

# DSC MODELLING FOR PREDICTING RESILIENT MODULUS OF CRUSHED ROCK BASE AS A ROAD BASE MATERIAL FOR WESTERN AUSTRALIA ROADS

Pakdee Khobklang<sup>1</sup>, Vanissorn Vimonsatit<sup>2</sup>, Peerapong Jitsangiam<sup>3</sup> and Hamid Nikraz<sup>4</sup>

(<sup>1</sup> Curtin University, GPO Box U1987 Perth 6845, Australia,

Pakdee.Khobklang@postgrad.curtin.edu.au)

(<sup>2</sup> Curtin University, GPO Box U1987 Perth 6845, Australia, [V.Vimonsatit@curtin.edu.au](mailto:V.Vimonsatit@curtin.edu.au))

(<sup>3</sup> Curtin University, GPO Box U1987 Perth 6845, Australia, [P.Jitsangiam@curtin.edu.au](mailto:P.Jitsangiam@curtin.edu.au))

(<sup>4</sup> Curtin University, GPO Box U1987 Perth 6845, Australia, [H.Nikraz@curtin.edu.au](mailto:H.Nikraz@curtin.edu.au))

## ABSTRACT

Crush Rock Base (CRB) is a commonly used road base material for Western Australia Roads. In order to increase the efficiency of using this material in pavement structure design, material modelling for analysis which is based on experimental results needs to be investigated. This paper is a preliminary study of the use of the Disturbed State Concept (DSC) to predict the resilient modulus for CRB. DSC was adopted as the modelling approach because of its simplicity and yet is powerful in capturing the elastic and inelastic responses of materials to loading. The main assumption of DSC is that the actual material deformation, at any loading state, can be determined from its assumed relative intact (RI) state. The DSC equation of CRB has been constructed by using a set of the experimental results of the resilient modulus tests and an idealised material model, namely the linear elastic model, of the relative intact (RI) part was considered. The results reveal that the resilient modulus-applied stress relationships, which were back-predicted using the DSC modelling, were consistent with the experimental results. The DSC equation, which is suited for predicting the resilient modulus of CRB specimens, will then be introduced.

**Keywords:** CRB, Disturbed State, Relative Intact, Fully Adjusted, Triaxial Test

## 1 INTRODUCTION

Nowadays, most of road and highway agencies in Western Australia still use CRB as a road base material for road pavement as well as hydrated cement treated crushed rock base (HCTCRB) [1], which is manufactured by mixing the original CRB with 2% of general purpose (GP) Portland cement [2]. Normally, strength of HCTCRB is higher than strength of CRB therefore HCTCRB is suitable for the highway carrying heavy traffic loading while CRB should be used for lower traffic loads. In Western Australia, flexible pavement having thin asphaltic concrete layer is usually selected by pavement designer [3], consequently base course layer is the most important layer in pavement structure because it must behave as a main flexural member which carries the bending stresses transferred from the wearing surface.

Although the National Association of Australian State Road Authorities (NAASRA) introduced the mechanistic approach for analysis and design of structural pavement in 1987 [4], most of road pavement in Western Australia is still designed base on the mechanistic-empirical approach [5] because of lack of knowledge for some area in pavement engineering. However, some of analysis and design approach should be improved further because the current method cannot explain some structural behaviour of materials in road pavement. Therefore modelling of material based on mechanistic approach for structural analysis and design of road pavement is a very interesting topic for pavement engineers. Due to there is a number of published paper which investigated about

material modelling of HCTCRB using the DSC [6, 7], the emphasis of this study was on the modelling of CRB.

For this study, the DSC is the mechanistic approach which was chosen as a tool for modelling of CRB because a constitutive modelling of material can be obtained by its versatile and unified approach. The main purpose for this study is to develop the DSC models of CRB which can be used for (a) predicting the stress-strain relation of CRB (b) predicting the resilient modulus of CRB. These DSC models should be able to adopt further for predicting the permanent deformation of CRB which is a criterion for pavement design. In the future, the combination of these models would become a constitutive modelling for analysis and design of CRB base course in pavement structure.

## 2 LABORATORY TEST

The tests for finding the mechanical aspect of material were composed of the static and the repeated load triaxial (RLT) tests. The static triaxial tests were conducted first to determine the internal friction angle ( $\phi$ ) and the cohesion ( $c$ ) of CRB, for classifying its basic property. The RLT tests, in accordance with the Austroads APRG 00/33–2000 standard [8], were performed to determine the relationships between the applied stresses and the resilient moduli. Then the CRB specimens were loaded until they failed to find their stress-strain relation after carrying the RLT test. These experiments were tested in the Geomechanics Laboratory, Department of Civil Engineering, Curtin University, by using the UTM-14P digital servo control testing machine, as seen in Figure 1.

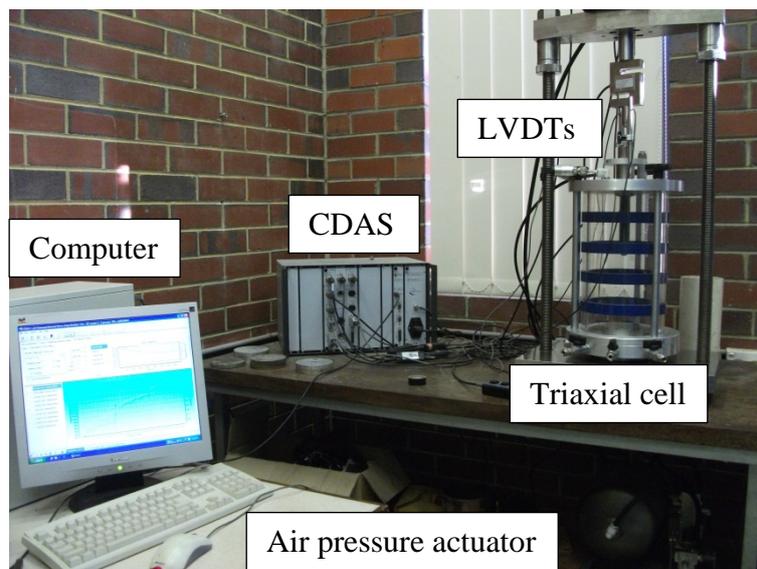


Figure 1. Configuration of testing instruments

### 2.1 Compaction tests

The CRB samples in this study were prepared at 100% optimum moisture content (OMC) condition therefore the modified compaction test, in accordance with the MRWA test method WA 133.1 [9], must be performed on standard crushed rock first. The results indicate that crushed rock had the OMC and the maximum dry density (MDD) around 5.5% and  $2.27 \text{ T/m}^3$  respectively.

## 2.2 Specimen preparation

CRB specimens were prepared by employing the modified compaction method. They were compacted in the standard cylinder mould, 100 mm in diameter and 200 mm in height. Each specimen was divided into 8 layers and a 25-blow was applied to each layer by the use of a rammer, 4.9 kg in lumped mass and 450 mm in drop height

After compaction finished, the mould was carefully taken off by the use of hydraulic ejecting machine. Then the porous stone discs were attached to the top and the bottom end of the specimen, as well as the top and the bottom platen of the triaxial cell. Finally, the specimen including the top and the bottom platen were wrapped by a rubber membrane and seal by the used of the o-rings fasten at top and bottom of the specimen and the triaxial cell was eventually installed into the testing machine.

## 2.3 Static triaxial tests

The standard confine compressive strength tests, having drain condition, were performed to determine the shear strength parameters ( $c$  and  $\phi$ ). The specimens were tested under the unsaturated condition (the compaction condition) by using three constant confining stresses, i.e. 40 kPa, 60 kPa and 80 kPa, and the specimens were loaded until they failed.

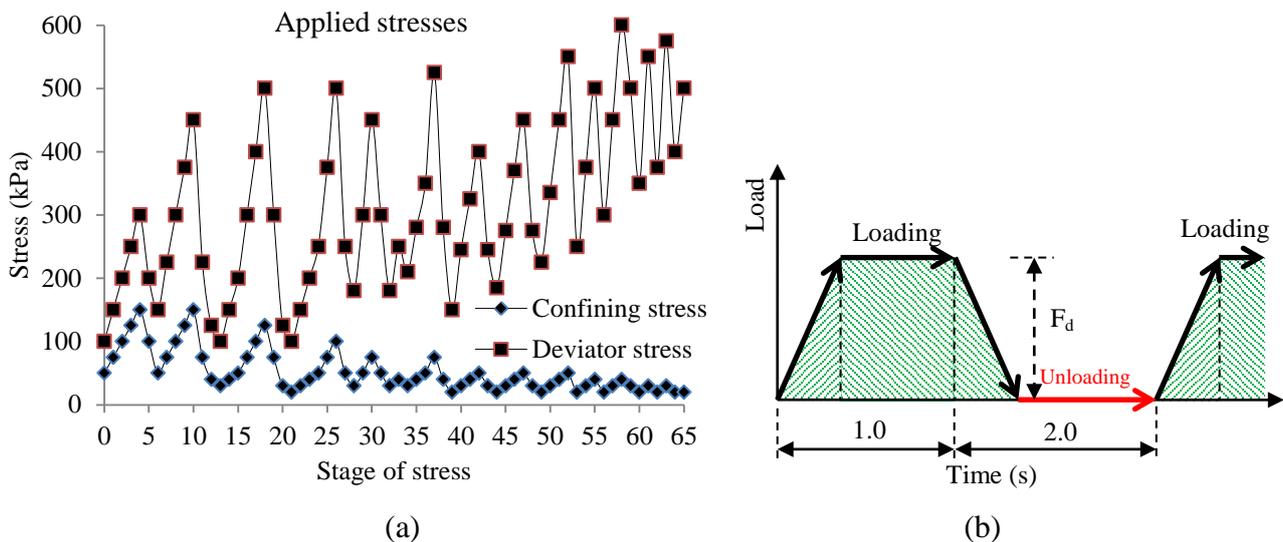


Figure 2. The applied stresses in accordance with the Austroads APRG 00/33–2000 standard

## 2.4 RLT tests

The Austroads-APRG 00/33 standard was employed for determining the resilient modulus of CRB samples. The tests were conducted by applying a 66-stage of stress on the specimens, as seen in Figure 2(a), in which the stress ratios ( $\sigma_1/\sigma_3$ ) were varied from 3 to 26. While the test was running, the axial deformations of the specimen were measured by a couple of linear variable differential transducers (LVDT) which was installed on the top of the triaxial cell. The testing machine, triaxial cell and LVDTs were connected to the control and data acquisition system (CDAS) which provided the signal conditioning, data acquisition, and control signals. A feedback-controlled high pressure air actuator, which was capable of accurately exerting a stress pulse in accordance with the standard, was used as the source of cyclic axial loadings. The cyclic loads having the trapezoidal wave form with a frequency of 0.333 Hz, as shown in Figure 2(b), was conveyed to the top of the triaxial cell by this system. Similarly, air pressures, which were generated by the closed loop controlled actuator, were applied around the specimen as the confining

stresses. All test data and results were recorded and interpreted using the UTM software in the computer which was connected to CDAS, as shown in Figure 1.

Before the RLT test was started, a pre-conditioning stage, which was a 1000 cyclic loading of 150 kPa axial stress ( $\sigma_1$ ) with 50 kPa confining stress ( $\sigma_3$ ), was applied for pushing the top and bottom caps to fully contact into the CRB specimen and improve the stability of the applied stresses and the resilient strains under the imposed stress condition. After pre-conditioning stage finished, 66 stages of stress were sequentially applied to the specimen at 200 cycles for each stage to find the resilient modulus value.

### 3 DISTURBED STATE CONCEPT

In 1974, Professor C.S. Desai introduced the DSC as a mechanistic approach for materials modelling [10]. The basic concept of the DSC is that the response of mixtures in material against the applied loading can be expressed in the form of interaction between its components. Self-adjustment of materials' microstructure is considered to be a part in the relative intact (RI) state and the fully adjusted (FA) state. The interaction mechanisms between its components in the mixture can be represented in the form of the disturbance function (D), which can be expressed in any form that is required by engineers, such as stress, modulus, void, moisture, etc.

#### 3.1 Relative intact state

The RI state is the reference part of materials before they are subjected to any interested factor, which is the applied loading in this study. The observed behaviour of materials is the summation of the effects of the deviatoric factors and the given RI state. The RI state can be represented in term of any suitable aspect, e.g. an elasticity, plasticity or visco-plasticity with an associative response. In this study, a fully plastic and a linear elastic model are employed as the RI state for the stress-strain and the resilient modulus-applied stress relation respectively.

#### 3.2 Fully adjusted state

The FA state is considered to occur in the ultimate range of materials' response, it can be characterised for both stiffening and degradation of material responses. However, it is very difficult to measure the ultimate response of materials in laboratory because the instrument for measuring would be automatically stopped operating when testing specimen fails. Therefore the response of materials at the FA state is usually determined based on the ultimate disturbance ( $D_u$ ) by using an approximate procedure.

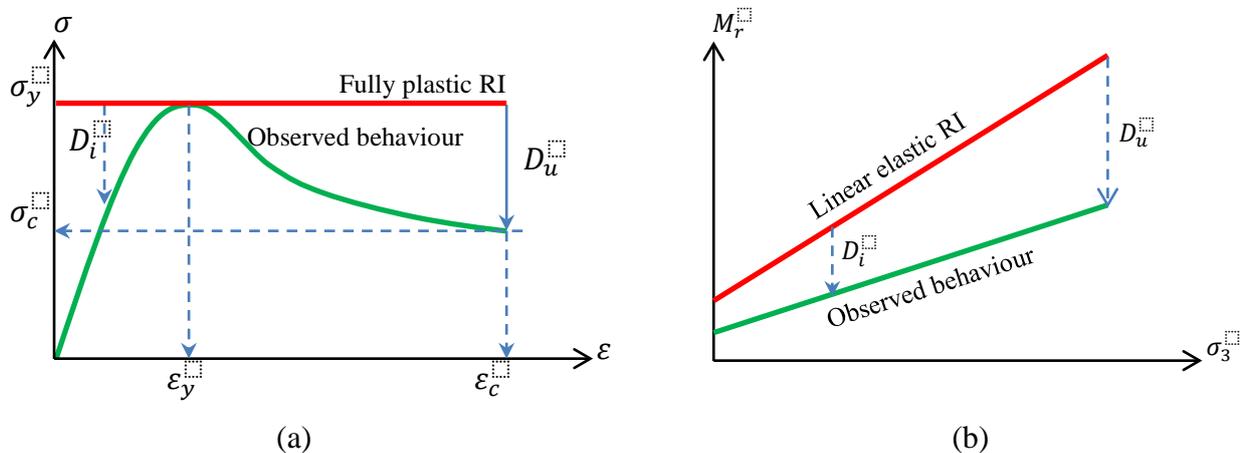


Figure 3. Representation of the DSC modelling for (a) the stress-strain relationship and (b) the resilient modulus-applied stress relationship

### 3.3 Disturbance function

The disturbance function ( $D$ ) represents the difference between the RI state and the observe behaviour. For this study, the fully plastic RI and the linear elastic RI states, as seen in Figure 3(a) and 3(b), were used to derive the DSC equation for predicting the stress-strain relation and the resilient modulus-applied stress relation respectively. Therefore the disturbance functions are a relationship of stress-strain,  $D = f(\sigma, \epsilon)$ , and a relationship of resilient modulus-applied stress,  $D = f(M_r, p)$ . Basically, the  $D$  values are gradually gained from the initial value at the initial state to  $D_u$  at FA state. Practically,  $D$  is the ratio of the interested factors to the with regard to the FA state, it can be characterised in the form of any materials response that can be measured in laboratory.

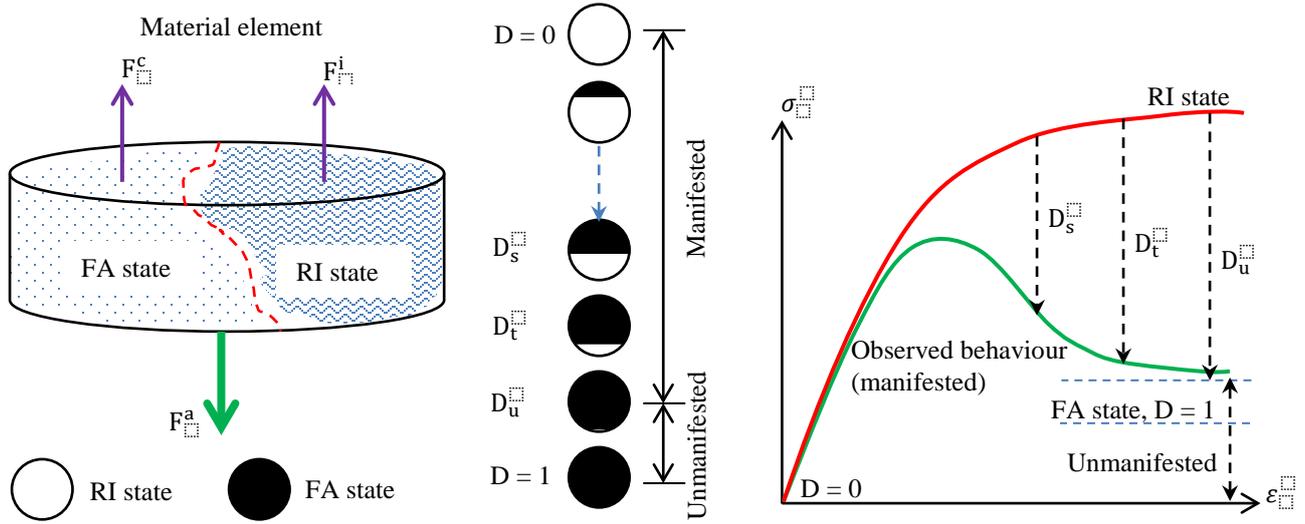


Figure 4. Illustration of the fundamental concept of the DSC [11]

### 3.4 Derivation of the DSC equation

Consider material element, as seen in Figure 4, which stay on the equilibrium of forces; the element comprised of the clusters of particle in the RI and the FA state, we obtain

$$F^a = F^i + F^c \quad (1)$$

where  $F^a$  is the observed force,  $F^i$  is the force in the relative intact part, and  $F^c$  is the force in the fully adjusted part

To compute the stress on the section, Eq. (1) was divided by its corresponding sectional area then the resultant equation was rearranged again, yields

$$\sigma^a = (1 - D) \cdot \sigma^i + (D) \cdot \sigma^c \quad (2)$$

where  $\sigma^a$  is the observed stress,  $\sigma^i$  is the stress in the RI part,  $\sigma^c$  is the stress in the FA part,  $A = A^i + A^c$  and  $D = \frac{A^c}{A}$ .

Eq. (2) is the primary equation of DSC which was adopted to derive the equation for predicting the response of the material, including the stress-strain and the resilient modulus-applied stress relation.

## 4 RESULTS AND DISCUSSIONS

### 4.1 Results from static triaxial tests

Figure 5(a) and 5(b) show the results from static triaxial tests of the controlled set of CRB specimens, they indicate that CRB in this study had the cohesion ( $c$ ) around 32 kPa and the internal friction angle around  $60^\circ$ . The results indicate that CRB performs as a cohesive granular material. Its behaviour strongly depends upon the degree of the cohesion and the internal friction angle factor.

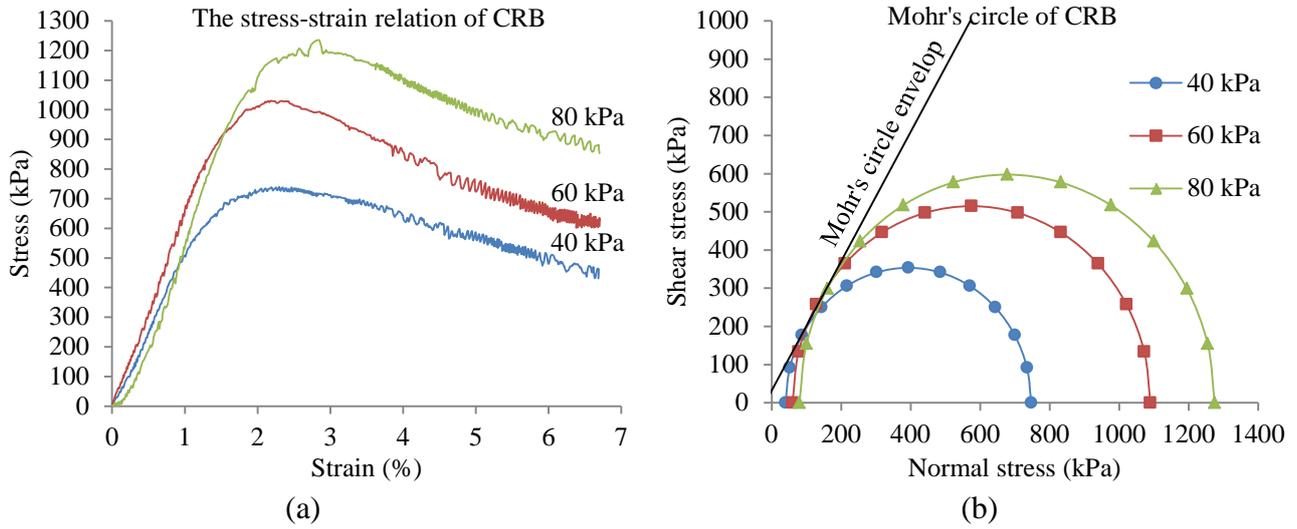


Figure 5. Results from static triaxial tests (a) stress-strain curve and (b) Mohr's circle of CRB

By observation the test results as shown in Figure 5(a), the stress-strain relationship of the specimens are formed as the exponential function, namely

$$\sigma = \frac{a \cdot \varepsilon}{e^{b\varepsilon}} + \frac{c \cdot \varepsilon}{e^{d\varepsilon}}, \quad \text{for } 0 \leq \varepsilon \leq \varepsilon_y \quad (3)$$

$$\sigma = \frac{a \cdot \varepsilon}{e^{b\varepsilon}} + \frac{c \cdot \varepsilon}{e^{d\varepsilon}} - f \cdot (\varepsilon - \varepsilon_y)^2, \quad \text{for } \varepsilon_y \leq \varepsilon \leq \varepsilon_c \quad (4)$$

where  $a$ ,  $b$ ,  $c$ ,  $d$ ,  $f$  are constant,  $\sigma$  is the axial stress, and  $\varepsilon$  is the axial strain.

By the use of the trial and error method applied with the averages procedure to determine the constants  $a$ ,  $b$ ,  $c$ ,  $d$  and  $f$ . Then fully plastic RI was applied together with Eq. (3) and (4), the disturbance function ( $D$ ) can be expressed as

$$D = D_u \left\{ 1 - \left[ \frac{\varepsilon e^{\frac{1-\varepsilon}{\varepsilon_y}}}{\varepsilon_y} \right] \left[ 1 - \left( \frac{5.5}{6.5} \right) m_1 e^{-\frac{4.5\varepsilon}{\varepsilon_y}} \right] + \left[ m_2 - \left( \frac{\varepsilon_c}{\varepsilon} \right) \left( \frac{\sigma_c}{\sigma_y} \right) \right] \frac{(\varepsilon - \varepsilon_y)^2}{(\varepsilon_c - \varepsilon_y)^2} \right\} \quad (5)$$

where  $\sigma_y$  is the yield stress,  $\sigma_c$  is the rupture stress,  $\sigma_3$  is the confining stress,  $\varepsilon_y$  is the strain at yield point,  $\varepsilon_c$  is the strain at rupture point,  $D_u = \frac{\sigma_y}{\sigma_y - \sigma_c}$ ,  $m_1 = \left[ 1 + (27.6 - \sigma_3) \left( \frac{\sigma_c}{\sigma_3} \right) \right]$ , and  $m_2 = \left( \frac{\varepsilon_c}{\varepsilon_y} \right) e^{1 - \left( \frac{\varepsilon_c}{\varepsilon_y} \right)}$

## 4.2 Results from RLT tests

As same as the stress-strain relation, Eq. (2) was employed to derive the DSC equation for computing the resilient modulus. By observation on the test results as seen in Figure 6(a) and 6(b), the relationship between the resilient modulus and the applied stress of CRB specimens are formed as a linear function, namely

$$M_r^a = (C_1) \left( \frac{\sigma_1}{\sigma_3} \right) + C_2 \quad (6)$$

where  $C_1$  and  $C_2$  are constant,  $\sigma_1$  is the axial stress (kPa) and  $\sigma_3$  is the confining stress (kPa).

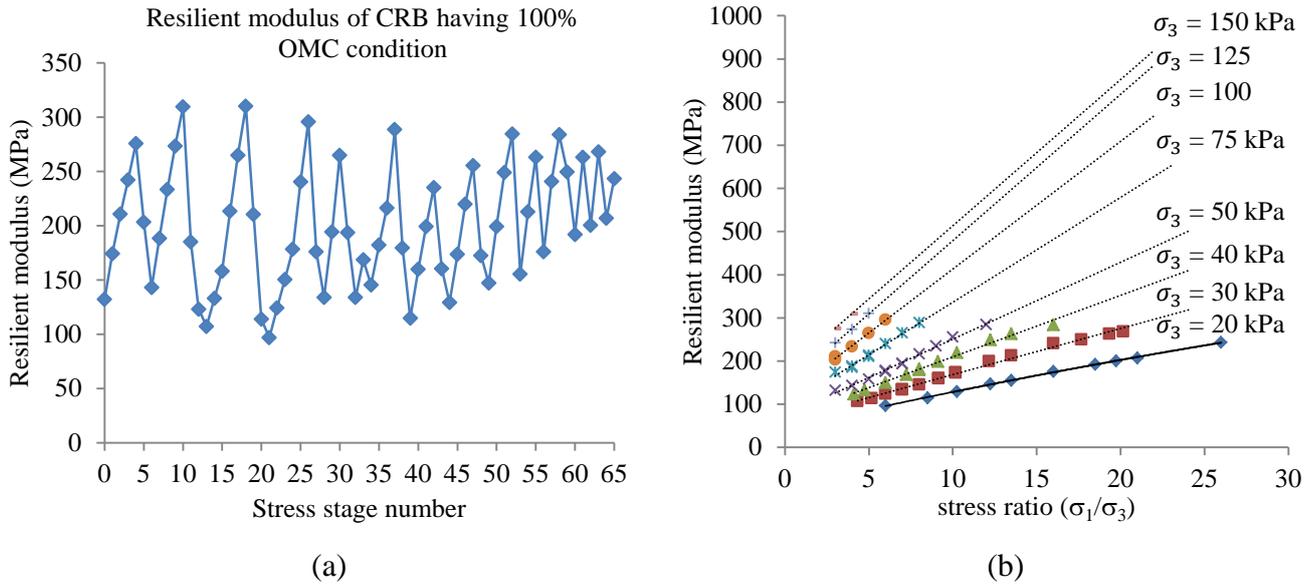


Figure 6. Results from the RLT tests (a) the resilient modulus value and (b) the relationship between resilient modulus and the applied stresses

By the use of the trial and error method applied with the averages procedure to determine the constants, it has been found that

$$C_1 = (0.22)(\sigma_3) + 3.30 \quad (7)$$

$$C_2 = (1.10)(\sigma_3) + 33.00 \quad (8)$$

And the disturbance function can be expressed as

$$D = \frac{[(1.10)(\sigma_3) + 33.00]}{[(1.32)(\sigma_3) + 36.30]} \quad (9)$$

Then the DSC equation for predicting the resilient modulus can be expressed as

$$M_r^a \text{ (MPa)} = \left\{ \frac{[(0.22)(\sigma_3) + 3.30]}{[(1.32)(\sigma_3) + 36.30]} \right\} (M_r^i) + \left\{ \frac{[(1.10)(\sigma_3) + 33.00]}{[(1.32)(\sigma_3) + 36.30]} \right\} (M_r^c) \quad (10)$$

where  $M_r^c = (1.32)(\sigma_3) + 36.30$  and  $M_r^i = (M_r^c) \left( \frac{\sigma_1}{\sigma_3} \right)$ .

Eqs. (9, 10) reveal that the relative intact resilient modulus is a function of stress ratio  $\left( \frac{\sigma_1}{\sigma_3} \right)$  and the disturbed function is a function of confining stress ( $\sigma_3$ ).

Figure 7 shows the use of DSC equation to back-predict the stress-strain curve and the resilient modulus of CRB specimens. The results show that the use of the proposed DSC equation for computing the stress-strain relation and the resilient modulus value gives a good prediction which is almost fitted to the result from laboratory.

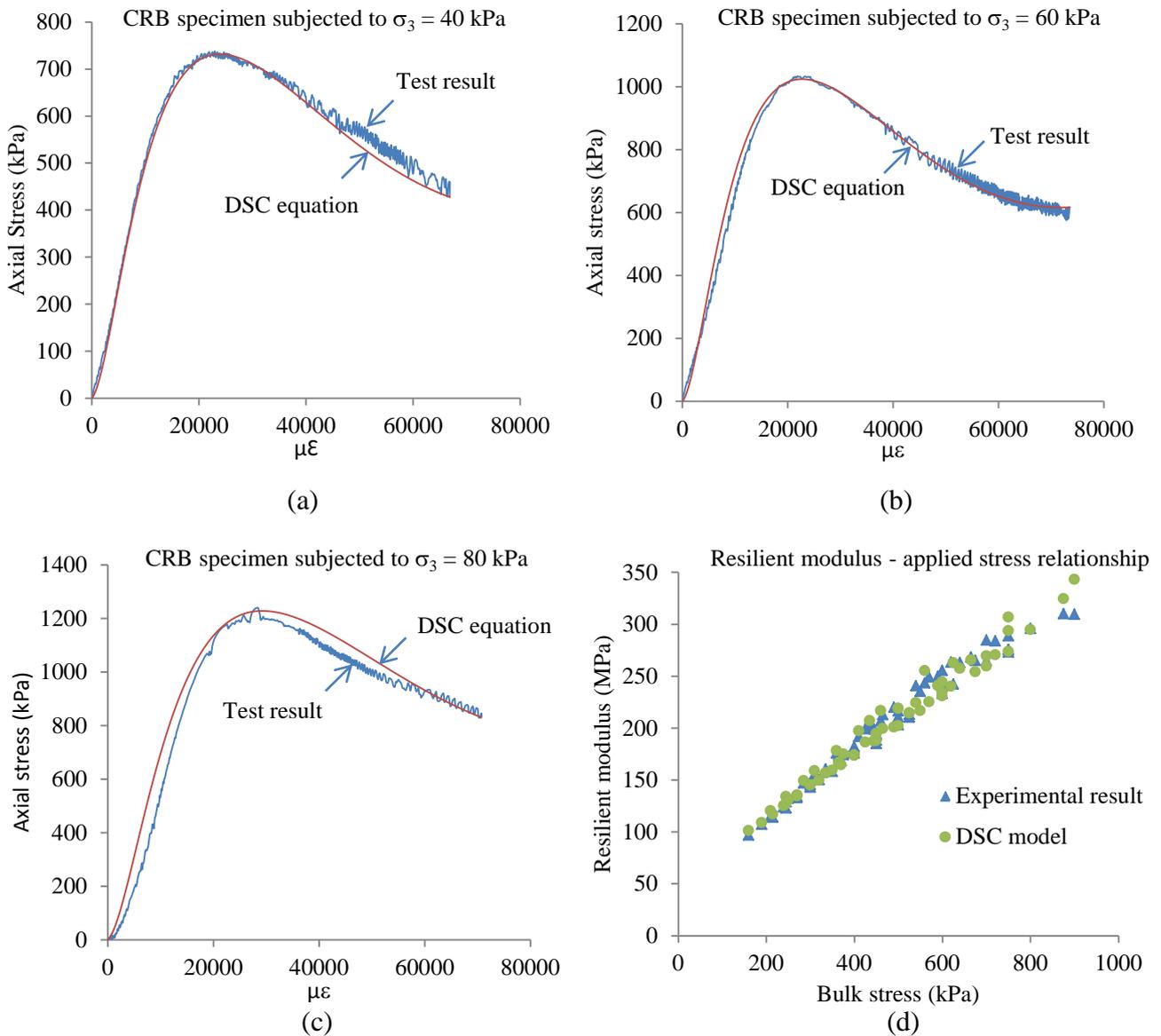


Figure 7. The use of the DSC equation; (a) – (c) to back-predict the stress-strain relation of CRB specimen; (d) to back-predict the resilient modulus of CRB specimen

## 5 CONCLUSIONS AND RECOMMENDATIONS

The stress-strain relation and the resilient modulus of base course material are the mechanical properties which are very important for analysis and design of pavement structure based on the mechanistic approach. By considering the results from this study, it can conclude that

1. The DSC can be used for defining the behaviour of CRB base course in pavement structure. For this study, emphasis was given to the prediction of the stress-strain relation and the resilient modulus, which almost obtained the consistent value with the test results.

2. The proposed DSC models can be applied to predict the stress-strain relation and the resilient modulus of CRB specimen having different moisture content. The relationship between

the moisture content and the variables, such as  $\sigma_y$ ,  $\varepsilon_y$ ,  $\sigma_3$ ,  $M_r^c$ , can be determined from the test results then input them in the DSC equation.

3. The proposed DSC models, both the stress-strain and the resilient modulus equation, can be together applied to predict the permanent deformation of the CRB specimen, which is an important criterion for pavement design.

However, these models come from the results of the tests which were conducted in accordance with the Austroads standard. Further investigation and validation with respect to the field behaviour of a pavement structure should be performed.

## 6 ACKNOWLEDGEMENTS

The authors would like to thank Curtin University and Kasetsart University, Chalermphrakiat Sakon Nakhon Province Campus for the grant provided via Curtin International Postgraduate Research Scholarship (CIPRS). In addition, their gratitude is extended to the Curtin Pavement Research Group (Curtin-PRG) for all their help, support and valuable recommendations.

## 7 REFERENCES

- [1] Main Roads Western Australia. Crushed Rock Base Basecourse. <http://www.mainroads.wa.gov.au/>. 2003.
- [2] Australian Standard. Portland and blended cements. <http://www.saiglobal.com>. 1997.
- [3] Adamson, L. Structural Design of Pavements University of Western Australia, Perth. 2011.
- [4] Youdale, G. Australian Pavement Research - the last 20 years. <http://www.auststab.com.au/pdf/tp02.pdf>. 2009.
- [5] Jitsangiam, P. & Nikraz, H. Characterization of Cement Treated Crushed Rock for Western Australia Roads, The 6<sup>th</sup> Regional Symposium on Infrastructure Development in Civil Engineering (RSID 6), 12-13 January 2009. Bangkok, Thailand. 2009.
- [6] Khobklang, P. et al. Constitutive Modelling of Hydrated Cement Treated Crush Rock Base with Cyclic-loading Behaviour. In International Conference on Advances in Geotechnical Engineering. Perth, Australia. 2011.
- [7] ----- . DSC CONSTITUTIVE MODELLING OF HYDRATED CEMENT TREATED CRUSHED ROCK BASE AS A ROAD BASE MATERIAL FOR WESTERN AUSTRALIA ROADS. In the 7th International Conference on Road and Airfield Pavement Technology 2011. Bangkok, Thailand. 2011.
- [8] Voung, B. T. & Brimble, R. 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. 2000.
- [9] Main Roads Western Australia. Dry density/moisture content relationship: modified compaction fine and medium grained soils. In Test Method WA133.1. 2007.
- [10] Sane, S. M. et al. Disturbed State constitutive modeling of two Pleistocene tills. Quaternary Science Reviews 27 (3-4): 267-283. 2008.
- [11] Desai, C. S. Mechanics of materials and interfaces : the disturbed state concept. 1st ed. Washington, D.C.: CSC Press. 2001.