Static and repeated loading triaxial testing of Hydrated Cement Treated Crushed Rock Base (HCTCRB)

Peerapong Jitsangiam
Hamid Nikraz
Department of Civil Engineering, Curtin University of Technology, Perth, WA, Australia

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ABSTRACT

Hydrated cement treated crushed rock (HCTCRB) is widely used as a base course material for Western Australia roads. In order to be able to use this material effectively, its shear strength, resilient modulus, and permanent deformation characteristics should be more investigated and deeply understood. This study aimed to perform the results of the laboratory testing which was carried out to assess the mechanical characteristics of HCTCRB. Our findings show that HCTCRB can be characterized as cohesive granular material which a cohesion (c) of 177 kPa and an apparent internal friction angle (ϕ) of 42°. The resilient modulus characteristics could be modeled by use the K-θ model, proposed by Hick and Monosmith (1971) and the permanent deformation characteristics could be modeled by use the Sweere's model from SMARIS (2004) based on the test results following the Austroads – APRG 00/33 test standard(Voung & Brimble, 2000).

1 INTRODUCTION

Crushed rock with the addition of 2% cement, described as Hydrated Cemented Treated Crushed Rock Base (HCTCRB), is commonly used as a base course material for Western Australia roads. The main function of the base course is to reduce the vertical compressive stress induced by traffic, in the subbase and the subgrade, to a stress level at which no unacceptable deformation will take place in these layers. Knowledge of HCTCRB shear strength, resilient modulus, and permanent deformation characteristics is important because if these characteristics are well understood, pavement analysis and design can be more reliable than in the past where design was empirically based.

Currently most road and highway agencies rely on the California Bearing Ratio (CBR) to characterise pavement materials for design of pavements. CBR, however, is a static parameter which has been corrected empirically with response of the pavement materials under dynamic loads of moving vehicles. The permanent deformation of pavement materials is manifested as rutting and shoving, the visible damage on the road coming from excess deformation of the pavement. This is caused by the pavement material having insufficient stability to cope with the prevailing loading and environmental conditions. Consequently, clearly understanding shear strength, resilient modulus and permanent deformation characteristics of HCTCRB is important for improved reliability in design.

This study reports results of tests for shear strength parameters, the resilient modulus, and the permanent deformation of HCTCRB and to report on its characteristics so that a better understanding of the beneficial uses of the material can be gained.

2 MATERIALS

2.1 Hydrated Cemented Treated Crushed Rock Base (HCTCRB)

Hydrated cemented treated crushed rock base (HCTCRB) is manufactured by blending 2 % GP or Portland cement, which shall be the General Purpose (GP) or Portland cement (Australian Standard AS 3972-1997), with standard crushed rock base (Main Roads Western Australia, 2003). HCTCRB is mixed and stockpiled in the range of -1.0% to +2.0% of the optimum moisture content of the untreated crushed rock base as obtained by WA 133.2(Main Roads Western Australia, 1994).

2.2 Crushed rock

The crushed rock, used in this study, was obtained from a local quarry (Gosnells Quarry). Crushed rock samples in accordance with WA 100.1 were collected randomly from a stockpile area and kept in sealed plastic containers. Samples properties were checked in the laboratory, at the Department of Civil Engineering, Curtin University of Technology, for compliance with the Crushed Rock Base (CRB) Basecourse Specifications (MAIN ROADS Western Australia, 2003).

2.3 Cement

The cement used in this study was the bagged type GP cement product of Cockburn Cement(Cockburn Cement, 2006).

3 LABORATORY PROGRAM AND TESTING

The crushed rock was initially tested in terms of the compaction test in accordance with Main Roads Test Method WA 133.2(Main Roads Western Australia, 1994) to establish the Modified compaction curve for determining its optimum moisture content (OMC) and maximum dry density (MDD). This resulted in an average MDD of the crushed rock base studied of 2.27 tonnes/m^3 at OMC of 5.5%. HCTCRB samples for triaxial tests then were made at 100% OMC of the crushed rock.

The test program consisted of both static and repeated loading triaxial tests. The static tests were carried out to establish cohesion (c) and internal friction angle (ϕ) of parameters HCTCRB. The repeated loading tests were performed to establish the relationships between the applied stress conditions, resilient modulus values, and the permanent deformation behaviour of HCTCRB.

3.1 Specimen preparation

All HCTCRB samples were prepared based upon 100% OMC of the crushed rock. The mixing procedure consisted of adding 2% GP cement (by dry masses) to the crushed rock at the 100% OMC condition and mixing then all mixtures in the mixing machine at least 10 minutes or until the mixture being uniform in colour and texture. The mixture then was kept at room temperature in sealed plastic bags for a 7-day period. After that, the mixture was then re-mixed in the same mixing machine at least for 10 minutes. Compaction was then carried out in a mould 100 mm in diameter and 200 mm in height, using 25 blows of a 4.9 kg rammer at 450 mm drop height in 8 layers.This is equivalent to 100% Modified energy in terms of total energy per unit volumn compared to conventional Modified mould. After compacting, the specimen was carefully removed from the mould. Immediately, after the specimen was removed from the mould, it was reweighed and wrapped with the plastic to prevent loss of moisture and then, the wrapped specimen was left overnight before it was transferred to the bottom platen of the triaxial cell.

3.2 Resilient modulus tests

The UTM-14P digital servo control testing machine included an external linealy variable differential transducer(LVDT) which has an ability to conduct resilient modulus tests and permanent deformation tests was used in the Geomechanics Laboratory, Department of Civil Engineering, Curtin University of Technology in accordance with Austroads method APRG 00/33-2000 (Voung & Brimble, 2000) for Repeated Load Triaxial Test Method was followed for the resilient modulus tests and the permanent deformation tests.

In accordance with the Ausroads method, the specimens were applied sequentially by the difference of the 65 stress stages to check the elastic condition of each specimen throughout the multiple loading stress stages as shown in Figure 1. For each of the 65 stress stages, apply and hold the static confining pressure to the sample, after that apply loading and unloading cycles of the respective deviator stress. This process simulates the complicated traffic loading acting on pavement.1000 loading cycles of pre-conditioning were used and for each stress stage after pre-conditioning, 200 loading cycles were applied to the specimens.

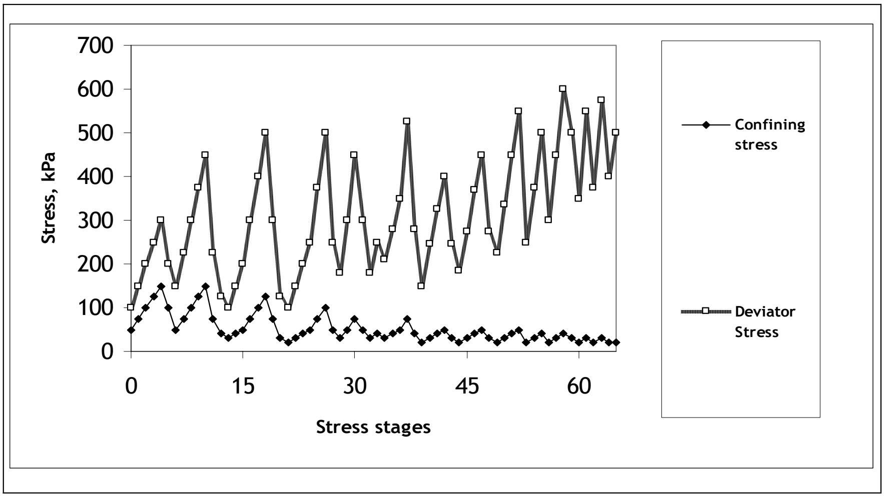

Figure 1: Applied stresses and its stress stages of the resilient modulus tests

3.3 Permanent deformation tests

New specimens were prepared following the same method as the resilient modulus specimens, described in item 3.1. Permanent deformation testing was calculated in accordance with Austroads – APRG 00/33 standard (Voung & Brimble, 2000). In this testing, the specimens were loaded with three stress stages of specific dynamic deviator stress of 350, 450,and 550 kPa and a static confining pressure of 50 kPa, each stress condition consisting of 10000 loading cycles.

3.4 Static Triaxial tests

The drained triaxial compression tests were conducted to determine Mohr-Coulomb shear strength parameters (c and ϕ) of HCTCRB. The secimens were tested under the unstaturated condition (at the compaction condition) and suctions were not measured during triaxial testing. In these tests, the specimen response was measured at three different constant confining pressures: 50 kPa, 100 kPa, and 150 kPa. These tests were carried out by using the same triaxial equipment and system used for the measurment of resilient modulus and permanent deformation.

4 RESULTS AND DISCUSSION

4.1 Static triaxial tests

Figure 2(a) depicts the relationship of the deviator stress and the axial strain at the three selected confining pressure. The peak strength of HCTCRB in these tests was interpreted by means of a Mohr-Coulomb failure criterion that the cohesion, c, and the internal friction angle, ϕ, are considered in a failure relationship, a straight line fitted to a Mohr envelope (Lamb & Whitman, 1979).Figure 2(b) shows the static triaxial test results of HCTCRB on the p-q diagram. On this diagram, the Mohr-Coulomb failure was defined in terms of principle stresses (principal stresses have been written as σ_1= the major principal stress and σ_2=σ_3 = the intermediate or minor principal stress). The deviator stress, q= (σ_1- σ_3), was plotted against the mean applied stress, p = (σ_1+2σ_3)/3. The results shown in Figure 2(b) indicate that the Mohr-Coulomb failure envelope (corresponding to the peak stresses) is approximately linear for the stress range tested and has the characteristic in p-q stress space: M_p=q/p=1.723 with a deviator stress intercept, q_c = 339 kPa. In the conventional Mohr-Coulomb stress space, thus the properties failure correspond to an internal friction angle (ϕ) at peak strength of 42° and apparent cohesion (c) of 177 kPa. The results of the static triaxial test of HCTCRB indicate an apparent cohesion indicative of a curvilinear envelope at low stresses caused by particle interlock and friction.

4.2 Resilient modulus tests

The resilient modulus determined from the repeated loading triaxial test is defined as the ratio of the repeated axial deviator stress to the recoverable or resilient axial strain:

$$M_r = \frac{\sigma_d}{\varepsilon_r} \tag{1}$$

Where M_r is the resilient modulus, σ_d is the repeated deviator stress (cyclic stress in excess of confining pressure), and ε_r is the resilient (recoverable) strain in the vertical direction.

Figure 3(a) shows the results of the resilient modulus which are plotted against with the bulk stress (σ_1+σ_2+σ_3). Generally, the resilient modulus is non-linear with respect to the magnitude of applied stresses. Figure 3(a) also shows the results of resilient modulus of HCTCRB can be modelled reasonably by using The K-Theta (K-θ) model(Hick & Monosmith, 1971). The representative K-θ model of HCTCRB is exhibited in equation (2).

$$M_r = k_1\theta^{k_2} = 7.684\theta^{0.591} \tag{2}$$

Where: M_r is Resilient modulus in MPa; θ is bulk Stress (σ_1+σ_2+σ_3) where (σ_1=σ_3); σ_1 is major principal stress (axial stress); σ_3 is minor principal stress (confining stress); k_1= 7.684 and k_2= 0.591 are regression coefficients.

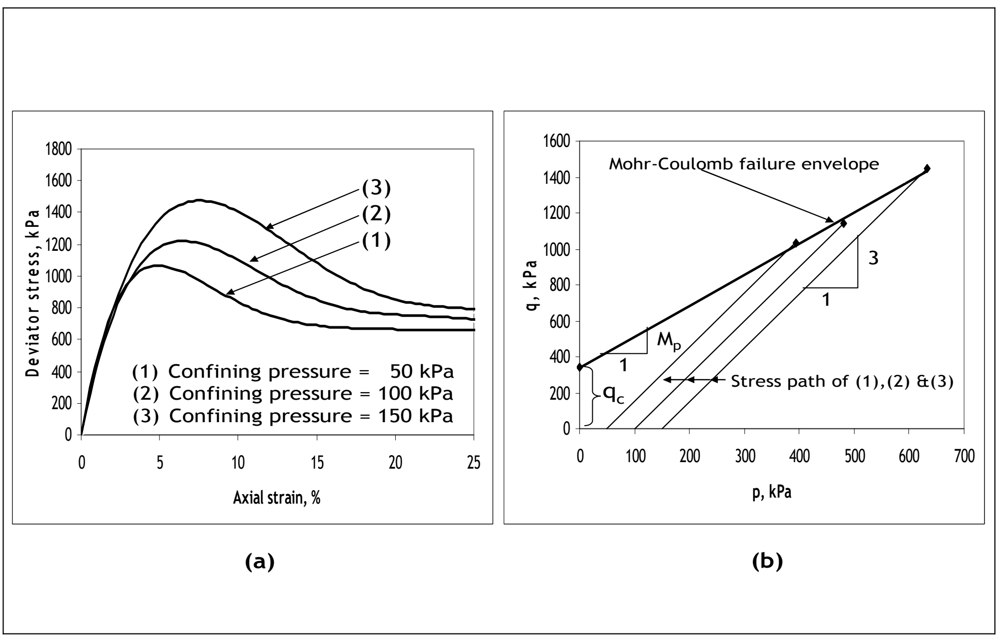

Figure 2: The static triaxial test results

4.3 Permanent deformation tests

Figure 3(b) shows the typical results of the permanent deformation test in terms of relationship between permanent deformation and loading cycles for HCTCRB. The various test values could be extracted from Figure 3(b) for uses in assessing the potential for permanent deformation. Furthermore, from Figure 3(b), it can be noted that the permanent deformation of HCTCRB is not dominanted by the applied load in the testing range because when the applied loads increase from loading stage 1 to loading stage 3, the permanent deformation of HCTCRB did not increase dramatically. In contrast, the number of loading cycles seemed to be more influential to the permanent deformation values. Figure 3(b) also exhibits the comparison of the measured permanent deformation values and the predicted values for a proposed permanent deformation model of HCTCRB. Figure 3(b) indicates that the permanent deformation can be modeled quite reasonably for HCTCRB by using the model suggested by Sweere, G.T.H from SAMARIS(SAMARIS, 2004). The proposed permanent deformation model of HCTCRB is shown in equation (3).

$$\varepsilon^{p} = A * N^{B} = 573.223 * N^{0.074} \qquad (3)$$

Where: ε^{P} is permanent deformation in Micrometers; A=573.223 and B=0.074 are regression constants; and N is the number of loading cycles.

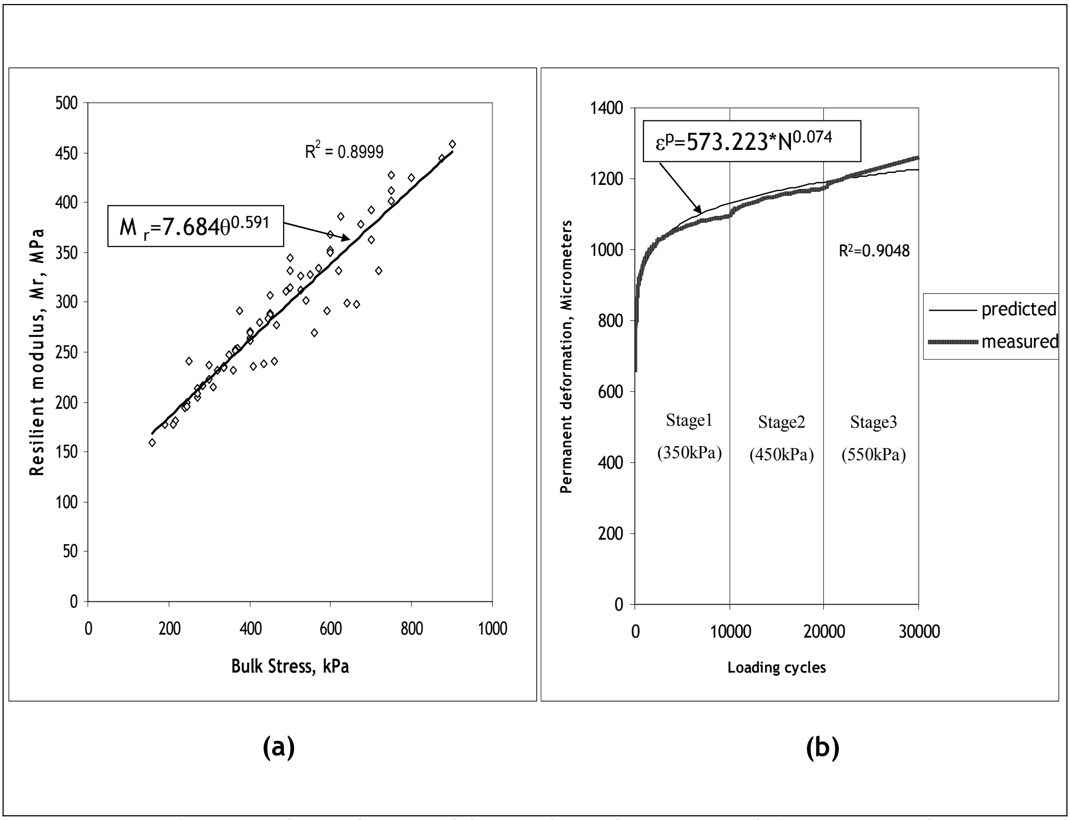

Figure 3: The resilient modulus results and permanent deformation results.

5 CONCLUSIONS

The mechanical behaviours of Hydrated Cement Treated Crushed Rock Base (HCTCRB) which is normally used for a base course material in Western Australia were investigated by means of static and repeated loading triaxial tests. The repeated loading triaxial tests were carried out in terms of the resilient modulus test and the permanent deformation test to provide insight into the resilient and permanent deformation characteristics of this material under the real conditions of traffic loading simulated in these tests.

It has been shown that HCTCRB can be characterized as an apparently cohesive granular material which has the cohesion (c) of 177 kPa and the internal friction angle (ϕ) of 42°over the stress range significant for pavement behaviour. Based on the Austroads – APRG 00/33 test standard, the resilient modulus characteristics could be modeled using the K-θ model. The permanent deformation characteristics could be modeled by using the Sweere' s model.

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REFERENCES

Australian Standard AS 3972-1997. *Porthland and blended cements*. http://www.saiglobal.com.

Austroads. (2004). *Pavement Design-A Guide to the Structural Design of Road Pavements* (Vol. Second revision 2004): Austroad Inc.2004.

Cockburn Cement (2006). *General Specification (COCKBURN GENERAL PURPOSE PORTLAND CEMENT-TYPE GP)*.http://www.cockburncement.com.au

Hick, R. G., & Monosmith, C. L. (1971). Factors influencing the resilient response of granular materials. *Highway Research Recond No. 345*, 15-31.

Lamb, T. W., & Whitman, R. W. (1979). *Soil Mechanics, SI Version*: John Wiley & Sons.

Main Roads Western Australia (1997). *DRY DENSITY/MOISTURE CONTENT RELATIONSHIP: MODIFIED COMPACTION FINE AND MEDIUM GRAINED SOILS*. http://www.mainroads.wa.gov.au

Main Roads Western Australia (2003). *Crushed Rock Base Basecourse*. http://www.mainroads.wa.gov.au (updated 17 April 2007)

Main Roads Western Australia (2006). *Test Method (Aggregate)*. http://www.mainroads.wa.gov.au

SAMARIS. (2004). *Selection and evaluation of models for prediction of permanent deformations of unbound granular materials in road pavement*, [SAM-05-DE10]. Sustainable and Advanced MAterials for Road InfraStruture. WWW.fehrl.org.

Suiker, A. J., Selig, E., & Frenkel, R. (2005). Static and Cyclic Triaxial Testing of Ballast and Subballast. *Journal of Geotechnical and Geo-environmental Engineering, 131*(6), 771-782. Retrieved: June 2005.

Uzan, J. (1985). *Characterization of granular material*, Washington DC: TRB.

Voung, B. T., & Brimble, R. (2000). Austroads Repeated Load Triaxial Test Method-Determination of Permanent Deformation and Resilient Modulus Characteristics of Unbound Granular Materials Under Drained Conditions. In *APRG DOCUMENT APRG 00/33(MA)*: Austroads.