Estimating in-situ resilient modulus values using Clegg impact soil tester

Estimation sur site des valeurs des modules resilients par la methode Clegg de testeur de sols par impact

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ABSTRACT: In the field of pavement engineering, the California Bearing Ratio or CBR is one of the most widely used and recognised soil parameter. The test is generally performed in the laboratory but field tests are sometimes necessary to obtain representative field conditions. The Clegg Impact Soil Tester (Clegg hammer) was proposed by Dr. Baden Clegg in 1970s as an alternative to CBR test. The hand-operated equipment has an excellent mobility such that tests can be quickly and easily performed in situ. With the advance of pavement technology, current pavement design now relies on the use of multi-layered elastic computer analysis that requires input of resilient modulus values. Resilient modulus is defined as the ratio of repeated deviator stress and resilient strain. In this paper, an attempt has been made to produce a correlation between Clegg Impact Values (CIVs) and resilient moduli for a granular soil.

RÉSUMÉ: Dans le domaine de l'ingenierie du recouvrement, le taux Californien de portance (CBR) est un des parametres le plus largement reconnu et utilise. Le test est generalement fait en laboratoire, mais les tests de terrain sont parfois necessaires pour representer les conditions reelles. Le Clegg Testeur de sols par impact (Marteau de Clegg) a etet propose par le Dr. Baden Clegg dans les annees 70 comme une alternative au CBR. L'equipement, se manipulant manuellement, possede une grande mobilite et permet de pratiquer facilement des tests sur site rapides. Grace aux avancees technologiques du recouvrement, les actuels designs de recouvrement sont calcules par la technique d'analyse 'multi-couches elastiques' assiste par ordinateur. Cette analyse requiert la connaissance des valeurs des modules resilients. Les modules resilient sont definis comme le ration du tenseur de contraintes deviateur. Dans ce papier, nous avons essaye de produire une correlation entre les valeurs d'impact de Clegg (CIVs) et les modules resilient pour un sol granuleux.

1 INTRODUCTION

A typical flexible pavement section may consist of three or more layers; an asphaltic concrete surface layer or wearing course, a coarse-grained unbound base course (aggregate), and the underlying soil subgrade. The quality of pavement design is greatly dependent on the accuracy and manner in which the material properties are evaluated and used in the analysis. Traditionally, the California Bearing Ratio (CBR) test and static triaxial test (or Texas Triaxial test) are two of the most commonly used laboratory test procedures used by various road organisations in Australia to rank road aggregates.

The laboratory CBR test is essentially a small-scale loading test which measures the force needed to cause a plunger to penetrate a soil specimen compacted into a cylindrical mould. The test does not reflect the field conditions since the soil deformation under the plunger is much greater than, and the strain rate much less than, those which would be produced by traffic loading. Moreover, tests on coarse-grained material can be very misleading because the material keys together in the mould and resists penetration of the piston (Nataatmadja 1988). Despite many criticisms made of CBR test, it has been the basis for major empirical methods of pavement design. Suggestions relating to minimum CBR value to be applied to a material for use as a pavement layer have been made by various road authorities in Australia and overseas.

Static triaxial test such as the Texas Triaxial test is used particularly to quantify the moisture susceptibility and the deformation resistance of base course materials. A number of specimens are normally loaded until failure under different confining pressures. The Texas Triaxial test can be considered as a reliable test for material selection, although it is only a measure of the shear strength of a material, i.e. of its load capacity prior to gross deformation. It is not a measure of the stiffness of the material, i.e. of its resistance to deflection under working loads, which is a more relevant parameter for pavement design.

The repeated load triaxial testing (RLTT) apparatus is a development of the traditional static triaxial machine. However, instead of loading monotonically to failure, repeated load is applied to examine the relationship between applied stress and the resulting resilient modulus and permanent deformation. It therefore, duplicates the principal components of the field conditions with regard to stress magnitude, stress path and load repititions.

Resilient modulus (M_r) is defined as the ratio of the repeated deviator stress (q) to the recoverable (elastic) strain. It appears that in the long term, classification based on resilient modulus would appear to be warranted (Dawson 1989).

The Clegg Impact Soil Tester (Clegg hammer) was proposed by Dr. Baden Clegg in 1970s as an alternative to CBR test. The hand-operated equipment has an excellent mobility such that tests can be quickly and easily performed in situ. A limited number of studies had since been carried out to obtain correlations between the Clegg Impact Values (CIVs) and the Young's moduli of soils. Resilient modulus can be several times higher than Young's modulus. Attempts had been made in the past to produce correlations between CBR and resilient modulus (Brown *et al.* 1990, Powell *et al.* 1984, Thompson & Quentin 1976), but failed to produce the desired accuaracy since resilient modulus is a stress-dependent elastic parameter.

This paper describes an investigation on the correlation between the CIVs and resilient moduli of a granular material. Laboratory tests were carried out on 200 mm diameter 400 mm high triaxial specimens. A 20 kg Clegg impact hammer with 130 mm tamping foot diameter was used to evaluate the soil stiffness. Triaxial specimens were prepared and fully covered with 0.5 mm thick rubber membrane (on its cylindrical- and top-surface) and tested for CIVs under controlled vacuum pressure to simulate the field confinement. The same specimens were subsequently tested using a RLTT machine under a broad range of repeated stress combinations to establish the variation of resilient modulus with the applied stresses.

Finally, a relationship has been developed between CIVs and resilient moduli for a granular soil. Making use of this relationship, an estimation of in-situ resilient modulus for such soils can be made using the Clegg impact soil tester.

2 TWO-PARAMETER MODEL

It is known that the resilient modulus is a stress dependent parameter. Until recently, the resilient modulus variation has been frequently modelled using the well-known K-Theta model (Hicks 1970):

$$M_r = K1\ (\theta)^{K2} \tag{1}$$

where θ = sum of the principal stresses; and K1 and K2 = experimental coefficients.

Despite its simplicity, the K-Theta model is not an accurate or correct model. This is because the resilient modulus is not only dependent on the sum of the principal stresses, θ, or the first invariant of stress, i.e. $(q + 3\ \sigma_3)$, but also significantly affected by the repeated deviator stress, q.

After conducting an extensive experimental work on granular soils (up to 37.5 mm particle size) using the largest repeated load triaxial equipment in Australia (Nataatmadja & Parkin 1988), the second author developed the Two-Parameter Model, which appears to be the most promising model for ranking unbound pavement materials. The empirical model has been well received in Australia and overseas (Nataatmadja 1990, Nataatmadja 1992, Nataatmadja 1994, Nataatmadja & Parkin 1989) and suggests that the resilient modulus of a soil is affected by both θ and q:

$$M_r = (\theta/q)\ (A + B\ q) \tag{2}$$

where A and B are experimental coefficients.

The Two-Parameter model can be used to characterise the stress-strain behaviour not only of unbound coarse-grained materials with non-plastic fines, but also those containing high amount of plastic fines. Comparing the model with the Mohr's envelope of static triaxial test, it is seen that coefficient A is analogous to the apparent cohesion c, while coefficient B is analogous to tan ϕ, where ϕ is the angle of internal friction.

3 CLEGG IMPACT SOIL TESTER

The Clegg Impact Soil Tester (Clegg hammer) was proposed by Dr. Baden Clegg in 1970s as an alternative to CBR test. The suggested standard procedure for making a Clegg Impact Test is quite simple and requires less than about 30 seconds. The hammer mass is 20 kg, the hammer diameter 130 mm and the height of drop of the hammer 300 mm. The value displayed at the end of the suggested test procedure of four successive drops per test location is considered the Heavy Clegg Impact Value and is denoted by CIV_H.

CIV_H indicates the strength or stiffness of the soil or flexible pavement layer under test. Because of the heavy weight of the hammer compared to the size and stiffness of the triaxial sample, the height of drop for the Clegg Impact Tests was selected as 50 mm instead of standard 300 mm.

For a given modulus, radius and basic assumptions, it is found that

$$CIV = \text{Constant} \sqrt{\frac{h}{m}} \tag{3}$$

where h is the height of drop and m is the mass of the hammer.

For the same mass of hammer, CIVs are thus proportional to the square root of h. This relationship was used to calculate the CIV_H values from the measured CIVs which were for a height of drop of 50 mm.

4 THEORETRICAL FORMULATION

In order to get the resilient modulus corresponding to varying vacuum pressures for the triaxisl specimens, Equation 2 needs to be modified as follows:

$$\begin{aligned} M_r &= (\theta/q)\ (A + B\ q) = ((q + 3\ \sigma_3)\ /\ q)\ (A + B\ q) \\ &= (A + B\ q) + ((3\ (A + B\ q))\ /\ q)\ \sigma_3 = D + F\ \sigma_3 \end{aligned} \tag{4}$$

where D = (A + B q); F = 3 (D/q); and σ_3 = the confining vacuum pressure.

Note that while the experimental coefficients A and B are determined from the RLTT results and σ_3 is measured directly from the vacuum gauge, the deviator stress, q is to be obtained from the CIV.

The peak contact stress, p due to the drop of hammer on to a specimen may be calculated from CIV using the formula:

$$p = \frac{m\,CIV.10.\,g}{\pi\, r^2} \tag{5}$$

where g is the acceleration due to gravity; and r is the hammer radius (= 65 mm).

The value of q to be used in Equation 4 is nothing but the value p as obtained from Equation 5, but only for the CIV obtained for the specimen with no confining pressure applied on to it.

After substituting the values for m, g and r in Equation 5, the values of q in terms of CIV (measured under the hammer only and no confining vacuum pressure) can be obtained as:

$$q = 147.67\ CIV\ (\text{in kPa}) \tag{6}$$

5 EXPERIMENTAL RESULTS

Triaxial specimens were prepared for a granular soil having maximum particle size of 20 mm, modified maximum dry density of 1.93 gm/cm^3 and a modified optimum moisture content of 11.5 percent. The CBR value (at 96% modified) for the soil was 70.

The triaxial specimen was subjected to repeated load triaxial tests for varying combinations of deviator stresses and confining stresses until failure of the specimen. Based on the experimental results, the variation of the resilient modulus of the soil using the Two-Parameter model is given in Figure 1.

As can be seen from Figure 1, the values for the experimental coefficients A and B for the soil were 405.48 and 0.5773, respectively.

The specimens, 200 mm in diameter and 400 mm high, were

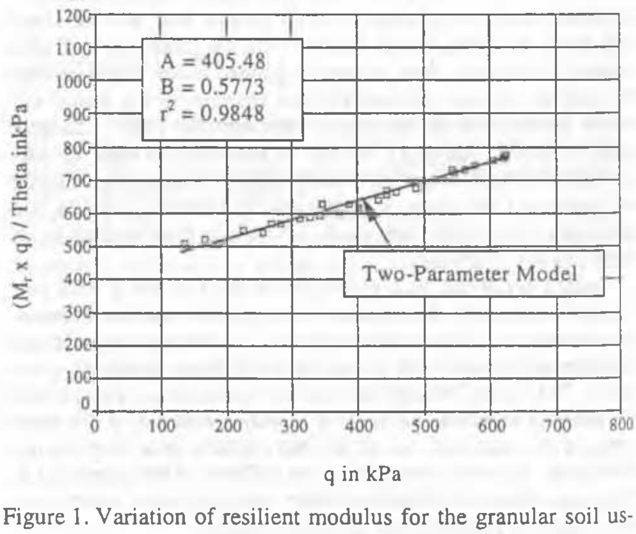

Figure 1. Variation of resilient modulus for the granular soil using the Two-Parameter model.

Table 1. Clegg impact test results for granular soil sample

Confining pressure, σ_3 (in MPa)	CIV (for a height of drop of 50 mm)	Deviator stress, q	D = (A + B q)	F = (3D / q)	M_r = (D + σ_3 F)	CIV_H (obtained using Equation 3)
15	1	147.67	490.73	9.97	640.28	3
20	3				690.13	8
25	3				739.98	8
30	4				789.83	10
35	5				839.68	13
40	4				889.53	10
45	4				939.38	10
50	4				989.23	10
60	4				1088.93	10

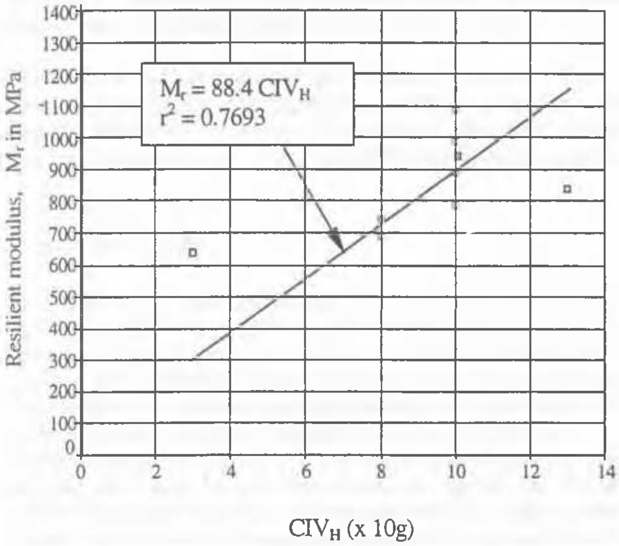

Figure 2. Relationship between resilient modulus and Clegg impact hammer values.

compacted using a Kango hammer to the maximum dry density. The specimen was fully covered with 0.5 mm thick rubber membrane (on its cylindrical- and top- surface) and tested for CIVs under controlled vacuum pressures. At the outset, the CIV with no vacuum pressure was first determined to obtain the deviator stress, q for a particular specimen. The value for this CIV for a height of hammer drop of 50 mm and for the granular soil tested was 1. Thus, from Equation 6, the deviator stress, q value for the soil sample was 147.67 kPa.

The CIVs corresponding to different vacuum (confining) pressures were measured for the soil specimen. All CIVs were measured for the height of drop of 50 mm. Making use of Equation 4, the resilient moduli corresponding to different confining pressures were calculated. The CIV_H values corresponding to the measured CIVs, which were measured for the height of drop of 50 mm, were also computed. These values are presented in Table 1 for the granular soil specimen.

Finally, the resilient modulus values as obtained above are plotted against the CIV_H for the soil sample to obtain the best-fit equation as shown in Figure 2. The resulting equation for the relationship between resilient modulus, M_r and the CIV_H is:

$$M_r = 88.4\ CIV_H \tag{7}$$

It should be noted that the r^2 value for the above correlation was 0.7693, which is quite reasonable considering the nature of empiricism in the relationship.

Also, the values of resilient moduli obtained in Table 1 were very close to the experimental values determined during the RLTT for the granular soil sample.

6 CONCLUSIONS

An investigation on the correlation between the Clegg Impact Values (CIVs) and resilient modulus of a granular soil has been described. Laboratory tests were carried out on 200 mm diameter and 400 mm high triaxial specimens. A 20 kg Clegg impact hammer with 130 mm tamping foot diameter was used. The relationship developed is reasonable as the values calculated for resilient modulus using the theoretical computation suggested herein were very close to those obtained from RLTT results.

Making use of this relationship, an estimation of in-situ resilient modulus for granular soils can thus be made using the Clegg impact soil tester.

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