The confinement and modulus evaluation of unbound granular base course

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ABSTRACT
This study aims to report theoretically the possible approach of confinement evaluation of unbound granular base course using the finite element method and laboratory results in order to implement current pavement material test algorithm. As is well known, repeated load triaxial (RLT) test is used to simulate the real condition of pavement materials under traffic loads by using static confinement with cyclic actuator loads. However static confining conditions in pavement structure occur only when no vehicle travels. As the effects of traffic loads and material attributes are generated when vehicles travel, horizontal stress and confinement behaviours of pavement structure were determined. The conventional pavement diagram consists of a surfacing, base-course, sub-base and sub-grade. During the load application procedure, a single wheel with a standard pressure of 750 kPa was selected. Test results showed that horizontal stress of base course layer consists of overburdened soil and passive force from applied stress. When vehicle travels pass observed point, horizontal pressures of base course layer increase from overburdened weight and complete with passive force effect depend on applied stress and its internal friction. Seemingly, the conventional RLT test with constant confinement is unable to simulate the real behaviour of pavement structure such as resilient and permanent deformation. In this study, dynamic bearing test and the confinement evaluation of unbound granular base course were introduced to explain and define limited use of pavement diagrams subjected to various conditions in order to implement the current performance test of unbound granular base course material.

1 INTRODUCTION

An unbound granular material (UGM) layer with a thin bituminous surfacing is widely used in Australian road network. Generally, crushed rock base (CRB) constitutes form the unbound granular base course material in Western Australia (Figure 1) whose function in pavements is to distribute and reduce the amount of compressive stresses and strains resulting from vehicle wheel loads through the subbase and the subgrade without unacceptable strain. As is well known, the strain resistance of unbound granular base course is a confinement dependency that means an obvious understanding of shear strength, confining characteristics of an UGM relevant to pavement mechanistic design is, therefore, very important to discover the effective use of such materials. Roads need to be studied to improve pavement analysis and design more precisely than in the past with respect to real behaviour and the amount of traffic during service life so that the most economical and appropriate pavement material can be employed.

The current pavement design procedure is based on experience and the results of simple tests such as the California Bearing Ratio (CBR), particle size distribution (PSD), moisture sensitivity, Los Angeles (LA) abrasion, shear strength and deflection (Austroads 2004). The performance of a base course material depends upon its stiffness and deformation resulting from a traffic load. A large deformation causes rutting on the bituminous surface. Basically, conventional pavement construction is designed to provide an adequate thickness cover over the sub layer in such a way that the pavement structure does not experience shear failures and that unacceptable permanent deformation does not take place in each layer.

For pavement design purposes, the stress level which is related to a reversible strain response must be determined and consequently not exceeded once unacceptable permanent strains are prevented. This has improved the possibility of a critical boundary stress between stable and unstable conditions in a pavement

This paper focuses on the confinement evaluation of CRB using finite element and laboratory test results for Western Australia pavement. The design method will be more improved if the performance of unbound granular bases can be predicted accurately more than using as load transferring layers.

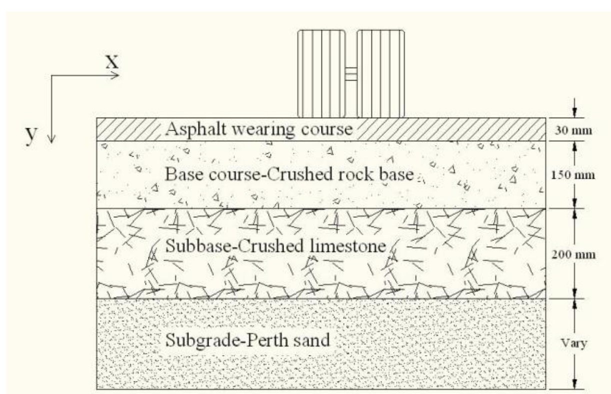

Figure 1 : Pavement structure diagram.

2 MATERIALS

2.1 Crushed Rock

The crushed rock samples used in this study were taken from a local stockpile of Gosnells Quarry and kept in sealed containers. RLT tests were performed on samples as part of the collaboration with the Civil Engineering Department, Curtin University of Technology. The samples were prepared (see Figure1 for the grading curve) at 100% of maximum dry density (MDD) of 2.27 ton/m^3 and an optimum moisture content (OMC) of 5.5%. Material properties achieve base course specifications (Main Roads Western Australia 2003). Significant comparisons of basic properties with specifications were made as shown in Table 1.

Table 1: Characterization tests (Main Roads Western Australia 2007).

Tests	Results	Tests	Results
Liquid Limit (LL)	22.4%	Coefficient of uniformity (Cu)	22.4
Plastic Limit (PL)	17.6%	Coefficient of curvature (Cc)	1.4
Plastic Index (PI)	4.8%	% fines	5 %
Linear Shrinkage (LS)	1.5%	Cohesion of CRB (C*)	32 kPa
Flakiness Index (FI)	22.5%	Internal friction angle of CRB (ϕ*)	59°
Maximum dry density (MDD)	2.27 t/m^3	Max. Dry Compressive Strength (MDCS)	3,528 kPa
Optimum moisture content (OMC)	5.5%	California Bearing Ratio (CBR)	180

3 LABORATORY PROGRAM AND TESTING

3.1 Specimen Preparation

Sample preparations were carried out using a standard cylinder mould 100 mm in diameter and 200 mm in height by the modified compaction method (Main Roads Western Australia 2007) at 100% MDD and 100% OMC. Compaction was accomplished on 8 layers with 25 blows of a 4.9 kg rammer at a 450 mm drop height on each layer. Fully bonding conduction between the layers of each layer had to be scarified to a depth of 6 mm before for the next layer was compacted. After compaction, the basic properties of each specimen were determined after which it was carefully carried to the base platen set of the chamber triaxial cell. A crosshead and stone disc were placed on the specimen and it was wrapped in two platens by a rubber membrane and finally sealed with o-rings at both ends.

3.2 Triaxial Tests

The tests were carried out with a static triaxial apparatus consisting of main set containing the load actuator and a removable chamber cell. The specimens were placed in the triaxial cell between the base platen and crosshead of the testing machine as in Figure 2. Controllers were used to manage the chamber, as well as the air pressure. The analogical signals detected by the transducers and load cell are received by a module where they are transformed to digital signals. A computer converts modules of the digital signals sent from the system. The system is located in the main set and facilitates the transmission of the orders to the actuator controller. User and the triaxial apparatus communication are controlled by a computer which uses convenient and precise software. This makes it possible to select the type of test to be performed as well as all the parameters, stress levels, data to be stored. The load cell, the confining pressure and the externally linear variable differential transducer (LVDT) on the top of the triaxial cell, used to measure deformations over the entire length of the specimens were measured by the control and data acquisition system (CDAS) which provided the control signals, signal conditioning, data acquisition. The CDAS was networked with the computer which provided the interfacing with the testing software and stored the raw test data, enabling the resultant stress and strain in the sample to be determined.

Confining pressure was generated to simulate the lateral pressure acting on the surrounding samples as occurs in a pavement layer and stresses were found at different points in the granular material. The results were expressed in terms of deviator stress q= σ_1-σ_3, mean normal stress p= (σ_1 -2σ_3)/3 and the confining pressure in this study was simulated from the pavement base course layer that is in common use in Western Australia. Drained triaxial compression tests were conducted to determine the shear strength parameters of CRB. Only specimens at 100% OMC and 100% MDD were tested under unsaturated conditions based on the CRB standard and suctions were not measured. In these tests, the specimen response was measured at three different constant confining pressures: 40, 60, and 80 kPa.

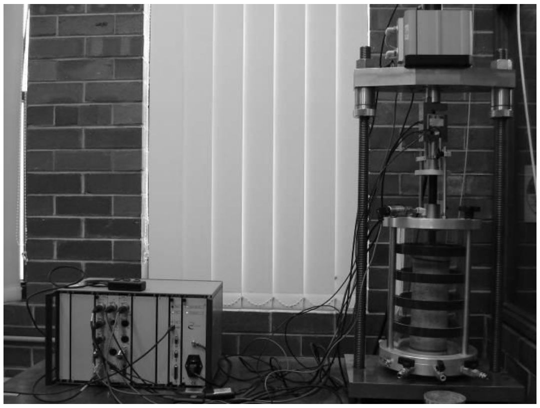

Figure 2 : The triaxial apparatus.

4 FINITE ELEMENT MODELLING

This study was undertaken to incorporate realistic material properties of CRB layers in the analysis of flexible pavements using the finite element theory. As a preliminary step, pavement materials within Western Australia were, subjected to a static loading, selected and modeled as a finite element model. An analysis was carried out using the finite element computer package ABAQUS/STANDARD (ABAQUS Version 6.9 2009), when this pavement model was subjected to static loading while considering the linear material properties of the pavement layers. The results of triaxial tests under loading were considered in pavement analysis.

In the modeling of the problem, the finite element program used eight nodes of isometric elements as a solid continuum. The problems were simplified under the plain strain condition and material properties (modulus and ultimate strain) from triaxial tests on the pavement were used. Dimensional parameters used in the modeling are illustrated in Figure 3 show the finite elements mesh of the problem and type of boundary conditions of the particular structure. The pavement structure was modeled as a single layer of base course using 152 mm height, 117 mm width and piston diameter of 49.6 mm based on the California bearing ratio (CBR) test as shown in Figure 3. Finite elements were unified by nodes at their common edges. The interfaces between layers are considered as fully bonded and rough. Boundary conditions were considered in the finite element modeling and rotation was allowed at all supports. The following conditions are applied with reference to Figure 3, when defining the boundary conditions. The vertical displacements of the bottom plane of the model are pinned. The side planes were fixed horizontally and vertically. FE analysis provided an approximate solution for an engineering structure with various types of boundary conditions and under various types of loading using a stiffness or energy formulation. In the derivation of the stiffness matrix for elements, three factors such as the geometry of elements, the degrees of freedom allowed for the nodes to displace and the material properties of elements are considered. This solution provides displacements at the nodal periods and stresses and strains at integration points.

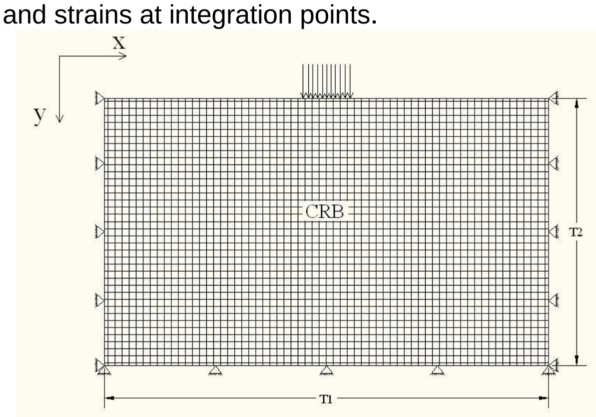

Figure 3 : Finite element diagram of pavement.

5 TEST RESULTS AND DISCUSSION

5.1 Static Triaxial Tests

This section presents the results and discusses the static triaxial shear tests operated on CRB at the compaction of 100% MDD and 100% OMC derived from the compaction curve. The purpose of the tests was to examine the strength characteristic and to determine the ultimate shear strength parameters of test materials under the triaxial shear test. These tests also established the ultimate strain of CRB to determine the maximum stress level of this material so that the limited uses of testing material could be indicated. Various confining pressures were applied on the test specimens in each test.

The peak deviator stresses from the stress-strain curves can be seen in Figure 4. Figure 4 also depicts the relationship between the deviator stress and the axial strain of the three selected confining pressures. For the stress-strain curves, it also can be observed that the static deviator stress initially increases with greater axial strain until it reaches peak strength. For a higher confining pressure, apparently, the peak strength becomes higher and the strain corresponding to the peak strength also becomes higher. All three curves in Figure 4 exhibit that after the peak strength, there is the post peak regime which the stress reduces with increasing strain. This characteristic is similar to that of dense granular materials and is normally described as strain softening. The strain-softening process is concomitant with the generation of large deformations, which cause geometrically non-linear effects to become important (Suiker, Selig et al. 2005). Based on these test results, all curves reach the peak at the strain level of 2.5% or 5 mm in each curve and always meet the failure after that. Subsequently, elastic modulus was determined at 31 MPa and was used to validate the test results in finite element analysis.

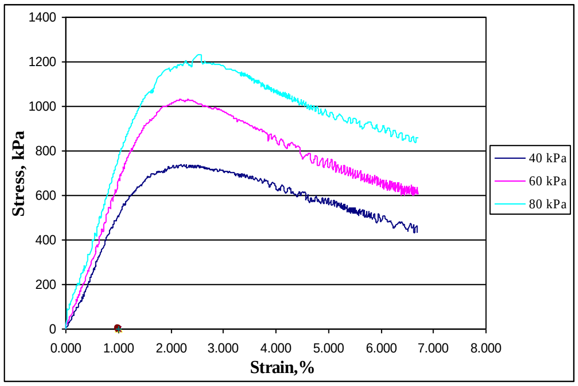

Figure 4: Triaxial test results.

5.2 Confinement Evaluation

Modulus of 31 MPa from triaxial test results was employed in this section to study stress-strain distribution of the triaxial test using finite element analysis. Figure 5 shows stress distribution of a triaxial sample that presents an asymmetric maximum stress at the both ends of testing sample even if the sample subjected to the applied load only on the top end. From this point, the ultimate strain of CRB in the tested condition could be estimated at 50% of the measured value from triaxial test results. Consequently, the ultimate strain of CRB was defined at the value of 2.5 mm which was used in next analysis to evaluate its strength and confinement. Figure 6 presents the finite element model of CBR which was analyzed at modulus of 31 MPa and deformation of 2.5 mm and it found the peak stress level of 1300 kPa as the ultimate strength of CRB.

The ultimate stress of 1300 kPa from finite element analysis was applied on the selected model of CRB in order to study confining behavior. The confining pressure starts around 210 kPa at the surface and increases relatively high at 2.5 mm below the surface around 420 kPa after that reduce gradually then reach the stable state at depth of 60 mm as shown in Figure 7. At the depth of 60 mm can be determined as influencing boundary (passive area) of the applied stress which was no more affect the confining pressure. The minimum confining pressure could be defined at the value of 75 kPa at depth of 60 mm.

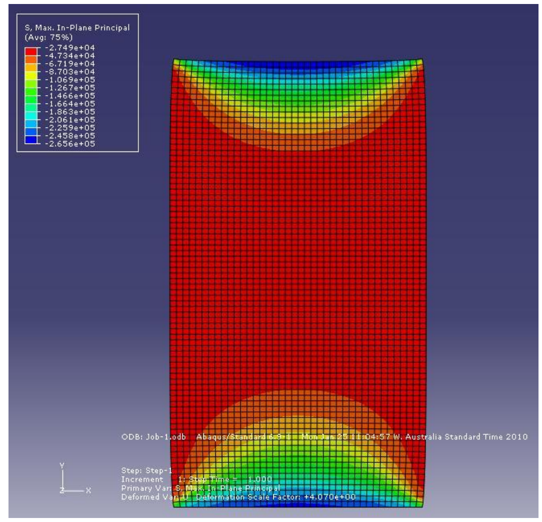

Figure 5: Finite element analysis of triaxial test.

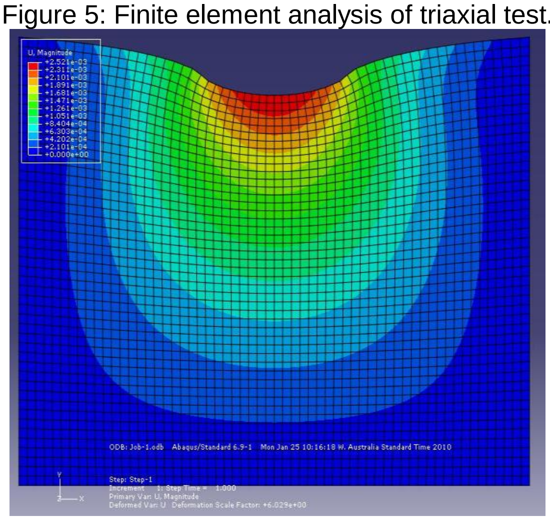

Figure 6: Finite element analysis of pavement structure.

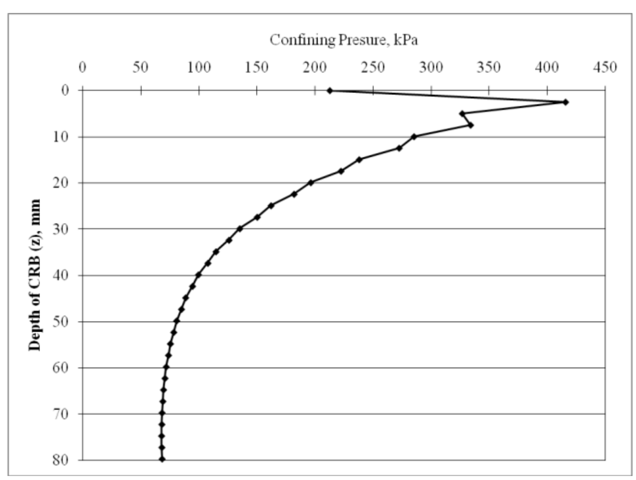

Figure 7: Confining pressure diagram.

6 CONCLUSIONS

The confining behaviors of Crushed Rock Base (CRB), normally used for a base course material in Western Australia, were investigated by means of static triaxial tests using finite element approach. The three confining pressures, namely 40, 60 and 80 kPa, of triaxial tests were carried out in order to provide an ultimate strain of CRB at the peak strength then input in finite element to study the confining pressure along the depth of CBR sample size modeling. The results can be drawn that:

- All triaxial test results of CRB always present the ultimate strain at 2.5% strain or 5 mm derived from the sample height at the peak load.
- The deformation behaviors of triaxial test completely differ to CBR test and pavement condition that the 50% strain results therefore can be used properly as the ultimate strain in CBR test and modeling.
- Based on this experiment, the confining pressure values of CRB under the ultimate strain of 2.5 mm are in the range of about 75 kPa to 420 kPa. It seems the applied load could influence the confining pressure underneath only twice of the contacting area of the applied stress and the confining pressure of 75 kPa was determined as the minimum value.
- The peak strength of CBR at 2.5 mm as ultimate strain is 1300 kPa which is higher around 2 times of current pavement design load of 750 kPa.
- A 3D finite element approach will improve the accuracy of the evaluation because it seems that the plain strain analysis for this study presents the conservative strength of CBR compared with the CBR test results.

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