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Repeated Load Triaxial Testing on Unbound Pavement Materials

Kejing Chen
B.E., M.E., Ph.D
Senior Engineer
Golder Associates, Cairns, Australia
Formerly Engineer, Department of Transport, Tasmania

Summary This paper presents an investigation on three unbound pavement materials typically used in Tasmania. The three base course materials were selected according to their field performance varying from good to poor. The assessments on the quality of these materials were undertaken using both conventional methods (eg. grading and CBR) and repeated load triaxial testing (RLTT). The results showed that the conventional methods may not always identify some poorly performed materials. However, the repeated load triaxial testing is able to identify the poorly performed materials in terms of permanent strain and it provides material assessments consistent with observed field performance.

1. INTRODUCTION

The base course materials used for a flexible pavement are normally unbound granular materials. The strength and durability of these materials are conventionally assessed through a soaked California Bearing Ratio (CBR) test and wet/dry strength test. The loading regimes of these tests are not compatible with the in-situ stress condition; hence the test data may not fully reflect the field behaviour of pavement materials. Repeated Load Triaxial Testing (RLTT) allows the unbound pavement materials to be tested under the loading conditions similar to those of in-situ materials. Hence, this method provides an opportunity for better understanding of the behaviour of granular pavement materials.

Repeated Load Triaxial Testing (RLTT) has been adopted as a standard method (eg AASHTO T 294-92 and AS 1289.6.8.1-1995) to characterise the mechanical properties of the pavement materials. This approach is also useful in ranking materials and in carrying out the specific studies on behaviour of granular materials (Chen, 1997, 1998). Two key parameters that derive from RLTT are:

1) Resilient modulus – which controls the load spreading ability of a pavement; and

2) Permanent strain – which relates to the development of rutting in a pavement.

The resilient modulus is also a critical parameter used in the mechanistic pavement design (Austroads, 1992).

Unbound flexible pavement comprises the majority of Tasmania's National/State Highways and rural Main Roads. A lot of instances of pavement distress, including premature failures and new pavement flushing (Chen, 1998), are associated with the behaviour of base/subbase materials. The cause of the distress is often not clear and it has been a controversial topic amongst road designers, contractors and maintenance staff. RLTT will provide a new horizon to this issue and help promote our knowledge on unbound pavement materials.

A preliminary testing program on three typically used local quarry materials has been concluded. Some of the findings and their implications will be presented in this report.

2. MATERIALS

Three Base A (BA) quality materials of different source, referred to as BA1, BA2 and BA3, were selected based on their field performance, being ranked as good, fair and poor. BA1 is one of the best performed materials across the State. BA2 and BA3 are recognised as fair and poor local materials. However, all these materials are 20mm fine crushed rock (FCR) and generally comply with the specifications of Base A quality materials. BA1 and BA2 are dolerite and BA3 is basalt.

The grading curves of these materials are shown in Figure 1. They generally conform to the grading requirements as indicated in the figure.

Some of mechanical properties of the materials and the relevant quality requirements are summarised in Table 1. The maximum dry unconfined compressive strength (MDUCS) is one of parameters used to define the material strength. The wet strength and wet/dry strength variation are used to describe the material durability. It can be seen that all the materials appear to have a adequate strength and

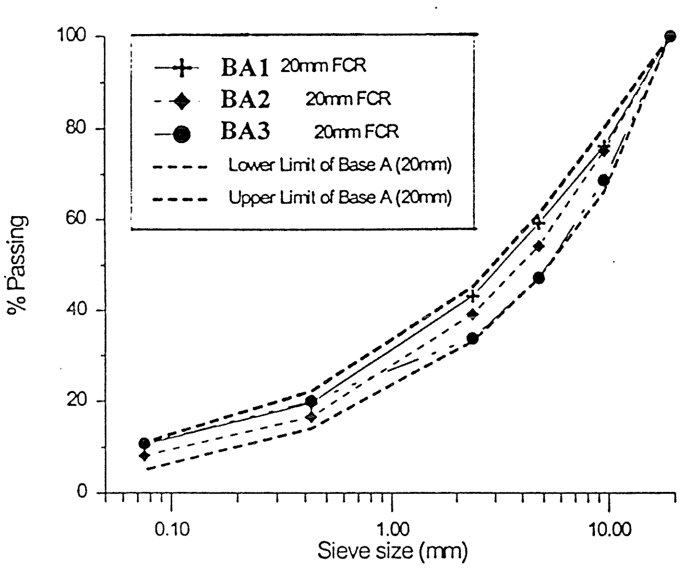

Figure 1. Grading of three materials.

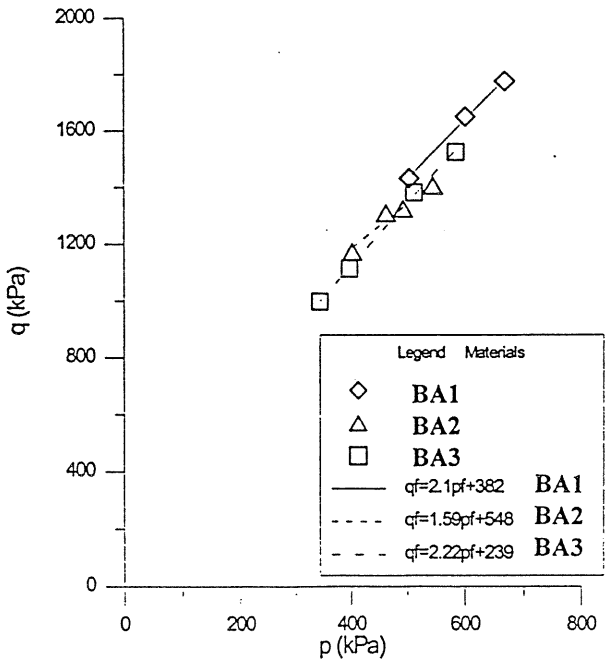

Figure 2. Monotonic strength.

Table 1. Mechanical properties of materials.

Materials	BA1	BA2	BA3	Quality requirement (DoT Tas)
MDUCS (MPa)	3.38	3.16	3.81	1.5 (Min)
Wet strength (kN)	316	229	271	100 (Min)
Wet/dry strength variation (%)	13	31	25	35 (Max)

Notes: MDUCS = Maximum dry unconfined compressive strength.

durability. The BA3 material has the highest MDUCS, and the BA1 material has the best durability.

The material strengths under monotonic loading have been determined by the Texas Triaxial Compression Tests (Texas Highway Department's Test Method S17-70 or DMR NSW's Test Method T171). The results of the Mohr's failure envelopes are presented in q-p graph in Figure 2. It can be seen that all three materials have competitive monotonic strength although the strength of BA1 material appears slightly higher. The monotonic strength data will be used to determine a *proximity index*, defined as the ratio of (repeated) shear stress to (monotonic) strength (Chen, 1997). The proximity index governs the material response to a repeated load.

3. REPEATED LOAD TRIAXIAL TESTING

3.1 Apparatus

The repeated load triaxial tests were conducted on UTM-5P, an apparatus manufactured by Industrial Process Controls Ltd (IPC), Melbourne, and installed and commissioned at the Materials and Research Laboratory of the Department of Transport, Tasmania. The apparatus is a close-loop, fully automatically controlled data acquisition system specially developed for use by State Road Authorities and industrial organisations. It has a capacity to test granular materials under a loading regime simulating road traffic.

3.2. Specimen Preparation

The modified compaction test results are presented in Table 2. All three materials seem to have a similar optimum moisture content of approximately 7%.

All the specimens were prepared at a nominal moisture content of 80% of the OMC. Actual moisture contents and the dry density achieved for the modified compaction are listed in Table 3.

Table 2. Results of modified compaction.

Materials	BA1	BA2	BA3
MDD (Mod) t/m^3	2.44	2.40	2.47
OMC, %	7.0	7.0	6.9

Notes: MDD = Maximum dry density, OMC = Optimum moisture content.

Table 3. Achieved moisture content ratio and density ratio (mean±std dev).

Materials	BA1	BA2	BA3
Moisture ratio (%)	80.4±1.3	80.2±3.4	82.4±2.7
Density ratio (%)	99.3± 0.7	98.3±0.5	97.9±0.2

Notes: Moisture ratio = the ratio of moisture content to OMC, density ratio = the ratio of dry density to MDD.

3.3 Definitions

Permanent strain (ε_p) and Resilient strain (ε_r)

The definitions of these two strains can be best illustrated in Figure 3. For a given number of loading cycles, N, the permanent strain is simply the strain remaining after unloading, whereas the resilient strain is the rebound strain due to unloading.

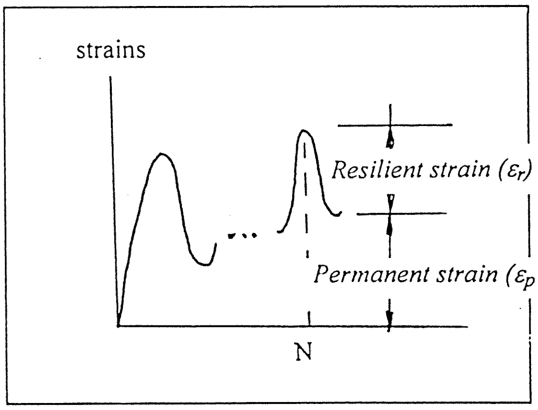

Figure 3. Definition of strains.

Resilient modulus

The resilient modulus is defined as:

$$E_r = \Delta\sigma/\varepsilon_r \qquad (1)$$

where $\Delta\sigma$ = magnitude of repeated axial stress.

Shear stress/strength ratio

The shear stress/strength ratio is defined as:

$$\text{Shear stress/strength ratio} = q_{max}/q_f \qquad (2)$$

where q_{max} = the maximum deviator stress applied to a specimen;
q_f = failure strength.

3.4 Test Program

As detailed in Table 4, the resilient modulus tests were carried out under the same loading regime. This regime consists of a series of stress levels varying from 20 to 450 kPa for the confining pressure and from 110 to 840 kPa for vertical stress. At each level, number of repetitions varied from 51 to 200. The total counts for each resilient modulus test was greater than 7000.

For the permanent strain tests, the magnitude of repeated load was fixed to one level for each test. Three tests with stress levels of q_{max}/q_f = 0.5, 0.74 and 0.9 were adopted. A total of 10000 counts of repeated load was applied for each test.

Table 4. Stress levels and number of pulses.

Type of Test	σ_3 (kPa)	σ_1 (kPa)	No of pulses
Resilient modulus	20-450	110-840	50-200 each stress level
Permanent strain			
q_{max}/q_f=0.50	120	370	
q_{max}/q_f=0.74	120	500	10000
q_{max}/q_f=0.90	120	500	

4. RESULTS

4.1 Effect of Shear Stress Level (q_{max}/q_f)

The effect of shear stress level on the strain response are presented in Figure 4 for tests on BA1 materials. As shown in Figures 4:

1) For the tests conducted with a shear stress/strength ratio of 0.5, both the permanent strain and resilient strain become settled as N increased.

2) For the tests carried out under a shear stress/strength ratio of 0.74, the permanent and resilient strain response was generally stable for N up to 100 and started acceleration from N=1000.

3) For the tests carried out under a shear stress/strength ratio of 0.9, the permanent and resilient strain response was unstable right at the beginning and started acceleration from N=100.

As reported by Chen (1997), there exists a transition value (=0.7) of the shear stress/strength ratio. Under the repeated loading, materials become progressively compressed (denser) when shear stress/strength ratio is less than 0.7 and become progressively dilated (looser) when this ratio exceeds 0.7. The observations made from Figure 4a are likely governed by the material features of compression/dilation in relation to the shear stress/strength ratio.

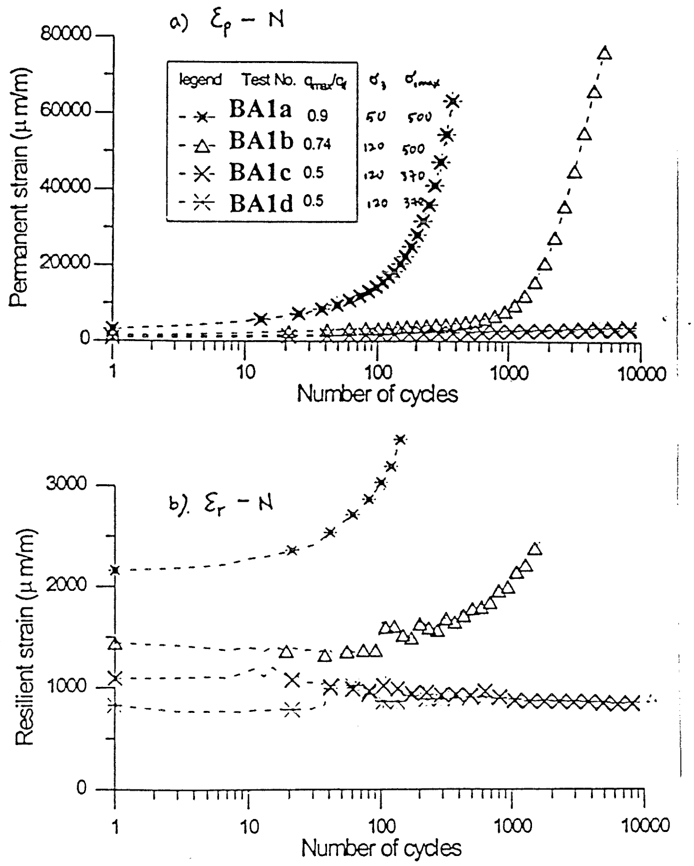

Figure 4. Effect of shear stress level on strain response.

4.2 Resilient modulus

Figure 5 presents the resilient modulus (E_r) versus mean stress (p) for all three materials. It can be seen that resilient modulus vs. mean stress relationship follows a linear curve. This agrees with current understanding of this type of material.

Although there are noticeable differences between the three materials, the resilient moduli of the three materials are competitive. For example, at the same mean stress of 300 kPa, the resilient moduli are 372 MPa for BA1, 321 MPa for BA2 and 353 MPa for BA3. The maximum difference amongst them is less than 15%. It should also be noted that the hierarchy of these values is consistent with that of the wet strength values in Table 1. This suggests that the resilient modulus may reflect the durability of materials.

4.3 Permanent Strain

The accumulation of permanent strain of three materials under the same loading condition is presented in Figure 6. It can be seen that while the BA1 and BA2 materials experienced a similar order of permanent strain accumulation, the BA3 material registered considerably higher permanent strain values. The ranking of these figures is quite different from that of the resilient moduli. This means that a material with higher stiffness may not necessarily have the better resistance to rutting.

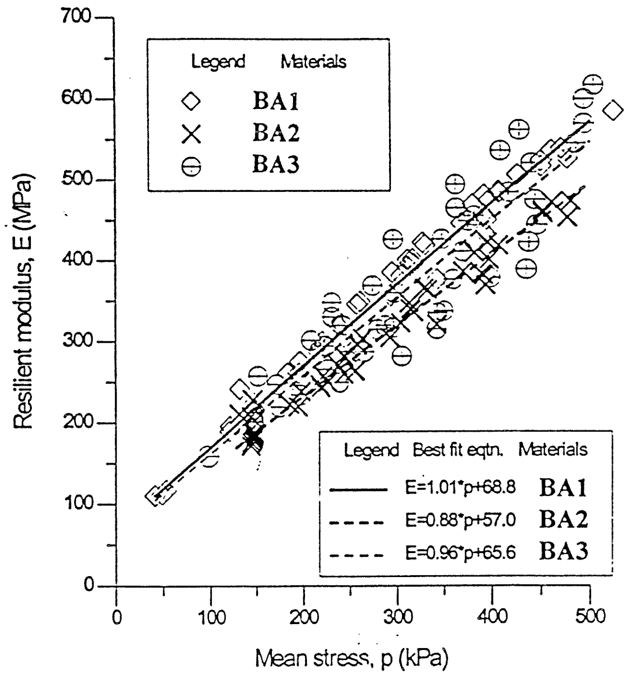

Figure 5. Resilient modulus.

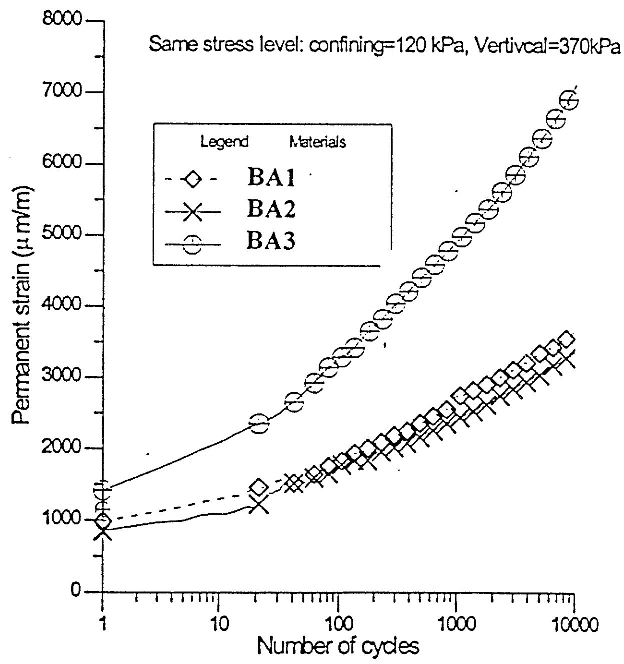

Figure 6. Accumulation of permanent strain.

4.4 Material Ranking

Table 5 presents a summary of material ranking based on Table 1 for the conventional assessments and Figures 5 and 6 for RLTT results. It can be seen that:

- The conventional ranking orders are BA3:BA1:BA2 by the strength (MDUCS of Table1) and BA1:BA3:BA2 by the durability (wet strength of Table 1), both contradicting the field performance (poor material BA3 has been ranked good and fair).
- The RLTT ranking orders are: BA1:BA3: BA2 according to the resilient modulus and BA2:BA1:BA3 according to the permanent strain. The combination of these two rankings generally reflects the poor performance of BA3 and the good capacity of BA2 to resist permanent strain (rutting).

Table 5. Material ranking.

Material ranking	1st	2nd	3rd
Conventional			
Strength	BA3	BA1	BA2
Durability	BA1	BA3	BA2
RLTT			
Resilient modulus	BA1	BA3	BA2
Permanent strain	BA2	BA1	BA3
Field Performance	BA1 (good)	BA2 (fair)	BA3 (poor)

Hence, the ranking based on RLTT is:

1) BA1 – this material presented the largest resilient modulus and low permanent strain accumulation, and hence it is the best material.

2) BA2 – this material appears to have the lowest resilient modulus (which however was more than adequate) and the best capacity against rutting. Therefore BA2 was ranked as the second best material.

3) BA3 – this material, although having the highest unconfined dry strength and a resilient modulus higher than BA2, is rendered a poorly performed material with the highest potential of rutting.

5. CONCLUSIONS

Three unbound pavement materials were investigated using repeated load triaxial tests (RLTT). Compared to the conventional assessments (eg. grading and CBR), RLTT is a more effective method to characterise pavement materials in relation to the performance related behavior (eg. rutting).

The RLTT results highlight the inadequacy of the current pavement material specifications. Further research is necessary to develop the performance based specifications.

6. ACKNOWLEDGMENTS

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