests results are significantly dependent on the compaction method used (References 1 and 2), it is important that different rammers (eg. the standard 2.7 kg rammer at 300 mm drop height as described in AS 1289.5.1.1 and the modified 4.9 kg rammer at 450 mm drop height as described in AS 1289.5.2.1), rammer distribution, numbers of layers and number of blows per layer used to achieve the target moisture and density ratios shall be reported.

When specimens are compacted with the modified 4.9 kg rammer at 450 mm drop height, the larger particles of the material may break down to a greater extent than is likely in a road construction process. It has been found that the standard 2.7 kg rammer at 300 mm drop height may allow less material breakdown. However, it requires a higher number of blows per layer to achieve the specified compaction effort.

It is essential that the rammer shall be moved evenly around the layer surface to produce uniform compaction. The automatic (mechanical) compaction apparatus permits a continuous and even compaction mode, viz. 8-10 locations around the periphery of the mould. However, it is more difficult to compact a uniform specimen using hand held compaction apparatus. A non-uniform specimen would tend to produce higher permanent deformation and lower resilient modulus (Reference 2). Therefore, when using the hand compaction equipment, care shall be taken to ensure uniform rammer distribution around the periphery of the mould, by marking the compaction locations and applying a continuous compaction pattern as that applied by automatic compaction equipment.

8. **Determination of number of layers and number of blows per layer:** If the specimen is to be compacted to maximum dry density at optimum moisture content as determined in accordance with AS 1289.5.1.1 (standard compactive effort of  $569 \pm 14$

kJ/m<sup>3</sup>) or AS 1289.5.2.1 (modified compactive effort of 2703 ± 60 kJ/m<sup>3</sup>) the number of blows to be delivered to each layer can be calculated from:

$$N_c = \frac{E_c \times V}{M_r \times H_d \times g \times N}$$

where

$N_c$	number of blows per layer
$E_c$	compactive effort, in kilojoules per cubic metre
$V$	volume of the mould, in cubic centimetres
$M_r$	mass of the rammer (2.7 kg standard, 4.9 kg modified)
$H_d$	drop height of the rammer (300 mm standard, 450 mm modified)
$N$	number of layers (5 standard, 8 modified)
$g$	acceleration due to gravity (9.80665)(m/s <sup>2</sup> )

The requirements of layer thickness and number of blows adopted in AS 1289.5.1.1 and AS 1289.5.2.1 can be applied to the compaction of the triaxial specimen to allow uniform compaction across the cross-sectional area and with depth as follows.

- the layer thickness shall not be less than 22 mm and not more than 50 mm for materials of 19 mm nominal size
- the number of blows shall not be less than 24 blows per layer.

Thus, if using a standard mould for the triaxial specimen (nominal volume of 1571 cm<sup>3</sup>), it requires 24 blows of standard 2.7 kg rammer at 300 mm drop height per layer to compact the specimen to the standard compaction effort (606 kJ/m<sup>3</sup>) in 5 layers, or 25 blows of 4.9 kg rammer at 450 mm drop height to compact the specimen to the modified compaction effort (2752 kJ/m<sup>3</sup>) in 8 layers.

If the specimen is to be compacted at other than the maximum dry density and/or optimum moisture content, suitable changes to the standard/modified rammer, the number of layers and number of blows per layer shall be adjusted to meet requirements of minimum layer thickness and minimum number of blows as specified above. However, over-compaction (say greater than 3 times the modified compaction effort) should be avoided to prevent degradation of the specimen (see Note 7). Drying and wetting the compacted specimen to the specified moisture content may be used to reduce over-compaction. In these latter cases, the initial moisture content of the compacted specimen should be as close as possible to the specified moisture content and the specimen shall be cured for an appropriate time for the soil type (see Note 10) before testing. The initial moisture content, final moisture content, method of drying/wetting and final grading of the compacted specimen should be reported.

9. **Oversize material:** If the sample contains more than 5% by mass of material retained on the 19 mm aperture sieve, the test result might not be representative of that obtained from testing the bulk material. Where oversize material is included in a compacted test specimen, the percentage of that oversize material contained within the specimen shall be reported.

10. **Mixing and curing:** It is important that the water is thoroughly mixed into and uniformly distributed through the soil since inadequate mixing gives rise to variable results. It is desirable to keep the mixed soil in a sealed container to allow the water to become more uniformly distributed through the soil before compaction. For materials of low plasticity and high permeability prepared in a moist condition close to optimum moisture content, little or no curing is required, but if the soil is completely dry and contains heavy clay, up to 7 days' curing prior to compaction may be required. The more cohesive a soil, the more time required for moisture to infiltrate and equilibrate throughout the sample.
11. **Moisture Loss:** Moisture loss may cause variation in the number of blows required to compact the specimen to a specified density. It is important that the subsample should be covered during the compaction process to maintain its moisture content to the specified level.
12. **Demoulding specimens:** Extruding force should be reduced, if not totally eliminated during demoulding process. It is recommended that either a two-piece or three-piece split mould with a thin lining of wax, be used, so that the specimen can be removed from the mould without damage.

For non-cohesive material, the specimen is likely to collapse after extrusion from the mould. The mould may be lined with a rubber membrane to hold the specimen together after extrusion. Corrections for the mass and volume of the membrane shall be made. If the membrane is punctured during compaction, a second membrane will be required for the test. To reduce handling, the specimen should be placed on the base of the test apparatus prior to demoulding.

13. **Selection of stress levels for permanent strain and resilient modulus tests:** Other stress levels may be specified if required. However, it should be noted that the repeated stresses (in both vertical and lateral directions) in actual granular pavement layers under rolling wheel loads are very complicated and can be different from the laboratory stress conditions, which only simulate repeated vertical stress and static confining stress combinations.

It should also be noted that different pavement design procedures may have different origins, in terms of the sources of field performance data and procedures used in the determination of design parameters (eg. elastic layer modulus, design axle load, consideration of reliability factors, etc). If the test is to characterise the permanent strain and resilient modulus of a specified pavement layer for the purpose of pavement design, the following information should be appended to the test report:

- the pavement design procedures adopted (eg. the AUSTRROADS mechanistic pavement design procedures)
- the procedures for selecting representative laboratory stress conditions (eg. using structural analysis with the linear elastic layer model CIRCLY and assumptions made in the analysis)
- the relationships between laboratory results of permanent strain and resilient modulus and the design parameters (related to layer modulus and permanent deformation) and observed/predicted pavement life.

14. **Membrane correction:** Where significant axial strains occur (i.e. >2%) or multiple membranes are used, membrane corrections may be significant and should be applied to the calculation of the static vertical stress ( $\sigma_{1s}$ ) and confining stress in accordance with Reference 3.
15. **Area correction:** For specimens which suffer significant vertical and lateral deformation (i.e. >2%)(such as specimens prepared near OMC), an area correction (AS 1289.F4.1) should be applied to accurately calculate both vertical static stress  $\sigma_{1s}$  and repeated vertical stress  $\sigma_d$ , if the specimen diameter is smaller than the loading cap diameter.
16. **Specimen length:** To determine the resilient strain, and hence resilient modulus, in real time, the gauge length used for modulus determination at any cycle (n), is the gauge length at the completion of the previous cycle (n - 1).

#### **Further reading**

- 1) AUSTRROADS Pavement Reference Group (1997). A summary report on inter-laboratory precision study of permanent strain and resilient modulus testing conducted by the APRG Working Group of RLTT Users (AWGRU). APRG Document 97/01 (MA).
- 2) Vuong, B.T. and Tepper, S.B. (2000). 1998-99 Inter-laboratory precision study of permanent strain and resilient modulus testing conducted by AWGRU. APRG Document 00/32 (MA).
- 3) HEAD, K.H. Manual of Soil Laboratory Testing, Vol. 2, London, Pentech Press, 1982. Paragraph 13.3.8.

## AMENDMENT RECORD

Amendment No.	Clauses amended	Action	Date
1	Method adapted from APRG Report 00/33 MA dated June 2000	New	September 2007

### Key

Format	Change in format
Substitution	Old clause removed and replaced with new clause
New	Insertion of new clause
Removed	Old clauses removed