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Estimation of resilient modulus of unbound granular materials using Clegg impact value and field stress levels

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ABSTRACT

Resilient modulus (M_r) is an important property that controls the performance of pavement materials under dynamic wheel loads. M_r can be determined in the laboratory from repeated load triaxial tests and is defined as the ratio of the deviator stress to the recoverable strain after a number of load applications. Inherently, it is a challenge to perform repeated load triaxial tests as routine tests due to their rather complicated, time-consuming and expensive procedure. Hence, researchers have attempted to develop empirical estimation models based on the mechanical properties of pavement materials, such as the California bearing ratio and the unconfined compressive strength or physical properties of materials. This study examines the correlation between the Clegg impact value (CIV) and the M_r of unbound granular materials (UGM) of pavements. The Clegg impact hammer test provides a parameter based on the response of the material to dynamic, rather than static or gradual, loading. Fourteen different unbound granular materials with particle sizes ranging from 7 mm to 19 mm used in the study. The results indicate that there exist a good to strong correlation between the resilient modulus M_r and Clegg impact hammer value, CIV, with the highest R^2 value of 0.82 and the average R^2 value of 0.76, from 48 stress levels used in M_r tests.

Introduction

A flexible pavement is a multilayered structure built with the purpose of carrying traffic loading. A typical flexible pavement structure consists of several layers, such as the surface course, base course, sub-base course and subgrade soil (Fig. 1). These materials have different physical and mechanical properties. Technically, a flexible pavement is designed to distribute the loading traffic from the top layer with highest resilient modulus (M_r) to the weakest subgrade soil without causing any damage to the structure. The surface course that is located on the top layer of the pavement helps to provide the smooth surface for the traffic. It can also help to resist abrasion and prevent the intrusion of water into the lower layers of the pavement. Sprayed and asphalt bituminous surfacing is commonly used for surface courses that are located on high quality unbound or cemented base course materials. Sub-base courses may also be required to provide additional thickness to the pavement or to maintain the separation between the base course and the subgrade soil. In some circumstances, the sub-base layer may also be used to create a stable surface over a weak subgrade soil for the construction of the pavement. In practice, the subgrade soil is generally compacted at the desired density and can consist of natural or fill soils.

The deflection of the base and sub-base materials in response to the anticipated design loads has to be limited to prevent failure of the top layer. The portable lightweight deflectometer is a popular tool for the evaluation of the

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Nomenclature

CIV	Clegg impact value	R^2	coefficient of determination
MDD	maximum dry density (t/m^3)	SEE	standard error of the estimate
MC	moisture content (%)	M_{rp}	predicted resilient modulus (MPa)
OMC	optimum moisture content (%)	σ_d	deviator stress (kPa)
M_r	resilient modulus (MPa)	σ_3	confining stress (kPa)
USCS	unified soil classification system	UGM	unbound granular materials

performance of these pavement materials in the field and in the laboratory (Fleming et al., 2007). More details about the techniques that are available to study the performance of unbound granular materials can be found in other studies, for example from a study by Brown (1996). The performance of these granular materials and their response to dynamic loading by vehicular traffic is characterised by resilient behaviour, which indicates their capacity to carry the load of the pavement (LeKarp et al., 2000). Resilient modulus (M_r) has been recommended by the AASHTO (1993) and Austroads (2012) design guides and has been widely-used as the main structural model input for pavement design.

This paper presents and discusses the results from a study on the relationship between the Clegg impact value (CIV) and the M_r of unbound granular materials (UGM) of pavements, with the purpose of developing a simple, inexpensive and acceptable indirect method for the estimation of resilient modulus of pavement granular materials.

Resilient modulus

Resilient modulus, M_r, is defined as the ratio of the deviator stress to the consequent recoverable strain, as shown in Eq. (1).

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

where:
M_r = Resilient modulus (MPa),
$\sigma_d = \sigma_1 - \sigma_3$ = Deviator stress (kPa),
$\varepsilon_r = \varepsilon_2 - \varepsilon_1$ = Recoverable strain (μm).

In the laboratory, Mr is obtained from a repeated load triaxial testing equipment. The image of the resilient behaviour of granular materials from repeated load triaxial tests is shown in Fig. 2.

From Fig. 2, it could be clearly seen that M_r was stress–strain dependent. Literature also showed that M_r was stress dependent (e.g. Rada and Witczak, 1981; Lekarp et al., 2000; Werkmeister, 2003). Dastich and Dawson (1995) explained this dependence of granular materials based on Hertz's theory. Each granular particle was represented by a sphere and when the stress applied on the specimen increased, the contact area among the spheres also increased. Therefore, the resistance against the closure of the centre of the sphere increased.

It was also reported that unbound granular materials were highly dependent on confining pressure and, to a lesser extent, on deviator stress (e.g. Hicks and Monismith, 1971; Lekarp et al., 2000; Amber and Harold, 2002; Zeghal, 2004; Papagiannakis and Masad, 2008). An increase in confinement corresponded to an increase in M_r. In addition to the stress and strain, several other factors affected the resilient behaviour of granular materials, such as stress history, load sequence and particle shape (LeKarp et al., 2000).

Generally, the M_r is reported as a function of the deviator and confining stresses after repeated load triaxial tests. The main reason behind this process was to illustrate the fundamentally stress-dependent property of the M_r. Over the last decade, several models have been proposed by many researchers for modelling M_r, in terms of the applied stresses. A summary of some of the models reported by different researchers is presented in Table 1.

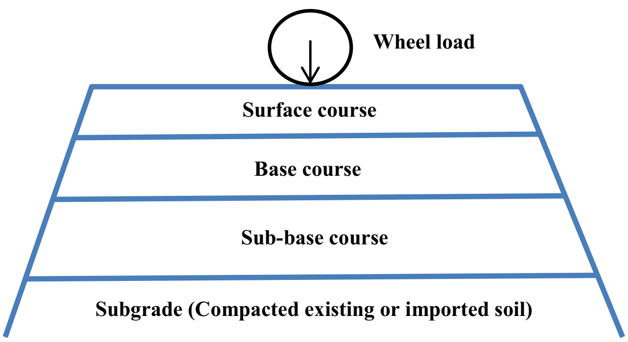

Fig. 1. A typical cross section for a flexible pavement.