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Characterisation, Analysis and Design of Hydrated Cement Treated Crushed Rock Base as a Road Base Material in Western Australia

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Abstract: Hydrated Cement Treated Crushed Rock Base (HCTCRB) is widely used as a base course in Western Australian pavements. HCTCRB has been designed and used as a basis for empirical approaches and in empirical practices. These methods are not all-encompassing enough to adequately explain the behaviour of HCTCRB in the field. Recent developments in mechanistic approaches have proven more reliable in the design and analysis of pavement, making it possible to more effectively document the characteristics of HCTCRB. The aim of this study was to carry out laboratory testing to assess the mechanical characteristics of HCTCRB. Conventional triaxial tests and repeated load triaxial tests (RLT tests) were performed. Factors affecting the performance of HCTCRB, namely hydration periods and the amount of added water were also investigated. It was found that the shear strength parameters of HCTCRB were 177 kPa for cohesion (c) and 42° for the internal friction angle (ϕ). The hydration period, and the water added in this investigation affected the performance of HCTCRB. However, the related trends associated with such factors could not be assessed. All HCTCRB samples showed stress-dependency behaviour. Based on the stress stages of this experiment, the resilient modulus values of HCTCRB ranged from 300 MPa to 1100 MPa. CIRCLY, a computer program based on the multi-layer elastic theory was used in the mechanistic approach to pavement design and analysis, to determine the performance of a typical pavement model using HCTCRB as a base course layer. The mechanistic pavement design parameters for HCTCRB as a base course material were then introduced. The analysis suggests that the suitable depth for HCTCRB as a base layer for WA roads is at least 185 mm for the design equivalent standard axle (ESA) of 10 million.

Key words: Hydrated cement treated crushed rock base (HCTCRB), base course, pavement, repeated load triaxial (RLT) test, mechanistic pavement analysis and design.

1. Introduction

Traditional base course, such as crushed rock, has over time, proven insufficient to sustain the ever-increasing traffic volume and traffic loads on WA roads. This has brought about the introduction of cement to improve the engineering properties of the parent material; cement stabilisation aims to increase the strength and reduce moisture susceptibility of base course [1]. Crushed rock, with the addition of 2% General Purpose (GP) Portland cement by mass of crushed rock, termed Hydrated Cemented Treated Crushed Rock Base (HCTCRB), is commonly used as a base course material in Western Australian roads. HCTCRB is dissimilar to conventional cement treated material in that it involves two additional processes, i.e., the hydration process and the retreated process (to break the bond generated through hydration). This stabilisation technique, unique to WA, aims to reduce the risk of the material becoming too stiff and prone to fatigue [1].

As a result of early damage to new highways and roads in WA, MRWA, its contractors and organisations have recently attempted to identify the causes of the damage. The aim has been to discover whether factors involved in HCTCRB's manufacture, road design, and/or construction are partly responsible for the problems. HCTCRB was developed, and previously

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proven to be successful, for only empirically based periods of time, therefore damage was only observed over time and with experience. The causes of noticeable early damage of pavements on current projects require a more effective method of investigation. All of the factors involved in HCTCRB use under today's pavement conditions have been extrapolated far beyond the bounds of the original data, and current experience shows that these require detailed reinvestigation. This paper sets out to remedy the shortcomings of current HCTCRB methods.

HCTCRB is currently produced daily in large volumes and then kept in stockpiles for an appropriate hydration period. It is a complex procedure to keep hydration periods uniform and control the appropriate amount of water added to HCTCRB. Furthermore, there are some doubts as to the effect of hydration periods and the amounts of added water on material performance. Both factors require investigation to allow more effective use of HCTCRB. Understanding HCTCRB with respect to shear strength, resilient modulus, and permanent deformation characteristics is crucial to improving pavement analysis and design.

To gain a better understanding of the use of the material, the objectives of this study include:

- analysing the shear strength parameters, resilient modulus, and permanent deformation of HCTCRB
- reporting on these characteristics
- investigating the effects of hydration periods and added water on HCTCRB performance, and,
- determining pavement design parameters for HCTCRB based on mechanistic pavement design.

2. Experimental Design

2.1 Materials

Hydrated Cement Treated Crushed Rock Base (HCTCRB)

Hydrated cement treated crushed rock base (HCTCRB) is made by blending 2 per cent of General Purpose (GP) or Portland cement, following the standard of AS 3972-1977 [2], with a standard crushed rock base [3]. In this experiment HCTCRB was 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 MRWA Test Method WA 133.1 [4]), during the initial 7-day hydration period.

2.2 Laboratory Program and Testing

The fresh crushed rock and HCTCRB (the fresh crushed rock with 2% cement by dry weight) were initially tested with a compaction test, in accordance with MRWA Test Method WA 133.1 [5], to establish the compaction curves for determining optimum moisture content (OMC). HCTCRB samples for Repeated Load Triaxial (RLT) tests were then prepared at 100%, 90%, and 80% OMC of HCTCRB by the varying hydration periods of 7, 14, and 30 days.

The test program consisted of both conventional static triaxial tests and RLT tests, complying with the standard method of Austroads APRG 00/33-2000. The static tests were carried out to establish the cohesion, c, and the internal friction angle, ϕ, of HCTCRB under the conditions of 100% OMC at a 7-day hydration period and 28-day curing time, including establishing the Mohr-Coulomb failure envelope. Repeated loading tests were performed to establish the relationship between the applied stress conditions and the resilient modulus values along with the permanent deformation behavior of HCTCRB.

2.2.1 Specimen Preparation

All tested HCTCRB samples were prepared based upon 100%, 90%, and 80% OMC of HCTCRB. The mixing procedure entailed the addition of 2% GP cement (dry mass) to wet crushed rock under the conditions of 100%, 90%, and 80% OMC of HCTCRB. Each sample was then blended in a mixing machine for at least 10 minutes or until the mixture became uniform in color and texture. The mixture was then kept at a controlled temperature of 25 degrees, in sealed plastic bags for the periods of 7 days, 14 days and 30 days. Following this, any mixture of a particular OMC and hydration period, was then re-mixed in the same mixing machine for at least 10 minutes. The compaction processes were then carried out using a standard mould of 100 mm in diameter and 200 mm in height and following a modified compaction method. Compaction of 8 layers was achieved with 25 blows of a 4.9 kg rammer from a 450 mm drop. The specimens were kept for 28 days, wrapped and inside the mould to prevent moisture loss.

2.2.2 Static Triaxial Tests

Drained triaxial compression tests were conducted to determine the shear strength parameters (c and ϕ) of HCTCRB. Only specimens of 100% OMC condition at a 7-day hydration period and 28-day curing time were tested under unsaturated conditions, based on the HCTCRB standard. Suction was not measured during triaxial testing. In these tests, the specimen's response was measured at three different constant confining pressures: 50 kPa, 100 kPa, and 150 kPa, using the same triaxial equipment and system for the measurement of resilient modulus and permanent deformation.

2.2.3 Resilient Modulus Tests and Permanent Deformation Tests

The standard method of Austroads APRG 00/33-2000 [6] for Repeated Load Triaxial Test Methods was followed for the resilient modulus tests and the permanent deformation tests. The UTM-14P digital servo-control testing machine, 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.

New specimens were prepared following the same procedure as described in the previous section. Permanent deformation testing was performed. In these tests, the specimens were loaded under stress in three stages at the ratios of the dynamic deviator stress, σ_d to the static confining stress, σ_3 as 350 to 150, 450 to 150, and 550 to 150, respectively, each involving 10,000 cycles for each particular stress condition.

Following the permanent deformation tests, in accordance with this standard, the same specimens had stress applied sequentially and immediately by 65 stress stages in order to conduct the resilient modulus test. The objective of the test was to check the elastic condition of each specimen throughout the multiple loading stress stages. This process simulated the variety and complexity of traffic loads impacting on pavement. Two hundred loading cycles for each stress stage were applied to the specimens.

2.2.4 Quality Control of All Tests

Triplicate tests were performed for each test and the averages of these three tests were reported as results. The coefficient of variation, CV (ratio of standard deviation to the mean) was less than 10% in all tests.

3 Test Results and Discussion

3.1 Static Triaxial Tests

Fig. 1 shows the static triaxial test results of HCTCRB on the p-q diagram where the Mohr-Coulomb failure was defined in terms of principal stresses (principal stresses being written as σ_1= the major principal stress and $\sigma_2 = \sigma_3$ = the intermediate or minor principal stress). The deviator stress, $q= (\sigma_1 - \sigma_3)$, was plotted against the mean applied stress, $p = (\sigma_1+2\sigma_3)/3$. The results shown in Fig. 1 indicate that the Mohr-Coulomb failure envelope (corresponding to the peak stresses) is linear for the stress range tested and has a characteristic in the 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, the failure properties correspond to an internal friction angle (ϕ) at a peak strength of 42° and an apparent cohesion (c) of 177 kPa.

The static triaxial test results of HCTCRB show that it exhibits cohesive granular material behaviour which is unlike that of non-cohesive granular materials such as sand and gravel. The behavior of HCTCRB depends strongly upon both the degree of cohesion and the internal friction angle.

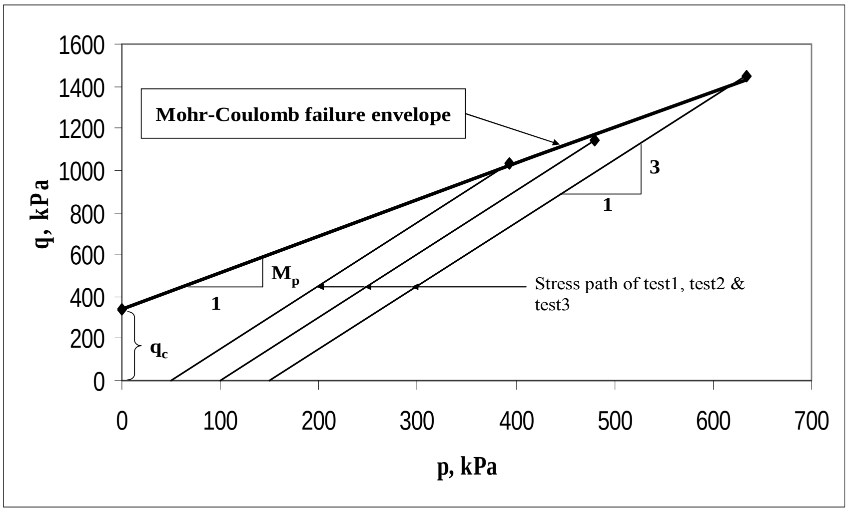


Fig. 1 Triaxial test results of HCTCRB in p-q stress spaces.

3.1.1 Resilient Modulus Tests and Permanent Deformation Test

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:

$$M_r = \frac{\sigma_d}{\varepsilon_r} \quad (1)$$

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.

Based on the specifications of HCTCRB, the results of HCTCRB at 100% OMC under a 7-day hydration period and a 28-day curing time show its characteristics and allow the determination of suitable mathematical models for the resilient modulus and permanent deformation of HCTCRB.

Fig. 2a shows the results of the resilient modulus which are plotted against the bulk stress ($\sigma_1+\sigma_2+\sigma_3$). Generally, the resilient modulus is non-linear with respect to the magnitude of applied stresses. Fig. 2a also shows that the results of the resilient modulus of HCTCRB can be modelled reasonably effectively by using the K-Theta (K-θ) model [7]. The representative K-θ model of HCTCRB is shown in Eq. (2).

$$M_r = k_1\theta^{k_2} = 7.684\theta^{0.591} \quad (2)$$

where: M_r is the resilient modulus in MPa; θ is the bulk stress ($\sigma_1+\sigma_2+\sigma_3$) where ($\sigma_1=\sigma_3$); σ_1 is the major principal stress (axial stress); σ_3 is the minor principal stress (confining stress); and k_1= 7.684 and k_2= 0.591 are regression coefficients.

Fig. 2b shows the typical results of the permanent deformation test in terms of the relationship between the permanent deformation and the loading cycles for HCTCRB. Fig. 2b also displays the comparison of the measured permanent deformation values and the predicted values for a proposed permanent deformation model of HCTCRB. Fig. 2b suggests that permanent deformation can be modelled quite successsfully for HCTCRB by using the model suggested by Sweere, G.T.H from SAMARIS [8]. The proposed permanent deformation model of HCTCRB is shown in Eq. (3).

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

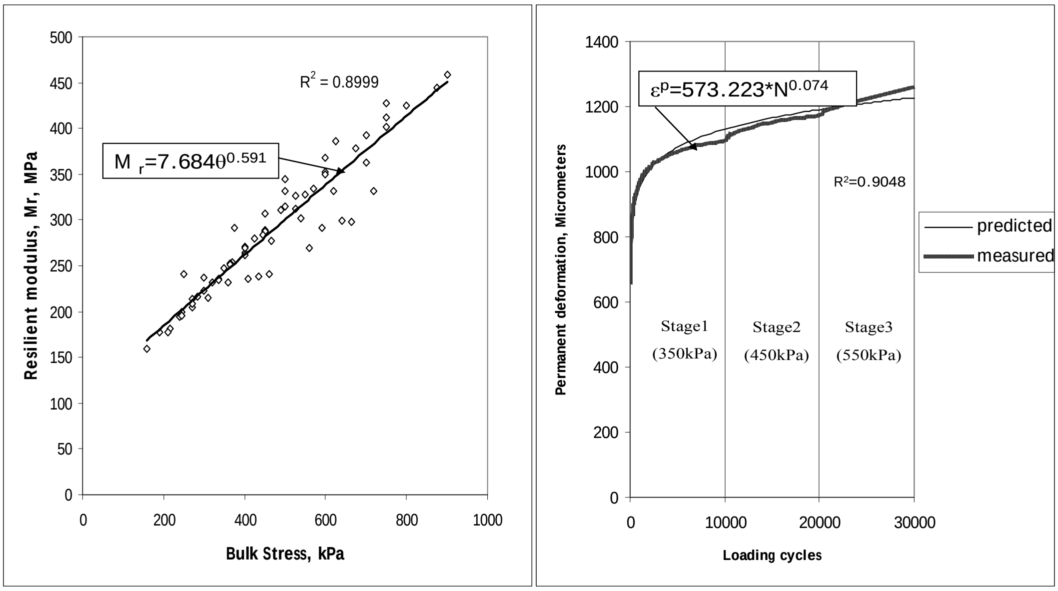
where: ε^p is the permanent deformation in microstrains or micrometers/meter; A=573.223 and B=0.074 are regression constants; N is the number of loading cycles.

3.1.2 The Effect of Hydration Periods and Water Added to HCTCRB Performance

Fig. 3 shows all the results of HCTCRB samples of 100% OMC, 90% OMC, and 80% OMC at 7-day, 14-day, and 30-day hydration periods. Resilient modulus values are plotted against loading sequences.

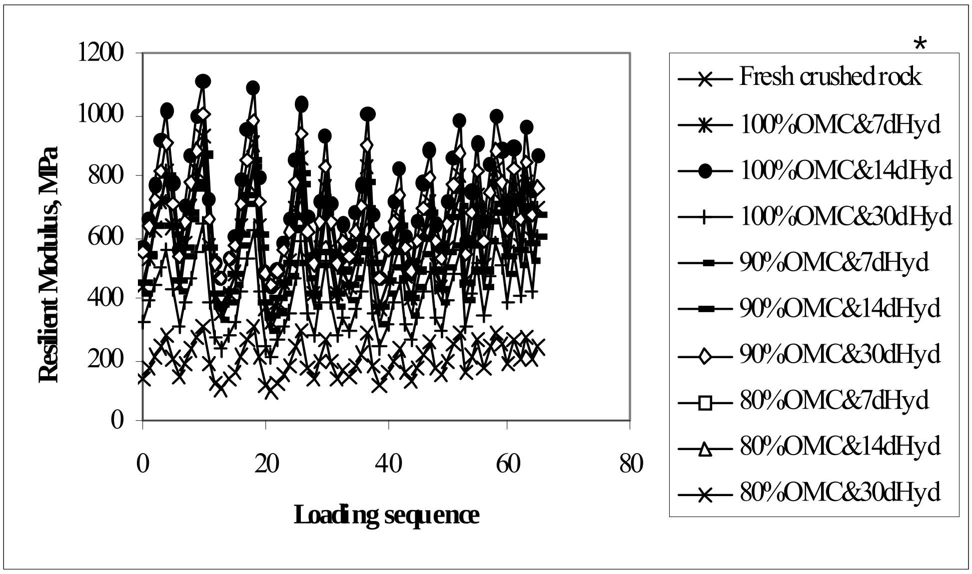
All HCTCRB samples show significantly higher resilient modulus values than CRB. This shows that the resilient modulus characteristics of CRB can be improved by utilising the HCTCRB technique. Further details are outlined below:

Different resilient modulus characteristics of HCTCRB were found at all percentages of OMC in the 7, 14 and 30-day periods. The hydration period and water added in this investigation therefore affected the performance of HCTCRB in terms of its resilient modulus characteristics. These uncertainties in the HCTCRB production process resulted from the re-treating before compaction. During the hydration period, the chemical reaction between cement and water occurred which generated the cementitious bonding. After the completion of the desired hydration



(a) **(b)**

Fig. 2 The resilient modulus results and permanent deformation results.



* x OMC& y dHyd means HCTCRB at x % OMC water added and y days of hydration period

Fig. 3 The resilient modulus results and permanent deformation results.

periods, the mixtures were then put into the mixer to break the cementitious bonds. This procedure is called re-treating or the rework process, and it aims to maintain the material as an unbound base. Although a compaction process is performed straight after the re-treating process, the chemical bonding significant to the strength, is difficult to generate further. The mixture is only compacted from the same energy effort. This explains why the resilient modulus characteristics of all samples under diffent conditions of water and hydration periods are slightly different.

All HCTCRB samples exhibited stress-dependency behavior.

Based on 65 stress level tests, the resilient modulus values for all HCTCRB samples under these conditions were in-between 300 MPa and 1100 MPa.

3.1.3 General Pavement Design for HCTCRB for Road Bases

Based on the mechanistic pavement analysis and design for HCTCRB, its modulus test results are shown to be stress-dependent. It was found that the stress dependency of the vertical modulus can be modelled with the elastic model CIRCLY [9] by dividing the granular layers into several sub-layers. From the mechanistic design steps, the pavement structure scenario was established from the generally used pavement cross-section in Western Australia which contains: asphalt as a road surface, HCTCRB as a road base, crushed limestone as a road subbase, and Perth silty sand as a road subgrade. The pavement was analysed to find the vertical and the horizontal stresses occurring in the HCTCRB base layer by using the MICHPAVE finite element program [10]. The suitable resilient modulus of HCTCRB for mechanistic design was determined based on the laboratory results.

CIRCLY 5.0 was used for the mechanistic pavement design to determine the traffic loading intensity of pavement structures. It is an integral component of the Austroads Pavement Design Guide, widely used in Australia and New Zealand. The system calculates the cumulative damage induced by a traffic spectrum consisting of any combination of user-specified vehicle types and load configurations, as well as using the usual equivalent single wheel and axle load approximations. CIRCLY is based on integral transformation techniques and offers significant advantages over linear elastic analysis techniques, such as the finite element method.

In this study, as computer programs are relevant to pavement analysis and design, a suitable resilient modulus model is an important input parameter of the program. Generally, it is non-linear with respect to the magnitude of applied stresses. Fig. 2a indicates that the K-Theta (K-θ) model [7], which is the significant model for the non-linear behaviour of granular materials, is suitable to model the stress dependence for HCTCRB, as shown in Fig. 2a.

Table 1 shows a summary of the pavement configuration analysed in CIRCLY 5.0. Fig. 4 illustrates the results from CIRCLY 5.0 in terms of the plotting of the traffic load intensity of an Equivalent Single Axial (ESA) of 80 kN, plotted against the varied depth of HCTCRB. CIRCLY 5.0 is capable of conducting parametric analysis with one independent parameter being an HCTCRB depth of 150 mm to 350 mm. This figure indicates that with a depth of more than 185 mm, HCTCRB could still resist a traffic load higher than the design (1.0×10^7 ESA). The design ESA is the estimated traffic volume for the whole of the service life of a road pavement. The design ESA was calculated based on cumulative data from current traffic conditions in target areas. This included some assumptions around forecasting such as conditions in

Table 1 Pavement configurations used in the CIRCLY analysis.

C&D aggregate pavement		Design traffic load = 1.0×10^7 ESA		
Layer No.	Material ID	Isotropy	Modulus (MPa)	Layer thickness (mm)
1	Asphalt	Isotropic	3000	40
2	HCTCRB	Anisotropic	750	150-350
3	Unbound granular crushed limestone	Anisotropic	350	200
4	Subgrade CBR 15	Anisotropic	150	Infinite

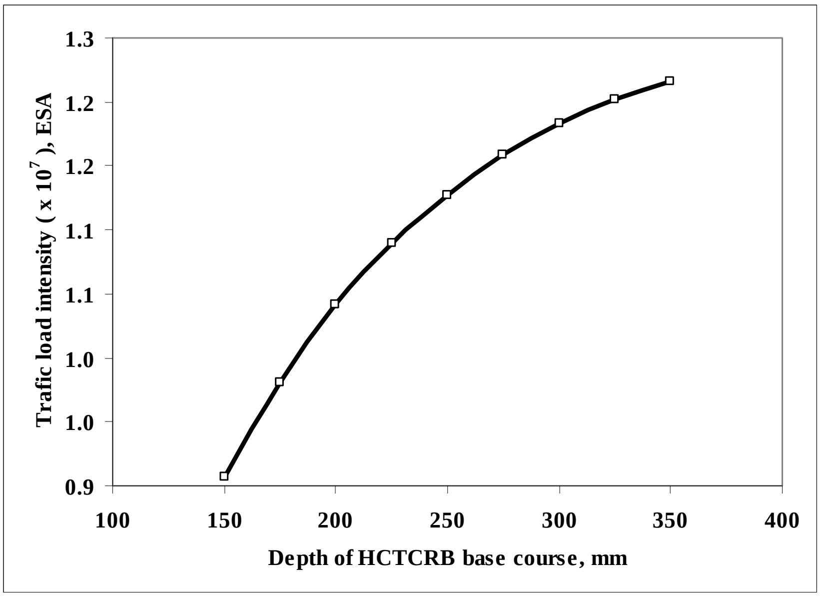


Fig. 4 CIRCLY analysis results.

the future. From these results, it can be suggested that the appropriate depth for using HCTCRB as a base layer should be at least 185 mm.

4. Conclusions

The mechanical behaviour of Hydrated Cement Treated Crushed Rock Base (HCTCRB), which is normally used as a base course material in Western Australian pavement, was investigated by means of static and repeated load triaxial tests. The repeated load triaxial tests were carried out in the form of a resilient modulus test and a permanent deformation test. These tests were conducted in order to provide insight into the resilient and permanent deformation characteristics of the material in question, under the real conditions of traffic loading which were simulated in these tests.

It has been shown that HCTCRB can be characterised as an apparently cohesive granular material with a cohesion (c) of 177 kPa and an 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 can be modelled using the K-θ model. Permanent deformation characteristics can be modelled using Sweere’s model.

In this investigation, the hydration period and added water affected the performance of the HCTCRB. However, the related trends usually associated with such factors could not be tracked. All HCTCRB samples showed stress-dependency behaviour. Based on the stress stages used in this experiment, the resilient modulus values of HCTCRB in this study were in the range of approximately 300 MPa to 1100 MPa.

In future designs for HCTCRB in road bases, following the typical model of pavement resulting from laboratory tests and the CIRCLY 5.0 program, it is suggested that:

The suitable depth of HCTCRB as a base layer for WA roads should be at least 185 mm.

The traffic load intensity of the HCTCRB - base course road is about 10 million ESA.

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References

[1] D. Harris and N. Lockwood, Pavements Engineering Report No. 2009/5 M, 2009, Main Roads Western Australia.

[2] Australian Standard, Portland and Blended Cements, 1997.

[3] Main Roads Western Australia, Crushed Rock Base Basecourse, 2003.

[4] Main Roads Western Australia, Dry Density/Moisture Content Relationship: Modified Compaction Fine and Medium Grained Soils, 1997.

[5] Main Roads Western Australia, Test Method (Aggregate), 2006.

[6] B. T. Voung and R. Brimble, 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), 2000, Austroads.

[7] R. G. Hick and C. L. Monosmith, Factors influencing the resilient response of granular materials, Highway Research Recond No. 345, 1971, pp. 15–31.

[8] SAMARIS, Selection and evaluation of models for prediction of permanent deformations of unbound granular materials in road pavement, Sustainable and Advanced MAterials for Road InfraStruture, 2004, p. 55.

[9] MINCAD Systems, CIRCLY 5 User Manual, 2004, Australia.

[10] R. S. Harichandran, M. S. Yeh and G. Y. Baladi, MICH-PAVE: A nonlinear finite element program for the analysis of flexible pavement, Transportation Research Record 1286 (1990) 123–131.