academicJournals

Vol. 8(10), pp. 404-413, 11 March, 2013
DOI 10.5897/SRE12.283
ISSN 1992-2248 © 2013 Academic Journals
http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

A preliminary study on characterisation of mechanical behaviour of hydrated cement treated crushed rock base using the disturbed state concept

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Accepted 12 February, 2013

For road pavements in Western Australia, base layers are usually constructed using hydrated cement treated crushed rock base (HCTCRB) of which the mechanistic properties with the reliable material model are necessary for rational pavement analysis and design. The purpose of this study is to present the experimental results produced from the assessment of the mechanical behaviour of HCTCRB and the material modelling based on the Disturbed State Concept theory-based process. The results reveal that HCTCRB can be treated as cohesive granular material where its internal friction angle (∅) is 43° and its cohesion (c) is 168 kPa. The Disturbed State Concept (DSC) and K-θ model can be used for establishing the relationship between the resilient moduli and the applied stresses. The permanent deformation of HCTCRB can be predicted by using models such as the DSC model and G.T.H. Sweere,'s model, which are presented in this paper. The use of the DSC model shows the advantage of showing the relationship between permanent deformations and applied stresses (σ_1, σ_3), and these are derived from the resilient modulus equation.

Key words: Resilient modulus, permanent deformation, hydrated cement treated crushed rock base (HCTCRB), Disturbed State Concept (DSC), shear strength.

INTRODUCTION

In Western Australia, hydrated cement treated crushed rock base (HCTCRB) is commonly used as a base course material in road pavement (Jitsangiam and Nikraz, 2009). HCTCRB is made by mixing crushed rock with 2% by weight, of General Purpose (GP) cement. The main function of a base layer in pavements is traffic load distribution to the layer underneath (that is, subbase course) without damaging. Therefore, HCTCRB must have the ability to withstand the resultant stresses, while the deformations should not exceed the allowable values. Consequently, an investigation of the shear strength, resilient modulus, and permanent deformation characteristics of HCTCRB is necessary in order to obtain relevant results for effectively analyzing and designing structural pavement.

The information required to assess the ability of HCTCRB to resist external loads is its shear strength characteristics. In addition, the failure envelop of HCTCRB, which is based on shear strength parameters (c and ∅), can be used for the evaluation of the maximum capacity for withstanding the applied loading (Siripun et al., 2009).

In a new era of pavement engineering however, resilient modulus and permanent deformation have become the main parameters for the analysis and design of pavement structure, as opposed to using the California

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Table 1. Chemical composition of Cockburn GP Cement (Cockburn Cement, 2007).

Parameter	Method	Units	Typical	Range	AS3972 Limits
SiO_2	XRF	%	20.2	19.8 – 20.6	
Al_2O_3	XRF	%	4.9	4.6 – 5.2	
Fe_2O_3	XRF	%	2.8	2.6 – 3.0	
CaO	XRF	%	63.9	63.1 – 64.7	
MgO	XRF	%	2	1.5 – 2.5	3.5% max
SO_3	XRF	%	2.4	2.1 – 2.7	
LOI	AS2350.2	%	2.5	2.1 – 2.9	
Chloride	ASTM C114	%	0.015	0.005 – 0.025	
Na_2O equivalent	XRF	%	0.5	0.4 – 0.6	

Bearing Ratio (CBR). The resilient modulus of a material is used as a design criterion for finding the most suitable thickness for pavement structure. The permanent deformation (or rutting), which is the visible failure on the wearing surface, comes from the prevailing loads carried by pavement materials. Therefore a clear understanding of shear strength, resilient modulus, and permanent deformation characteristics of HCTCRB is necessary for engineers.

Presently, there are three approaches for pavement analysis and design (Desai, 2007), that is, the empirical approach, the mechanistic-empirical approach, and the full mechanistic approach. The empirical approach is based on the knowledge of some index properties, for example, the CBR, together with practical experience. The mechanistic-empirical approach is based on both empirical procedures and the principles of mechanics. In this approach, the pavement structure is analysed by using a mechanistic model for finding the stresses and strains in each layer. The pavement is then designed by comparing the analysis results with the empirical formulae of design criteria. In the full mechanistic approach, the use of empirical formulae is not necessary. The distresses can be determined as a part of the solution procedure by using such methods as the finite-element method. This is due to the fact that the geometry, non- homogeneity, anisotropy, and nonlinear material properties of the pavement layers can be modelled in a unified manner.

The Disturbed State Concept (DSC) is a mechanistic approach introduced by Professor C.S. Desai in 1974 (Sane et al., 2008). The DSC has been adopted by engineers to model the responses of several materials, both unbound and bound, (Akhaveissy et al., 2009; Park and Desai, 2000; Sane et al., 2008; Yu and Shi, 2009) as its nature is hierarchical and unified. It also uses a simplified approach with a lower number of parameters (Desai, 2007). It is believed that a versatile and unified approach for the constitutive modelling of materials can be provided by the DSC. Consequently, the DSC was selected for the modelling of HCTCRB in this study.

In this paper, the characteristics of shear strength parameters, resilient modulus, and permanent deformations in HCTCRB were investigated and the DSC was used for developing the constitutive model which is expected to lead to a better understanding of the beneficial uses of HCTCRB.

MATERIALS AND SPECIMEN PREPARATION

Crushed rock

The crushed rock samples used in this study were collected from the stockpile area of a local Gosnells Quarry and kept in sealed plastic bags. Its basic properties conformed to the Crushed Rock Base (CRB) Base course Specifications (Main Roads Western Australia, 2003).

Cement

Bagged cement, (product of Cockburn Cement Limited), in accordance with AS 3972-1977 standard (Australian Standard, 1997) of General Purpose (GP) Portland Cement, was used in this study. The chemical composition of the cement is shown in Table 1.

HCTCRB specimen preparation

By adhering to the MRWA's specification (Main Roads Western Australia, 2003), HCTCRB samples were produced by mixing wet crushed rock, of 100% optimum moisture content (OMC), with 2% by weight, of GP cement, in the mixer. They were then blended for at least 10 min until the mixture was uniform in texture and colour. After mixing, the mixture was kept in sealed plastic bags at room temperature for 7 days of the initial hydration period. On the 8th day, the mixture was re-mixed for at least 10 min in the same mixer, producing the resultant HCTCRB. It should be noted that this re-mixing process is to replicate the HCTCRB construction processes. After 7 days due to some progression in hydration reaction, a part of cement particles will be hydrated. Therefore remixing the mixture will break the hardened cement structure and will considerably reduce the final stiffness of stabilized soil.

The next step was to cast HCTCRB samples in the standard mould (100 mm in diameter and 200 mm in height) by using the modified compaction method, according to WA133.1 test method (Main Roads Western Australia, 2007). For each mould, the HCTCRB was divided into 8 layers and 25 blows of a hammer, with a 450 mm drop height and a lumped mass of 4.9 kg, were applied

(a) (b)

Figure 1. HCTCRB sample preparation; (a) setting up with bottom and top platen and (b) wrapped in rubber membrane and O-rings.

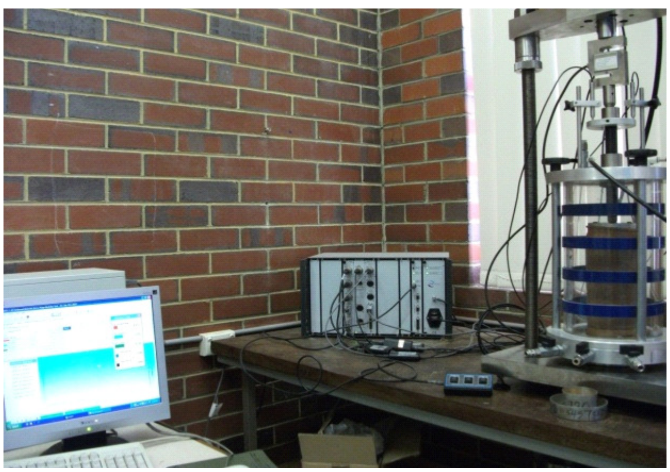


Figure 2. The UTM-14P digital servo control testing machine.

to each layer. To increase the bonding between layers, the surface of each layer was scarified to around 6 mm deep before compaction of the next layer. After compaction of each specimen, its weight was taken and recorded.

Specimens, as illustrated in Figure 1, were then prepared for testing, firstly by carefully removing the mould. The specimen's weight, without the mould, was recorded again; it was then wrapped in plastic immediately and left overnight at room temperature. Following this, the plastic wrap was removed and the specimen placed on the bottom platen of the triaxial cell. The top platen was then put on the top of the specimen. Finally, the specimen, top platen, and bottom platen were wrapped in a rubber membrane and O-rings used to seal the top and bottom of the sample.

EXPERIMENTAL PROGRAM

The experimental program was composed mainly of static and cyclic load triaxial tests. The static load tests were conducted for determining the internal friction angle (Ø) and the cohesion (c) of HCTCRB. A Mohr-Coulomb failure envelop was then constructed by using the results of the static load tests. Cyclic load triaxial tests, or repeated load triaxial (RLT) tests, in accordance with the standard method of Austroads APRG 00/33-2000 (Voung and Brimble, 2000), of HCTCRB were performed to establish the relationships between its permanent deformation and resilient modulus versus the applied stress conditions. All tests were conducted in the Geomechanics Laboratory, Department of Civil Engineering, Curtin University.

All tests, except the compaction tests, were carried out using the UTM-14P digital servo control testing machine as seen in Figure 2. This machine can be used for static triaxial tests, RLT tests, resilient modulus tests and permanent deformation tests.

Table 2. Applied stress for permanent deformation test of base materials.

Stage	Applied stress (kPa)	
	Confining stress	Deviatoric stress
1	50	350
2	50	450
3	50	550

Compaction tests

Firstly, compaction tests conforming to MRWA Test Method WA 133.I (Main Roads Western Australia, 2006) were performed for finding the OMC and the maximum dry density (MDD) of crushed rock. The results indicated that the crushed rock had an average OMC of around 5.5% and an average MDD of around 2.27 T/m^3. The HCTCRB samples, used for the triaxial tests, were then prepared at 100% OMC of crushed rock. A series of test samples in this study were prepared at the 100% OMC of crushed rock which is slightly different (that is, 0.01%) from the OMC of the crushed rock and cement mixture (Jitsangiam and Nikraz, 2009).

Static triaxial tests

The shear strength parameters (c and Ø) of HCTCRB were determined by conducting the standard drained triaxial compression tests. During testing, suction was not measured, and the specimens were tested under compaction conditions (unsaturated conditions) by applying three constant confining stresses, that is, 50, 100 and 150 kPa. It would be noted that a range of confining pressured used for static triaxial tests in this study was designed to cover the stress conditions of Austroads-APRG 00/33 standard. The samples were loaded until failure was reached.

Permanent deformation tests

As mentioned above, the Austroads-APRG 00/33 standard was adopted for the testing of permanent deformation. The samples were tested at three different stages of deviatoric stresses, as listed in Table 2, and a 10,000-cycle repeated load was applied at each stage.

The samples were placed into the testing machine with the cyclic axial load exerted by a feedback-controlled high pressure air actuator capable of accurately applying a stress pulse, following the

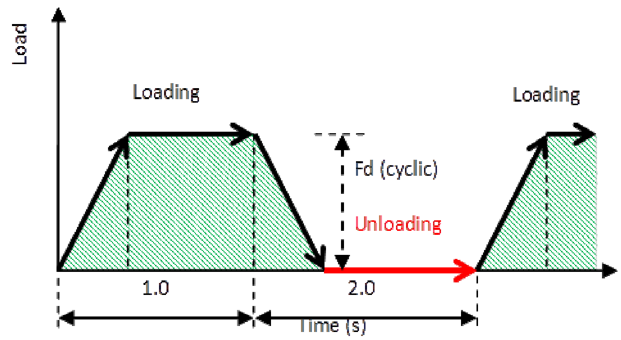


Figure 3. Waveform of the vertical cyclic load (Austroads, 2007).

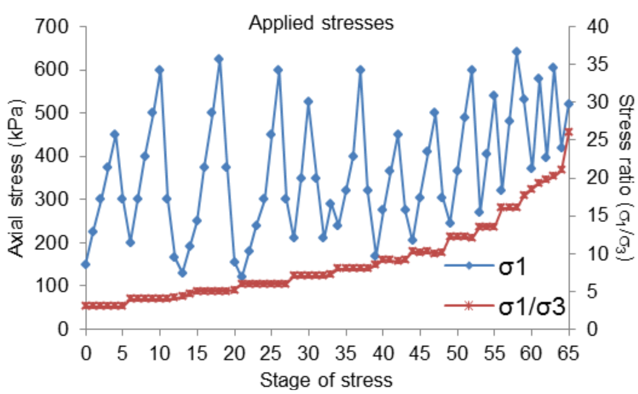


Figure 4. The 66-stages of stress according to the Austroads-APRG 00/33 standard.

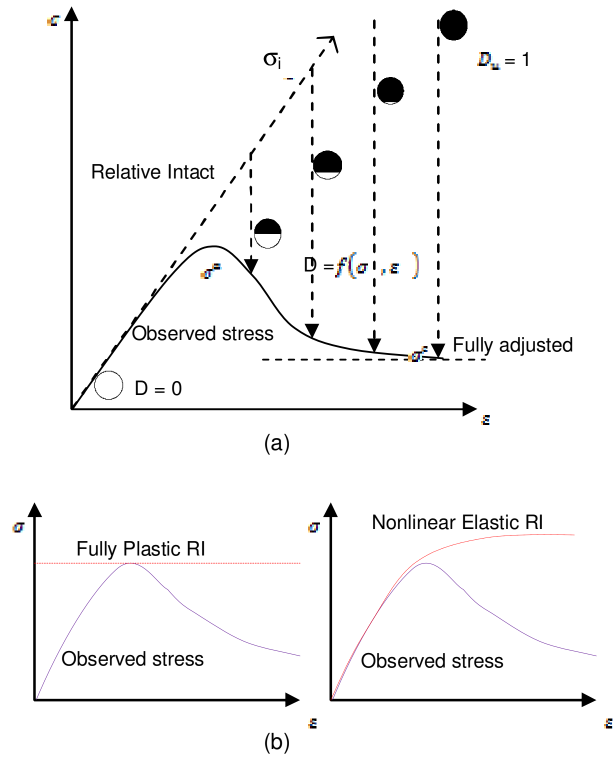


Figure 5. (a) Representation of DSC with linear elastic RI; (b) Examples of RI model (Desai, 2001).

standard. The vertical axial load of trapezoidal waveform, as shown in Figure 3, with a frequency of 0.33 Hz, was conveyed by the machine. The lateral pressure (confining stress) surrounding the samples was generated by a closed loop controlled actuator and applied to the samples by air pressure.

Resilient modulus tests

Similar to the permanent deformation tests, the resilient modulus tests were conducted following the Austroads-APRG 00/33 standard, by applying a 66-stage of stress (Figure 4), sequentially on the samples. The stress ratios of the Austroads-APRG 00/33 standard (σ_1/σ_3) were varied from 3 to 26. The longitudinal deformations of the specimens were measured by the externally linear variable differential transducer (LVDT), which was firmly attached on the top of the load cell. The testing machine, load cell, and LVDT were connected to a control and data acquisition system (CDAS) which provided the data acquisition, control signals, and signal conditioning. All test results were recorded and interpreted by computer software which was connected to CDAS.

For each sample, before starting the resilient modulus tests, 1,000 loading cycles of pre-conditioning were applied to the end caps in order to bed them in to the specimen, thereby making the applied stresses and resilient strains more stable under the imposed stress conditions. For the resilient modulus test, all 66 applications of stress were performed by applying a 200-cycle of loading to the sample at each stage.

DISTURBED STATE CONCEPT

The main idea of the DSC is that the distribution of the loading of mixtures in material can be represented as the interaction between its components. The self-adjustment of the material's microstructure, which can involve decay (damage) or growth (healing), is considered to be a material part of the relatively intact (RI) or "continuum" state and the fully adjusted (FA) state. The behaviour of materials exhibited through the interacting mechanisms of components in a mixture can be expressed in terms of the responses of the components, connected through a coupling function called the disturbance function (D). The disturbance can be expressed in any term that is required by engineers, such as stress, modulus, void, area, mass, velocity, etc. (Desai, 2001)

Relative Intact (RI) State

The RI state is the response of the material, which excludes the effects of the factors that make the observed behaviour of the material deviate from the given RI state, and it is relative in this sense. A model of elasticity or plasticity with an associative response, or any other suitable continuum model (viscoplastic, thermoviscoplastic, etc), can be characterised by its RI behaviour.

Fully Adjusted (FA) State

The FA material possesses strength properties and certain deformations. Usually, the FA state can be determined based on the ultimate disturbance, D_u, as the FA state cannot be measured in the laboratory.

Figure 5, for instance, shows the schematics of stress-strain

Table 3. Characteristics of static triaxial tests of HCTCRB.

Test	Confining Stress (kPa)	Wet Density (ton/m^3)	Dry Density (ton/m^3)	Moisture content* (%)
1	50	2.22	2.12	4.52
2	100	2.19	2.09	4.64
3	150	2.19	2.10	4.48

* After 7-day hydration period.

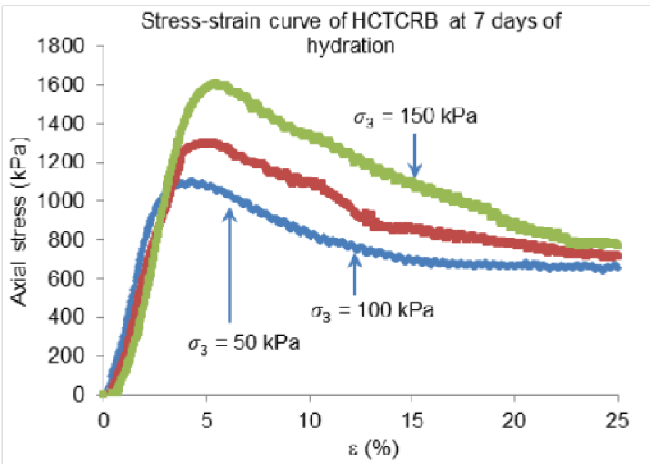


Figure 6. The relationships between deviatoric stress and strain for various confining stressors.

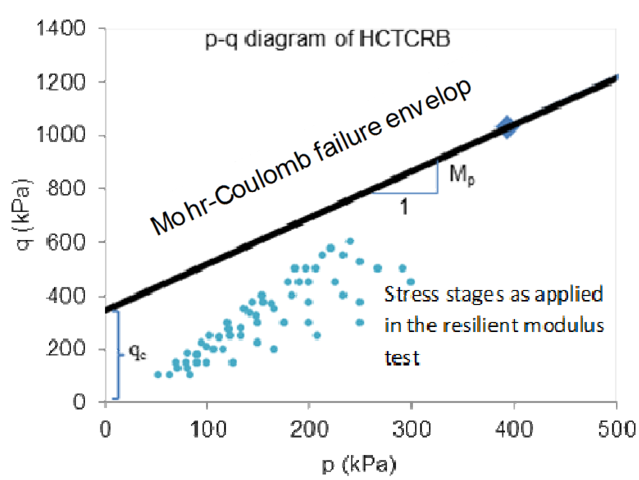


Figure 7. The p-q diagram for showing the stress stages of the resilient modulus test following the Austroads-APRG 00/33 standard and compared to the Mohr-Coulomb failure envelop.

behaviour. The disturbed state is the difference between the RI stress and the observed stress. It is a function of stress and strain, D = f(σ,ε), and its value is gradually increased from zero at the origin, to D_u at the fully adjusted state.

The formulation of the Disturbed State Concept

The basic hypothesis of the DSC is that the stresses on any section of material are made up of the stressors at a particular point of the entire sectional area. The point can stay in the RI or the FA state, and the observed stress of the section is calculated from the summation of the stresses in the RI and the FA parts. This hypothesis can be written as Equation (1)

$$F^a = F^i + F^c \tag{1}$$

Dividing Equation (1) by sectional area and rearrange equation yields:

$$\sigma^a = (1 - D)\sigma^i + D\sigma^c \tag{2}$$

where F^a and σ^a are the observed force and stress respectively. F^i and σ^i are the force and stress in the relative intact part, and F^c and σ^c are the force and stress in the fully adjusted part.

Equation (2) is the basic equation for the DSC and we can use this equation to predict the response of the material. Normally, the disturbance function is the ratio of interested factors to the with regard to the FA state. The foregoing disturbance function can be expressed in terms of any material properties which can be measured by laboratory tests.

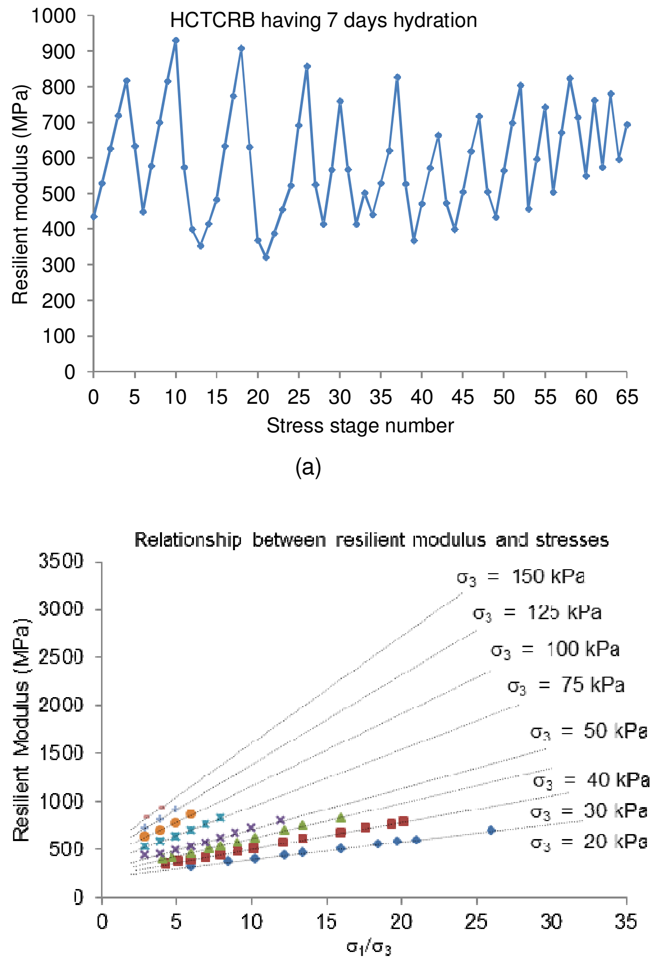
RESULTS

Deviatoric stress and strain relationship

The characteristics of static triaxial tests, as shown in Table 3, indicate that HCTCRB, after a 7-day hydration period, has a dry density and moisture content slightly less than that of crushed rock at OMC.

The relationships between deviatoric stress and axial strain for various confining stress are depicted in Figure 6. From observation, the ultimate strength, and the strain at ultimate strength become greater when the confining stress is increased. During the post-peak regime, after ultimate strength is reached, the strain increases as the stress reduces. Based on the results, this characteristic is normally described as strain-softening, and it is similar to the behaviour of dense granular materials.

These results were interpreted by using a Mohr-Coulomb failure law (Lamb and Whitman, 1979), as shown in Figure 7. On the p-q diagram, the Mohr-Coulomb failure was defined in terms of the principal stresses, σ_1, σ_2, and σ_3 where σ_1 is the major principal



(a)

(b)

Figure 8. The results from the resilient modulus test: (a) resilient modulus value and (b) relationship between the resilient modulus and the applied stresses.

stress, σ_2 and σ_3 are the intermediate or minor principal stresses. The mean applied stress, $p = (\sigma_1 + \sigma_2 + \sigma_3) / 3$, is plotted against the deviatoric stress, $q = (\sigma_1 - \sigma_3)$ and the Mohr-Coulomb failure envelop is a straight line, having the inclined slope of 1.723 ($= M_p = q / p$) and it intercepts the deviatoric stress at 339 kPa ($= q_c$). By plotting the conventional Mohr-Coulomb stress space, it indicates that the internal friction angle (Ø) at ultimate strength is approximately 43° and the apparent cohesion (c) is approximately 168 kPa.

The results show that HCTCRB can be characterised as a cohesive granular material (that is, c and Ø are the shear strength parameters). Its behaviour strongly depends upon the degree of the internal friction angle and the cohesion factor. The Mohr-Coulomb failure envelope was also used to check the condition of the materials while the resilient modulus tests were being performed.

Resilient modulus and applied stress relationship

Generally, the resilient modulus of HCTCRB can be considered as an elastic property, as the samples were tested under an elastic loading regime in which all applied stresses are under the Mohr-Coulomb failure envelope, as shown in Figure 7. In addition, this means the HCTCRB samples did not fail even after the resilient modulus tests were finished. In theoretical definitions, the resilient modulus is the ratio of the repeated deviatoric stress to the recoverable (or resilient) axial strain, as shown below:

$$M_r = \frac{\sigma_d}{\varepsilon_r} \tag{3}$$

Essentially, the relationship between the resilient modulus and the applied stress is nonlinear and there are two significant models, namely the K-θ model (Hick and Monismith, 1971) and the Uzan model (Uzan, 1985), which are suitable for the characterisation of granular materials. However, a study by Nikraz and Jitsangiam (2007) indicated that reasonably accurate results for the characterisation of the resilient modulus of HCTCRB were provided by using the K-θ model. Consequently, in this study, the resilient modulus model of HCTCRB derived from the DSC was compared to the K-θ model.

The K-θ model, which was introduced by Seed, has been in used since 1962 (Seed et al., 1962). It is a nonlinear model based on a stress-dependent power function. The model uses a curve-fitting approach with regression constants k_1 and k_2 as shown in Equation (4)

$$M_r \text{ (MPa)} = k_1\,\theta^{k_2} \tag{4}$$

where σ_1 is the axial stress (kPa), σ_2 is the confining stress (kPa), σ_3 is the confining stress (kPa), and θ is the bulk stress ($= \sigma_1 + \sigma_2 + \sigma_3$).

Based on the experiment results as seen in Figure 8, the regression constants k_1 and k_2 were around 10.15 and 0.6637 respectively. Therefore, the representative K-θ model of HCTCRB used in this study can be expressed as:

$$M_r \text{ (MPa)} = 10.15\theta^{0.6637} \tag{5}$$

With the DSC model, the resilient modulus can be found by dividing both sides of Equation (2) by the resilient strain (ε_r), thus we obtain:

$$M_r^a = (1 - D)M_r^i + DM_r^c \tag{6}$$

The disturbance function was calculated by:

$$D = \frac{(M_r^i - M_r^a)}{(M_r^i - M_r^c)} \tag{7}$$

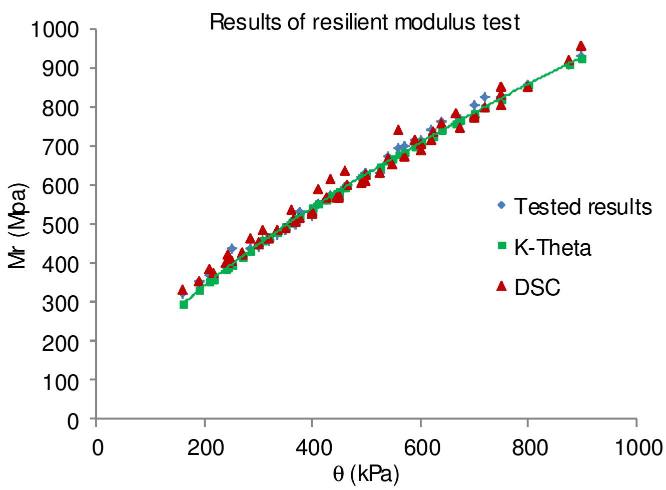


Figure 9. The illustrator used for comparison of the models with the test results.

In this study, the disturbance function, Equation (7), and the linear elastic RI response were used to back predict the permanent deformation and the resilient modulus of the HCTCRB specimens.

By using the trial and error method applied with the averages procedure, the disturbance function (D) can be expressed as:

$$D = \frac{[(2.400)(\sigma_3)+165.00]}{[(3.075)(\sigma_3)+165.00]} \tag{8}$$

Subsuming Equation (8) into Equation (6) and rearranging the equation to conform to the DSC formula, yields:

$$M_r \text{ (MPa)} = \left\{\frac{[(0.675)(\sigma_3)]}{[(3.075)(\sigma_3)+165.00]}\right\}(M_r^i) + \left\{\frac{[(2.400)(\sigma_3)+165.000]}{[(3.075)(\sigma_3)+165.00]}\right\}(M_r^c) \tag{9}$$

Or we can rearrange Equation (9) in the form of stress-strain as:

$$\frac{\sigma^a}{\varepsilon_r} = \left\{\frac{[(0.675)(\sigma_3)]}{[(3.075)(\sigma_3)+165.00]}\right\}\left\{\frac{\sigma_1}{\frac{\sigma_3}{[(3.075)(\sigma_3)+165.00]}}\right\} + \left\{\frac{[(2.400)(\sigma_3)+165.000]}{[(3.075)(\sigma_3)+165.00]}\right\}\left\{\frac{\sigma_3}{\frac{\sigma_3}{[(3.075)(\sigma_3)+165.00]}}\right\} \tag{10}$$

where M_r^c = (3.075)(σ_3) + 165.00 (the resilient modulus in fully adjusted part; MPa), M_r^i = M_r^c(σ_1 / σ_3) (the resilient modulus in relative intact part; MPa) and $\varepsilon_r = \sigma_3$ / (3.075σ_3 + 165.00). And $\sigma_2 = \sigma_3$ in this study.

Equations (8) and (9) show that the disturbed function is a function of confining stress (σ_3) and the relative intact resilient modulus is a function of stress ratio (σ_1/σ_3).

Figure 9 shows the use of the DSC model and K-θ model compared with the results from the resilient modulus test. It indicates that the DSC model gives reasonably accurate results that are comparable with the K-θ model. However, the data (ε_r) for predicting the permanent deformation can be retrieved from the DSC model only.

Permanent deformation and relationship to cyclic loading

Permanent deformation of road pavement, particularly along the wheel path, is a result of both the prevailing load and the material having insufficient stability to resist the environmental conditions (Austroads, 2004). Although the permanent deformation of base course materials is not included as part of the design criteria failure in the Austroads standard, the addition of this variable is worthy of consideration for Western Australia roads because most of the roads in Western Australia are constructed as with thin asphalt pavement of around 30 mm. This differs from the Austroads standard which suits for the road having the thickness of wearing surface at least 40 mm, and only the permanent deformation of subgrade is a design criterion. This study however, used the simplified test procedure of the Austroads-APRG 00/33 standard for estimating the rutting characteristics of base course materials.

Because HCTCRB is derivative of soil material (granular material) the permanent deformation would thus be produced by the compaction of granular aggregates. Consider Figure 10(a), where the permanent strain is affected by both the magnitude of loading and the type of material. When the load is applied to the material where permanent deformation can be exhibited, the permanent strain increases at a lower rate during the period in which repeated loads are continuously applied. Then both permanent and recoverable strain becomes constant. Consequently, Figures 10 (a) and (b) are used to derive the equation for predicting permanent strain based on the DSC.

The test results of permanent deformation in HCTCRB are shown in Figure 11. In this study, the model suggested by G.T.H. Sweere from SAMARIS (2004), as shown in Equation (11), was adopted to model the permanent deformation of HCTCRB for comparison with the DSC model.

Similar to the K-θ model, G.T.H. Sweere's model is a nonlinear equation based on the number of cyclic loading power functions. This model is based on a curve-fitting approach, using regression constants a and b as shown in Equation (11). By applying these to the test results, a

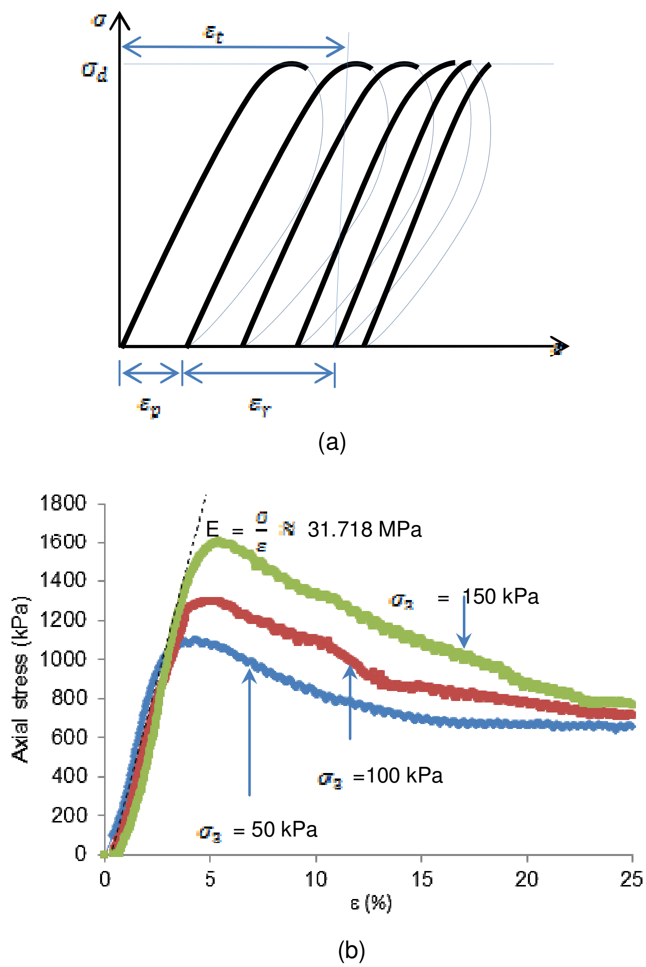


Figure 10. Stress-strain relationship of HCTCRB; (a) representation of permanent strain and recoverable strain of HCTCRB subjected to cyclic loadings and (b) representation of linear elastic aspect of HCTCRB sample based on the results from static triaxial tests.

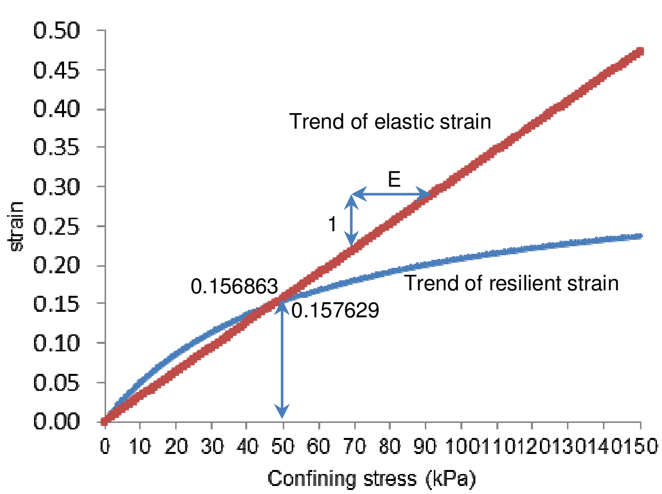


Figure 11. Trend of resilient and elastic strain against confining stress.

and b are found to be 0.0004518 and 0.6318 respectively. Thus,

$$\delta_p = (a)(N)^{(b)} = (0.0004518)(N)^{(0.6318)} \tag{11}$$

For the DSC model, the resilient strain (ε_r) and the results from static triaxial tests were used for finding the relationship between permanent deformation and applied stress.

Thus, in theory, the permanent strain can be calculated by deducting the resilient strain from the total strain (ε_t), with the equation written as:

$$\varepsilon_p = \varepsilon_t - \varepsilon_r \tag{12}$$

The total strain can be estimated using the results from the static triaxial tests, as shown in Figure 10(b), which are the elastic strain. Consider Figure 11, which shows the trend of elastic and resilient strains, suggesting that the permanent strain point (deduction of resilient strain from total strain), at the end of the resilient modulus test, converges at 0.25. At a confining stress of 50 kPa, 0.157629 and 0.156863 of strain can be read for elastic and resilient strain respectively. Equation (12) was then used to calculate the permanent strain, the result producing around 0.000767. Finally, the equation for predicting the permanent deformation of the HCTCRB sample was established, based on both power function and unit step function, as shown in Equation (13),

$$\delta_p^a = \delta_p^i + \delta_p^c = (d)\left(\frac{N}{10000}\right)^{(g)} + \sum_{m=1}^{n}(d)\left[\frac{(2)(\Delta\sigma_d)}{\sigma_d^i}\right]\langle N-(10000)(m)\rangle^{(g)} \tag{13}$$

where δ_p is the permanent deformation (mm), a, b, d, f and g are the regression constants, N is the number of loading cycles, δ_p^i is the permanent deformation in relative intact part (mm), δ_p^c is the permanent deformation in fully adjusted part (mm), σ_d^i is the deviatoric stress in the first stage of stress (kPa), $\Delta\sigma_d$ is the stress increment (= σ_d^m - σ_d^i), σ_1 is the axial stress ($\leq \sigma_y$), σ_3 is the confining stress,

$$d = \frac{\left(\frac{\sigma_3}{\sigma_1}\right)}{10000^g},\ f = (200)\left[\frac{\sigma_3}{317.2}\right]\left[\frac{3.075\sigma_3 - 152.2}{3.075\sigma_3 + 165}\right],$$

and $g = \dfrac{\log\left[\dfrac{f}{\left(\frac{\sigma_3}{\sigma_1}\right)}\right]}{\log(3)}$.

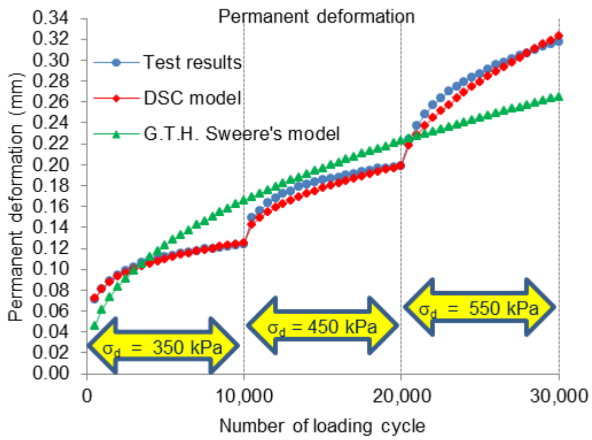


Figure 12. Results from the permanent deformation test and its model.

Equation (13) and Figure 12 indicate that the permanent deformation of HCTCRB is dominated by the applied load, both axial stress (σ_1) and confining stress (σ_3). The use of the proposed DSC model for predicting the permanent deformation of HCTCRB gives more accurate results than the use of G.T.H. Sweere's model.

Although all equations in this paper were derived based on the experimental data of HCTCRB, it can be applied for modelling of other materials, such as CRB. Only the constants in equation would be changed up on each material.

Conclusion

HCTCRB after a 7-day hydration period can be characterised as a cohesive granular material where its cohesion (c) and its internal friction angle (∅) are 168 kPa and 43° respectively. The resilient modulus and the permanent deformation can be modelled by using the DSC with reliable validation. The model can be incorporated to the analysis and design of pavement structure. However, the models were derived from the results of an experiment in accordance with the Austroads -APRG 00/33 standard; further research and validation with respect to field behaviour and simulation of pavement behaviour and characteristics should be performed. The application of the proposed DSC model requires further investigation to determine whether these models can be used to improve the current method of analysis and design of structural pavement.

FURTHER RESEARCH

The results from this preliminary study reveal the potential of the DSC for developing the material model of HCTCRB. However, further works are being performed to investigate relevant effecting parameter, including the effect of hydration period and the effect of dry back condition on the resilient modulus and the permanent deformation of the specimen of the HCTCRB material.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Curtin Pavement Research Group (Curtin-PRG) for all their help, support and valuable recommendations. Thanks go to Dr Komsun Siripun for providing some of the experimental results derived from his study. In addition, thanks are extended to Curtin University and Kasetsart University, Chalermphrakiat Sakon Nakhon Province Campus for the grant provided via Curtin International Postgraduate Research Scholarship (CIPRS).

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