

CONSTRUCTION AND DEMOLITION (C&D) WASTE AS A ROAD BASE MATERIAL FOR WESTERN AUSTRALIA ROADS

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ABSTRACT

This paper describes a preliminary examination of the engineering issues relating to the utilisation of C&D waste as a base course material for Western Australia roads. A series of laboratory tests were performed during which Repeated Load Triaxial (RLT) tests were conducted to determine the resilient modulus and permanent deformation characteristics of C&D waste and the commonly used base course material, Crushed Rock Base (CRB), as a reference material. A comparison of test results of both materials was then made. CIRCLY, a computer program based on the multi-layer elastic theory was used in the mechanistic approach of pavement design and analysis to determine the performance of a typical pavement model using C&D as a base course layer. Based on the study's findings, C&D waste should be considered an adequate substitute for traditional aggregate in Western Australia road construction.

INTRODUCTION

C&D waste, regarded as a material with limited economic potential, can be identified as potentially having suitable material characteristics for a base course aggregate and may provide an ideal solution to minimise the problems of virgin material exhaustion while providing other various economic and environmental benefits.

This research aims to:

- i) determine whether the resilient modulus and permanent deformation behaviour of C&D waste under dynamic loading is equivalent to or better than those of Crushed Rock Base (CRB), the natural aggregate that satisfies Western Australia Mainroads (MRWA)'s specifications (MRWA, 2003) for a base course material.
- ii) provide information about C&D waste to promote its usage as a road construction aggregate with confidence in terms of its engineering impacts.

MATERIALS

C&D WASTE

The C&D waste that was investigated in this research came from the C&D Recycling Plant located at the Corner of Abernethy Road and the Great Eastern Highway Bypass, Hazelmere, Western Australia. The 20 mm graded recycled aggregate from C&D recycling is produced by feeding large pieces of construction and demolition waste into a jaw crusher. All construction and demolition waste is placed on a conveyor system and examined by workers who remove all unwanted plastic and timber materials. A large magnet removes steel pieces, the remaining waste is fed into the jaw crusher and the crushed waste or recycled aggregate is then passed through large screens to stockpiles.

CRUSHED ROCK BASE (CRB)

The crushed rock used in this study as a reference material was obtained from a local Gosnells quarry from which samples were also collected randomly from a stockpile area and kept in sealed plastic containers. These were re-checked, at the Department of Civil Engineering, Curtin University of Technology in the laboratory as to their conventional properties in accordance with CRB Specifications (MRWA, 2003).

The particle size distributions of the Crushed Rock Base (CRB) with C&D waste in this study comply with the specification in terms of gradation characteristics.

TESTING METHODOLOGY

The laboratory work involved testing the C&D waste and CRB in Repeat Load Triaxial (RLT) apparatus to determine the resilient modulus and permanent deformation characteristics of both. A comparison of the experimental results between C&D waste and CRB was made to evaluate its suitability. All tested samples were prepared under the condition of 100% optimum moisture content (OMC) and 100% maximum dry density (MDD) of the materials.

LABORATORY TESTING

C&D materials and the crushed rock were initially tested in terms of the compaction test in accordance with MRWA Test Method WA 133.1 (MRWA, 2006) to establish the compaction curve to determine its OMC and MDD. This resulted in an average MDD of the crushed rock base studied of 2.31 ton/m³ at OMC of 5.8% and an average MDD of C&D material of 1.92 ton/m³ at OMC of 13.5 %. All samples for triaxial tests then were made at 100% OMC of both materials

The test program was that RLT tests were performed to establish the relationships between the applied stress conditions and the resilient modulus values and the permanent deformation behaviour of both materials.

SPECIMEN PREPARATION

Based upon 100% OMC of both materials, compaction processes were carried out using a modified compaction method in a standard mould 100 mm in diameter and 200 mm in height. Compaction was achieved with 25 blows of a 4.9 kg rammer at a 450 mm drop height in 8 layers. To assure a good bond between the layers, each layer had to be scarified to a depth of 6 mm before the next layer was compacted. After compacting, the weight of each specimen and mould was determined and the specimen carefully removed from the mould. Immediately after removal, it was re-weighed and wrapped in plastic to prevent loss of moisture and left overnight before being transferred to the bottom platen of the triaxial cell. The top platen was placed on the specimen and a rubber membrane placed over the specimen and both platens. Finally the sample was sealed by o-rings top and bottom.

PERMANENT DEFORMATION AND RESILIENT MODULUS TESTS

The standard method of Austroads APRG 00/33-2000 (Young and Brimble, 2000) for Repeated Load Triaxial Test Method was followed for the resilient modulus 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 for permanent deformation as described in the previous section. Permanent deformation testing was performed first in accordance with Austroads – APRG 00/33 standard (Young and Brimble, 2000) . In this testing, the specimens were loaded with three stress stages, each involving 10,000 cycles at a stress condition of specific dynamic deviator stress from loading stage 1 to 3 as 350 kPa, 450 kPa, and 550 kPa, respectively, at all stages of constant static confining pressure of 50 kPa.

After the permanent deformation tests, in accordance with this standard, the same specimens were applied sequentially by a difference of the 65 stress stages straightaway to conduct resilient modulus tests, the objective of which was to check the elastic condition of each specimen throughout the multiple loading stress stages as shown in Figure 1. This process simulates the complicated traffic loading acting on a pavement. Two hundred loading cycles of each stress stage were applied to the specimens.

RESULTS AND DISCUSSION

REPEATED LOADING TRIAXIAL (RLT) TESTS

Permanent deformation

Permanent deformation testing aims to characterise the plastic strain response at one stress level over a large number of loading repetitions. In accordance with the standard of APRG 00/33-2000 (Young and Brimble, 2000), Figure 2 shows the typical results of the permanent deformation test in terms of the relationship between permanent deformation and loading cycles for both aggregates. It is clear from Figure 2 that the permanent deformation occurring in the C&D waste is larger than that of CRB in all loading cycles. However, it can be noted that at the end of the permanent deformation test, the final values of both aggregate have reached almost the same value, about 3.6 mm. Furthermore, from Figure 2, it

can be seen that the permanent deformation of the C&D waste is not dominated by the applied load in the testing range because when the applied loads increase from loading stage 1 to loading Stage 3, permanent deformation does not increase dramatically while CRB exhibits more stress dependency characteristics.

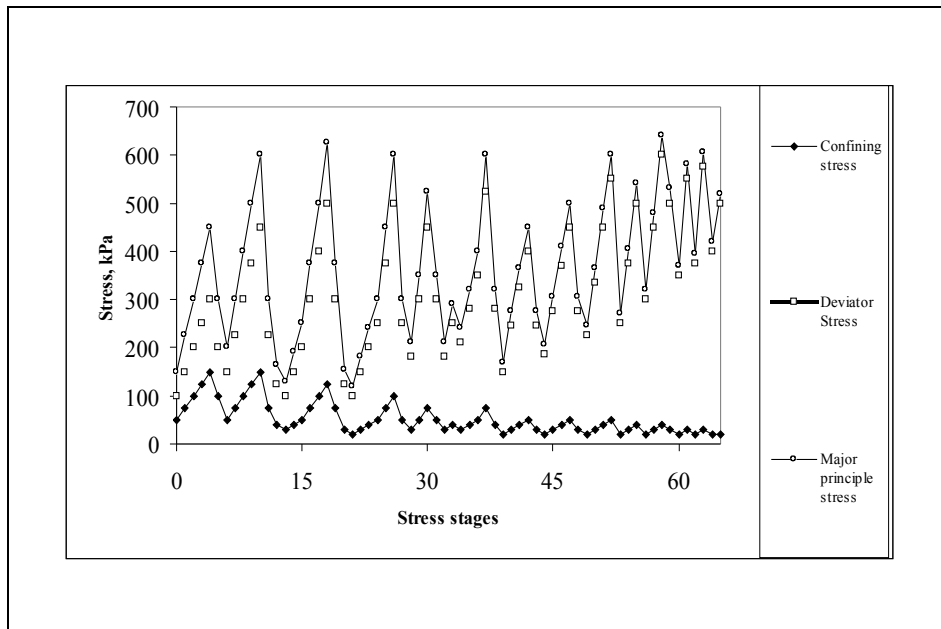


Figure 1: Applied stresses and its stress stages of the resilient modulus tests.

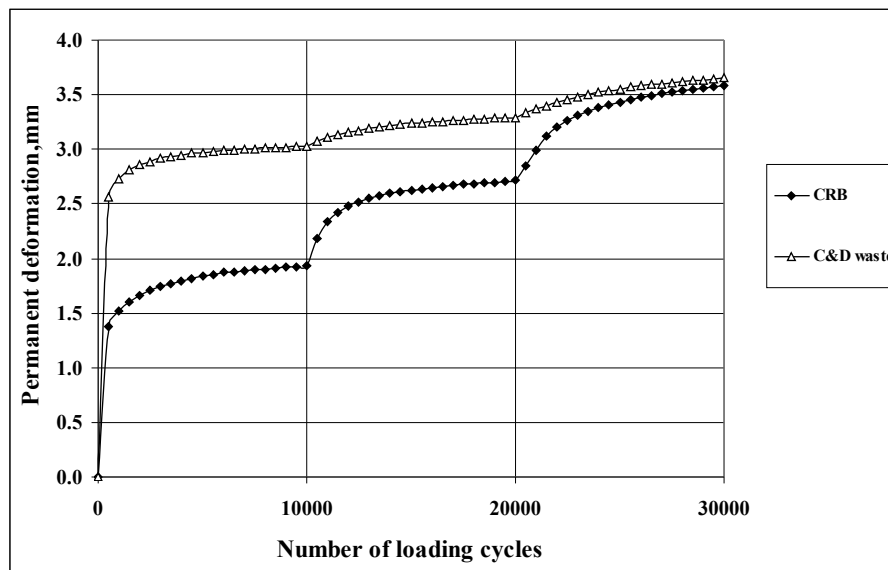


Figure 2: Permanent deformation test results.

Resilient modulus

Figure 3 shows the results of the resilient modulus tests between the C&D waste and CRB plotted against the number of loading sequences. Figure 3 indicates that the C&D waste provides very close resilient modulus values to the reference aggregate of CRB for all the different stress states applied on the tested specimen. This would result from the fact that the resilient modulus tests were conducted on the same specimen of the permanent deformation tests in which the specimens were re-compacted into the same level of a denser condition during the permanent deformation tests. Following the testing program, permanent deformation tests were performed as the preconditioning stage of the resilient

modulus tests. In general, the intent of the preconditioning loading phase is to induce any early settlement from a gap between a top platen and a specimen which is prone to occur so that the elastic strains remain during resilient modulus loading (Craig *et al.*, 2004). It should be noted that based on the permanent deformation results and resilient modulus characteristics, the C&D waste could be compacted to reach the dense condition of CRB and provide the same resilient characteristics of CRB that is the reference material.

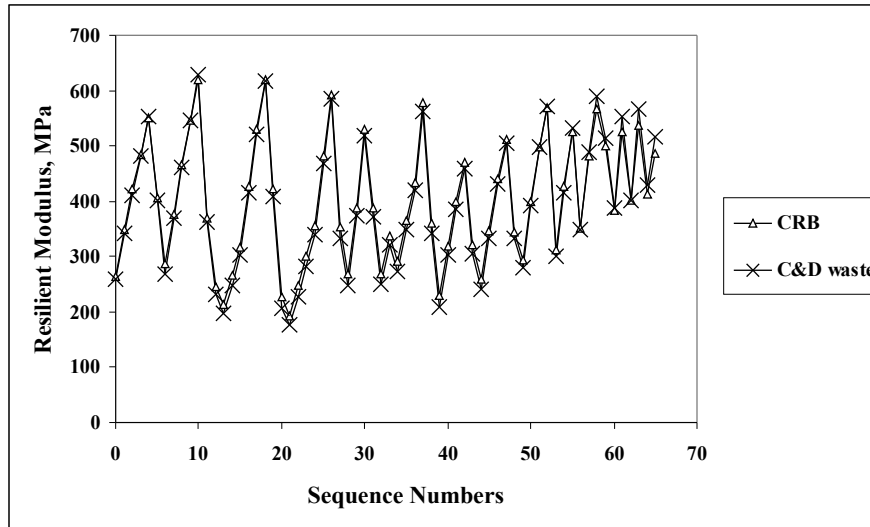


Figure 3: Resilient modulus results.

GENERAL PAVEMENT DESIGN ON THE C&D AGGREGATE FOR ROAD BASES

Based on the mechanistic pavement analysis and design, for the C&D aggregate, its modulus test result is stress dependent. It was found that the stress dependency of vertical modulus can be modelled by using the elastic model CIRCLY (MINCAD Systems, 2004) by dividing the granular layers into several sub-layers. From the mechanistic design step, the pavement structure scenario was established first 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 sub-base, and Perth silty sand as a road subgrade. For the base layer, the commonly used material, HCTCRB, was replaced with the C&D aggregate. The pavement was analysed to find the vertical and the horizontal stresses occurring in the C&D aggregate base layer by using the MICHPAVE finite element program (Harichandran *et al.*, 1990) The suitable resilient modulus of the C&D aggregate for mechanistic design was determined from its resilient modulus model with relying on the laboratory results of the modulus tests. CIRCLY 5.0 was used for mechanistic pavement design to determine the traffic loading intensity of the C&D aggregate base course road.

In this study, because computer programs are relevant to pavement analysis and design, a suitable resilient modulus model is an important input parameter for the program. Generally, it is non-linear with respect to the magnitude of applied stresses. Figure 4 indicates that the K-Theta (K-θ) model (Hick and Monismith, 1971) is the significant model for non-linear behaviour of the granular materials suitable to modelling the stress dependence quite reasonably for the C&D waste aggregate. Consequently, the representative K-θ model of C&D waste is exhibited in Equation (1).

$$M_r = K_1 \theta^{K_2} = 3.065 \theta^{0.792} \tag{1}$$

Where: M_r is the resilient modulus in MPa; θ is a bulk stress ($\sigma_1 + \sigma_2 + \sigma_3$) where ($\sigma_2 = \sigma_3$); σ_1 is a major principal stress; σ_3 is a minor principal stress (= a confining stress); and K_1 and K_2 are regression constants.

Table 1 shows a summary of the pavement configuration analysed in CIRCLY 5.0. Figure 5 illustrates the results from CIRCLY 5.0 in terms of the graph of the traffic loading intensity of Equivalent Single Axial (ESA) of 80 kN plotted against the varied depth of the C&D aggregate. CIRCLY 5.0 is capable of conducting parametric analysis with one independent parameter of the C&D aggregate depth from 150 mm to 350 mm. This figure indicates that more than 185 mm of the C&D aggregate depth could resist a traffic load higher than the design (1.0×10^6 ESA). From these results, it can be suggested that the appropriate depth of the C&D aggregate as a base layer be at least 185 mm.

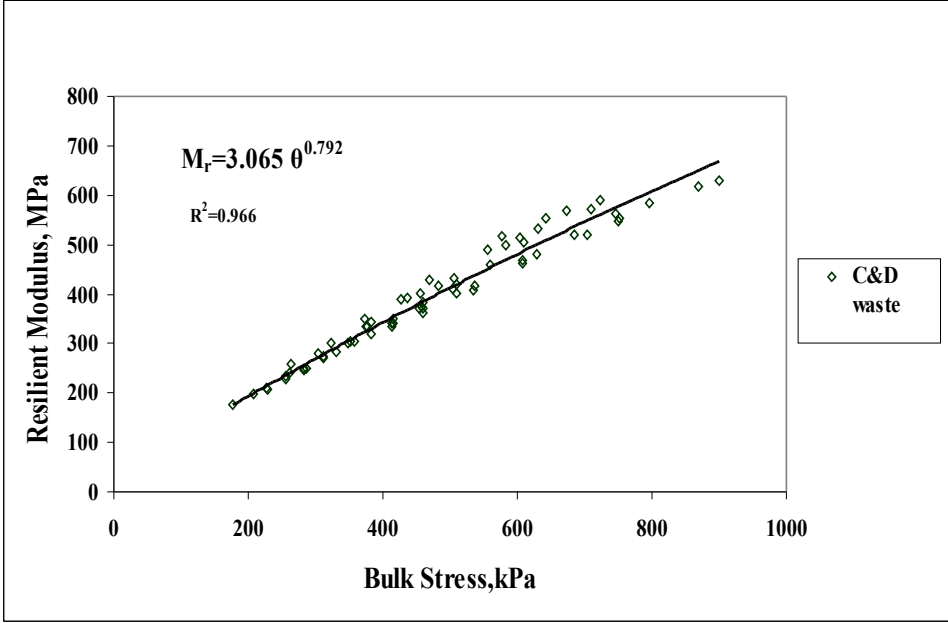


Figure 4: The relationship between bulk stress and the resilient modulus with its suitable model for C&D waste.

Table 1: Pavement configurations used in the CIRCLY analysis.

C&D aggregate pavement		Design traffic load = 1.0 x 10 ⁶ ESA		
Layer No.	Material ID	Isotropy	Modulus (MPa)	Layer thickness (mm)
1	Asphalt	Isotropic	3000	40
2	C&D aggregate	Anisotropic	450	150-350
3	Unbound granular crushed limestone	Anisotropic	350	200
4	Subgrade CBR 15	Anisotropic	150	Infinite

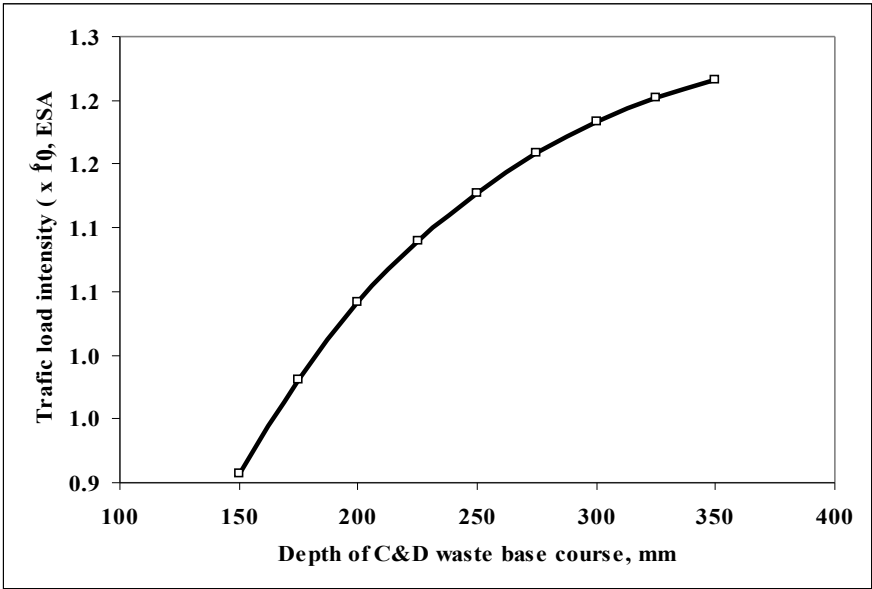


Figure 5: CIRCLY analysis results.

CONCLUSIONS AND RECOMMENDATIONS

The evaluation of Construction and Demolition (C&D) waste for a base course material in Western Australia was performed based on the mechanistic approach for pavement analysis and design using laboratory results from Repeated Loading Triaxial (RLT) tests. The loading tests were carried out in terms of the resilient modulus and the permanent deformation tests to provide insight into the resilient and permanent deformation characteristics of this material under real traffic loading conditions. This study also establishes a typical pavement model of the pavement using C&D waste as a base course material by relying on the laboratory results and CIRCLY 5.0, the commercial computer program for mechanistic pavement design and analysis.

The main conclusions and recommendations from this study can be summarized as follows:

1. The permanent deformation characteristic of C&D waste is not dominated by the applied load in the testing while CRB exhibits more stress dependency characteristics. At the end of the permanent deformation tests, both C&D waste and CRB tend to illustrate the same permanent settlement value at 3.6 mm based on the Austroads – APRG 00/33 test standard.
2. In considering the permanent deformation tests to be the preconditioning stage of the resilient modulus test, a model of C&D waste resilient modulus using the K-Theta (K- θ) model (Hick and Monismith, 1971) was introduced based on the Austroads – APRG 00/33 test standard.
3. For the design of the C&D aggregate for road bases following the typical model of pavement relying on the laboratory results and CIRCLY 5.0 program, it is suggested that:
 - The suitable depth of the C&D aggregate as a base layer for WA roads be at least 185 mm.
 - The traffic load intensity of the C&D aggregate-base course road be about 1×10^6 ESA.
4. More research is needed to determine threshold stress ratios which are the boundaries of behaviour changes and to investigate the possibility of using a shakedown theory or suitable theory to examine the behaviour of C&D waste under cyclic loading.
5. More research is needed to find out a suitable compacting method to achieve the typical densest condition of C&D waste. At this stage, it seems the standard modified compaction test is not the best because the material becomes denser during re-compacting in the preconditioning stage.
6. The application of models introduced in this research needs to be investigated to find whether they have an impacted on a current pavement design and if cross-sections resulting from these models differ from those designed and constructed from a previous design method.

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