Construction and Building Materials 180 (2018) 491–502

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental evaluation of constitutive models for the estimation of resilient modulus values and an assessment of pressure sensitivity of granular blends containing reclaimed asphalt pavement materials

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HIGHLIGHTS

- Models of Uzan and Witczak & Uzan to predict resilient modulus are aptly useful.
- Presence of RAP contents increase the pressure sensitivity of the blended samples.
- Use of RAP materials in excess of 50% in the blended samples may be challenging.

ARTICLE INFO

Article history:
Received 8 September 2017
Received in revised form 31 March 2018
Accepted 27 May 2018

Keywords:
Pavement structure
Recycled materials
Material properties
Empirical correlation
Laboratory experimentation

ABSTRACT

The resilient modulus (M_r) of granular materials is one of the basic mechanical property required for the mechanistic-empirical design of flexible pavement structures. Reclaimed asphalt pavement (RAP) has a potential to be used under controlled conditions in different layers of the pavement structure in considerable percentages with the fresh granular materials. Inherently, it is a challenge to perform repeated load triaxial tests as routine tests for the determination of M_r values due to rather complicated, time consuming and expensive procedure involved. Hence, as a substitute, empirical constitutive models are also adopted for the estimation of M_r values under a range of loading conditions. This research paper presents an evaluation of five different constitutive models commonly used for the estimation of M_r values incorporating 27 number of experimental data sets obtained during this research work. Statistical analysis of data shows that the models presented by Uzan (1985, 1992) and Witczak and Uzan (1988) are desirably efficient to predict the M_r values while the model presented by Johnson et al. (1986) has the least certainty. On the basis of experimental results, a new constitutive model is also proposed which exclusively takes into account the value of bulk stress and the percentage of RAP contents used in the blended samples tested under a range of loading conditions as specified in AASHTO T 307. The new model may generate the coefficient of determination *(R^2)* in the range of 0.81–0.95. Furthermore, *t*-test demonstrates that the value of *t-statistic* is many folds the corresponding value of the *t-critical*, suggesting a strong correlation between the measured and the estimated M_r values in addition to a fair distribution of the data points along the unity line. Experimental investigations also indicate that the presence of the RAP materials in the blended samples make them more pressure sensitive when compared with the samples containing virgin materials only. Data shows that in blended samples containing 50% and 75% of RAP contents by mass, the residual strain may increase of the tune of 500% and 2500% when compared with the corresponding value for the virgin material for the specified cyclic loading conditions. This response of the blended samples certainly identifies some undesirable consequences with the use of RAP materials at higher percentages in the pavement structures.

1. Introduction

A typical flexible pavement structure consists of several layers, such as the surface course, base course, sub-base course and subgrade soil (Fig. 1). Each layer has a certain thickness and specific material properties depending upon the anticipated traffic loading characteristics and/or environmental conditions. More rationally speaking, a flexible pavement is designed to distribute the traffic loading from the top layer to the weakest sub-grade soil without causing any destruction to the whole pavement structure [5].

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https://doi.org/10.1016/j.conbuildmat.2018.05.234
0950-0618/

In the mechanistic-empirical design approach, the performance of pavement layers in response to repetitive loading by vehicular traffic is characterised by resilient behaviour [6] which is elaborated in terms of the resilient modulus (M_r). Resilient modulus (M_r) is defined as the ratio of cyclic deviator stress (σ_d) to resilient strain (ε_r) as shown in Fig. 2 [7] has the ability to describe the factual martial performance of unbound pavement layers under repetitive traffic loading.

Factors affecting the M_r value for base/subbase layer of the pavement may include the soil type, physical properties of the soil such as gradation characteristics, moisture contents, density and stress conditions in addition to stress level [6,8,9]. A brief summary of such influential factors is given in Table 1.

1.1. Valuation of resilient properties of the granular materials

AASHTO (American Association of State Highway and Transportion Officials) provides standard test procedures for the determination of resilient modulus using the repeated load triaxial test, which include AASHTO T 292 [10], AASHTO T 294 [11] and AASHTO T 307 [12]. The current protocol for the determination of resilient modulus values of soils and aggregate materials is the AASHTO T 307, which in fact has been evolved from the Long Term Pavement Performance (LTPP) Protocol P46. This is worth to mention that the M_r values obtained through laboratory methods is dependent on loading sequence, experimental stress conditions (testing procedure) and position of the linear variable differential transducer (LVDT) for the measurement of specimen deformation [13].

Although the determination of M_r values through laboratory methods is desirable but this requires a higher level of technical expertise and more sophisticated equipment, hence leading to higher cost and more time for the design/construction of the pavement project. Consequently, under this situation use of prediction models for the estimation of M_r values may prove to be a dependable alternative.

There are many constitutive models for the estimation of resilient modulus by taking into account the various types of stress invariant, for example bulk stress [14]; bulk stress and atmospheric pressure [15]; bulk stress, atmospheric pressure and deviator stress [16]; confining pressure and deviator stress [17]; atmospheric pressure, octahedral normal stress and octahedral shear stress [18]; bulk stress, atmospheric pressure and octahedral shear stress [19] . M_r values obtained through constitutive models are more reliable when compared with those obtained through empirical models taking into account some strength or stiffness characteristics of the unbound pavement material including CBR values [20–24]; R-test value [14,25–28]; unconfined compressive strength [29] and undrained compressive strength [30]. This is due to the fact that such strength or stiffness values are themselves very much empirical in nature. Furthermore, many researchers have documented presumptive M_r values for different types of unbound granular materials [5,31].

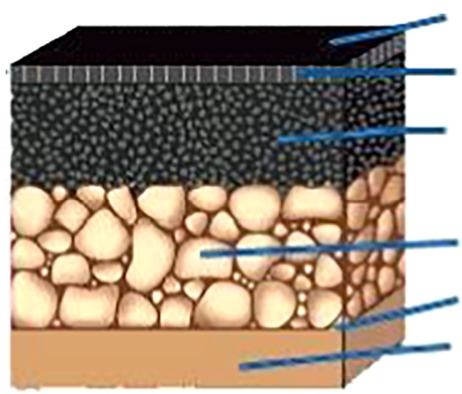

Fig. 1. A typical cross section of a flexible pavement.

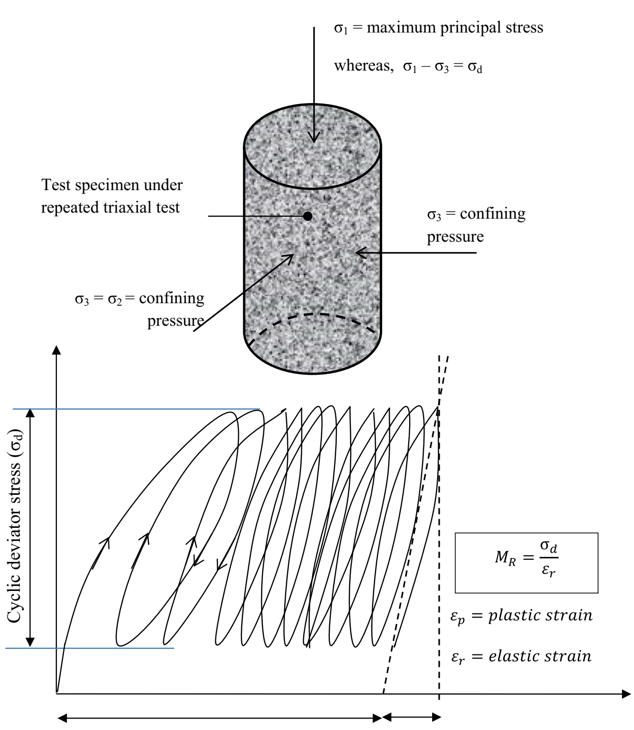

Fig. 2. A schematic view of elastic & plastic strain and definition of the resilient modulus under repeated loading.

1.2. Reclaimed asphalt pavement (RAP) material

Reclaimed asphalt pavement (RAP) material is amongst the most frequently used recycled materials in different layers of flexible pavements. This material is generated when asphalt pavements are removed for reconstruction, resurfacing, or to obtain access to buried utilities and it consists of coarse and fine aggregates and bitumen refer to a congregation of loose materials from asphalt pavements [32,33]. When properly crushed and screened, RAP consists of high-quality, well-graded aggregates coated by asphalt cement. RAP materials have to be used as base and subbase material in considerable percentage with fresh granular materials to reduce the cost of the road construction project and to eliminate the adverse environmental effects involved with the use of fresh granular materials [33,34]. In recent years, many researchers have

Table 1
Summary of the factors influencing the resilient modulus value.

If the following factors/parameters increase	then resilient modulus will	Importance
Shear stress level	Decrease	High
Bulk stress	Increase	High
Deviatoric stress	No effect	Low
Number of load repetition	Not clear (may increase or decrease)	Low/high
Density of sample	increase	Low
Fine aggregate content	Not clear (may increase or decrease)	Medium
Medium aggregate content	Increase	Medium
Coarse aggregate content	Increase	Medium