International Journal of GEOMATE, May, 2018 Vol.14, Issue 45, pp.124-129
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2018.45.7336
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

MECHANISTIC BEHAVIOR OF OPEN AND DENSE GRADED UNBOUND GRANULAR MATERIALS UNDER TRAFFIC LOADS

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*Corresponding Author, received: 10 June 2017, Revised: 05 Aug. 2017, Accepted: 09 Sept. 2017

ABSTRACT: The absence of abundant amount of natural unbound granular materials (*UGMs*) necessitates investigating alternatives such as processed crushed rock. Extensive use of crushed rock in pavement design requires proper modification of characterization, design and construction practices. Many specifications and standards require adopting of dense gradation of base materials. Although dense gradation has a high dry density, it also has low permeability or voids. This low permeability results in a decrease in material strength when the pavement is exposed to moisture. This research examines the effects of fines content on mechanistic behaviors of *UGMs*, particularly resilient modulus (M_r) and permanent deformation (*PD*) using repeated load triaxial test (*RLTT*). Class 2 crushed rock is used in two gradations- dense gradation and open gradation. Results from *RLTT* show that open graded Class 2 has an acceptable *PD* resistance under repeated loads for test's Stages 1, 2 and 3 followed by a significant collapse at Stage 4 as per Australian pavement design guide. This investigation has found that open graded Class 2 has higher M_r than dense graded Class 2. This paper suggests that open graded Class 2 could be used as a porous base material for roads with low traffic volumes.

Keywords: Unbound granular materials, Resilient modulus, Permanent deformation, Fines content, Repeated load triaxial test.

1. INTRODUCTION

Unbound granular pavement materials (*UGMs)* are used in many pavement structural systems as base and subbase materials to support the surface layer by distributing the traffic stresses to subgrade. *UGMs* are mainly naturally occurring sourced rocks, gravel or manufactured crushed rock [1].

The absence of natural aggregate necessitates the need for alternatives such as processed crushed rock [2]. Crushed rock is the most widely used products in construction materials. It is produced by mining and processing suitable rocks, followed by breaking down process to reach the proper size using crushers [3]. A proper adjustment of characterization, design and construction guides is needed after the extensive usage of manufactured aggregates [4]. In addition, producing fine particles from the crushed rock is costly and energy consuming. Some quarries are closed because of the lack of fine particles, and row rocks in these quarries are robust and difficult to process into fines.

The *UGMs* are nonlinear and have a complex behavior under repeated wheel loads (time-dependent elastoplastic response) [5] [6]. Many researches have been conducted to better understand the behavior and the characteristics of *UGMs* [7-12]. These materials reflect both permanent strain (permanent deformation) and

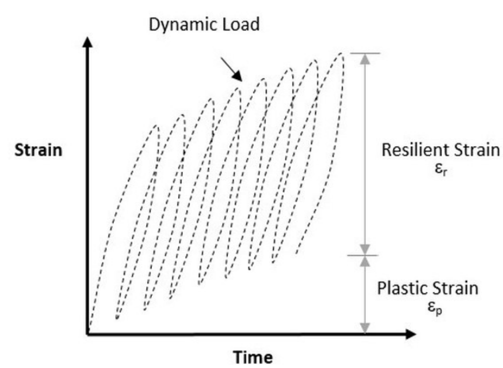

Fig. 1 Plastic strain and resilient strain

recoverable strain (resilient deformation) as shown in Fig. 1. The deformation behavior of *UGMs* is essential for performance and stability of the pavement structure [11]. Permanent and resilient deformations usually are tested by using repeated load triaxial test (*RLTT*), which is the best test that simulates the field traffic loads [13]. Both strains are used in flexible pavement structural design through the Mechanistic-Empirical (*M-E*) design methods. For instance, Austroads pavement design method and *NCHRP* design method [14].

Gradation of aggregates is one of the main features when studying the mechanical behavior of

UGMs [15]. Specifications on gradation are intended to guarantee that the designer selects the superlative available combination of materials to achieve the desired mechanical responses. Many gradation specifications' ambits assure to preserve a dense gradation to attain the maximum dry density of the compacted materials such as specification of VicRoads (Roads Corporation of Victoria). Therefore, gradation specifications are so restricted for this purpose. Pavement is susceptible to moisture which comes from a variety of sources such as rainfall [16]. As mentioned latterly, dense graded base layer materials have a high dry density that coincides with low permeability because of the low voids ratio. If the pavement is exposed to moisture, then this low permeability allow water to get trapped inside the base and subbase layers. Eventually, pore pressure is induced yielding a decrease of material strength [17]. The purpose of aggregate base material in low volume pavement is to protect the surface layer from the contamination of subgrade's fines and do not add much strength to the pavement system [18]. Therefore, high quality gradation with high resilient modulus (M_r) and high permanent deformation (*PD)* resistance are not needed all the time, low traffic volume pavement can be designed with low mix quality.

Several factors affect the pavement strain response of *UGMs.* These factors can be classified broadly into two categories: stress and materials related factors. Stress related factors include: exerted repeated stresses by tire loads, load duration, frequency of loading and load sequence. Materials related factors include material density, particles gradation, fines content, maximum grain size, aggregate types, particle shapes and moisture content [19].

1.1 Effect of Grading and Fines Content

The significance of identifying proper aggregate gradation has been recognized for achieving suitable performance in pavement design [15]. There are limited studies that investigated the effect of gradation and fines content on the dynamic properties of the *UGMs.* Hicks and Monismith [20] tested two types of materials, partially crushed aggregate and crushed aggregate with different relative densities and percentage of passing sieve number 200 (filler) using *RLTT*. The effect of gradation on M_r was not clear. However, when the fines content (in partially crushed aggregate) increases, M_r decreases. In the other hand, M_r increases with the increase of fines content of crushed aggregates. Raad, Minassian [21] studied the behavior of *UGMs* with different gradations under saturated and undrained *RLTT* conditions. It was recognized that the saturated dense graded aggregates under dynamic loads induce excess pore pressure which leads to a decrease in the M_r. In addition, open graded aggregates resist higher stresses and strains compared to dense graded aggregates. Type 5 aggregate base was tested by Richardson and Lusher [22] in order to investigate the effect of gradation on M_r. The purpose of the proposed gradation is to help the manufacturer to lower the production cost of said aggregate. A comparison has been made between the proposed gradation (open gradation) and as-delivered gradation. It was concluded that the open graded gradation for the Type 5 aggregate base (without fines passing #200) is better than as-delivered one (dense, high fines content) because M_r is higher and the degree of saturation is low. Contrary to the previous findings, the variation of M_r is less significant depending on the material gradation. However, the moduli were highest for the open graded specifications than the dense graded specifications for limestone aggregates [23]. Barksdale [24] observed the effect of fines content in a crushed granite gneiss base after 100,000 load repetitions. Increasing the fines percent from 3 to 11.25 caused 60 percent increase in rut index. Thus, when the fines percentage increase, the plastic strain increase significantly. Kamal, Dawson [25] conducted *RLTT* on *UGMs* at a range of gradations and the results of the tests revealed that the resistance to *PD* was high for well graded mix in comparison to the open graded one. A recent study on the deformation behavior of *UGMs* established by Rahman [11] has been suggested to examine the influence of the grain size distribution (gradation) and fines content on the permanent deformation behavior of the *UGMs*.

It can be clearly seen from the previous works that there is no agreement about the effect of gradation and particularly the fines content on the behavior of *UGMs* under repeated dynamic loads. Therefore, this research focused on the fines content effect on the deformation behavior of Class 2 crushed rock under repeated loading. Similarly to Richardson and Lusher [22], open and dense graded crushed rock are investigated. In addition, permanent deformation test is included, and different material is used. The main objective of this research is to find the response of *UGMs* without filler (particles passing sieve 0.0075 mm) as an approach to design a porous base layer. This research is part of an ongoing study to investigate the response of *UGMs* under traffic loads.

2. EXPERIMENTAL INVESTIGATION

2.1 Material

Crushed rock Class 2 is used as *UGMs* for this research. Class 2 is recommended by VicRoads specifications to be used as base material. Igneous (basalt) rock is the origin of crushed Class 2, which was collected from Mountain View quarry located in Point Wilson, Victoria, Australia and delivered in plastic boxes. Fig. 2 shows Class 2 (as-delivered) particle size distribution. It can be clearly seen that Class 2 is a dense graded material and fits inside the VicRoads specification limitation envelope: upper and lower limits (*UL*, *LL*).

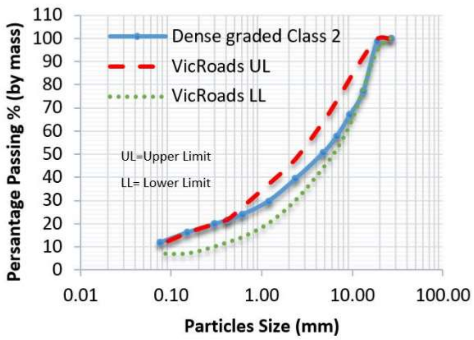

Fig. 2 Class 2 particle size distribution

2.2 Specimen Preparation

To prepare the open gradation, VicRoads' Class 2 (as-delivered dense graded crushed rock) is washed through sieve 0.0075 mm to purge out the fine particles. The specimens from these two gradations are compacted into three split cylindrical mold with respect to optimum moisture content (*OMC*) and maximum dry density (*MDD*) of the two gradations as presented in Fig. 3.

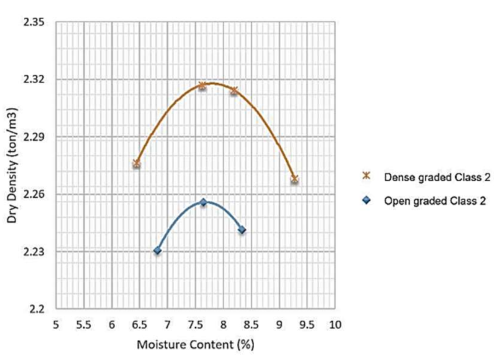

Fig. 3 Dry density-moisture content relationship

Each specimen is compacted into 8 layers using modified compactive effort with 25 blows per layer. The final specimen size is 200 mm high and 100 mm diameter. Rubber membrane is encased the cylindrical specimen as shown in Fig 4. The preparation process is applied in accordance with Austroads [26].

Fig. 4 New specimen confined by membrane

2.3 Testing Equipment

Repeated load triaxial test is conducted on the cylindrical crushed Class 2 specimens. The main parts of the system consist of load frame, actuator motor, triaxial cell, digital control system, pneumatic controller, external displacement transducer and computer control. The actuator is electro-mechanical with maximum dynamic axial load capability of 5 kN, high precision position feedback is provided capable of measuring the axial displacement. The other transducer is used as an additional transducer to check the internal axial displacement reading. The range of the LVDT is ± 11 mm. The system can exert up to 500 kPa of static confining pressure. Air and water are used as a confining medium. Triaxial cell pressure is controlled via a pneumatic controller which controls air pressure. The digital control system is capable of logging data from eight transducers.

2.4 Testing Sequences

Specimens are subjected to 4 stress stages. The first preconditioning stage involves 50 cycles and each permanent deformation stage involves 10,000 cycles. Repeated deviator stress, static confining stress magnitudes, and number of cycles are presented in Table 1.

Table 1 Stress sequences for permanent deformation test [26]

Stages	σ_3 (kPa)	σ_d (kPa)	Cycles
1	50	90	50
2	50	350	10000
3	50	450	10000
4	50	500	10000

Note: Preconditioning stage is added by the authors as described in the European standard [27]. σ_3: confining stress. σ_d: deviator stress.

3. RESULT AND DISCUSSION

In order to investigate the fines content effect on the deformation behavior of the *UGMs*, zero fines content gradation (no particles passing sieve 0.0075 mm) is prepared by using the washing process through sieve 0.075 mm to prepare the open graded Class 2 crushed rock. Both dense and open graded Class 2 were examined under *RLTT* to investigate the deformation behavior.

Fig. 5 compares the axial *PD* behavior for the two gradations of crushed rock materials, dense graded Class 2 and open graded Class 2.

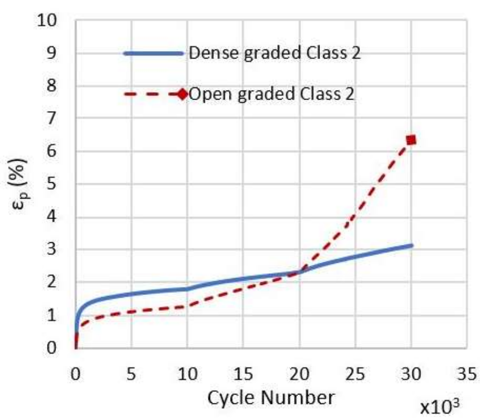

Fig. 5 Permanent deformation

It can be seen that open graded Class 2 has high *PD* resistance in the second stage (σ_d =350 kPa) and the third Stage (σ_d =450 kPa) of the *RLTT* than dense graded Class 2. This finding is contrary to Kamal, Dawson [25]. Afterwards, when the test entered Stage 4 (after 20000 cycles, σ_d =500 kPa), *PD* resistance starts to decrease showing steep upwards trend while *PD* resistance of dense graded Class 2 decreases steadily. A possible explanation of this behavior could be that the open graded Class 2 could not withstand the high deviator stress at Stage 4 (σ_d =450 kPa) because of the absence of fine particles, which support the mix by transmitting the loads to other big particles. This preliminary finding suggests that open graded Class 2 could be used as a porous base material but for low traffic volume. Missing fine particles tend to high permeability which minimizes the failure probability from moisture. Even though further tests are required to confirm this result with a high degree of confidence.

Fig. 6 shows no significant variation in the *RD* behavior for the two gradations.

Fig. 7 reveals that M_r values of open graded Class 2 are greater than the M_r values of dense graded Class 2, as concluded by Richardson and Lusher [22]. Surprisingly, at Stage 4 of the *RLTT* stress sequence (σ_d =450 kPa), M_r of open graded Class 2 remain greater than M_r of dense graded Class 2 despite the dramatic PD as shown in Fig. 7. This finding confirms that pavement design procedures should not only be based on M_r values of pavement materials, the *PD* needs to be examined likewise.

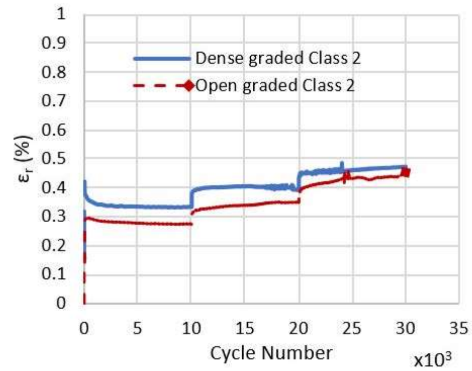

Fig. 6 Resilient deformation

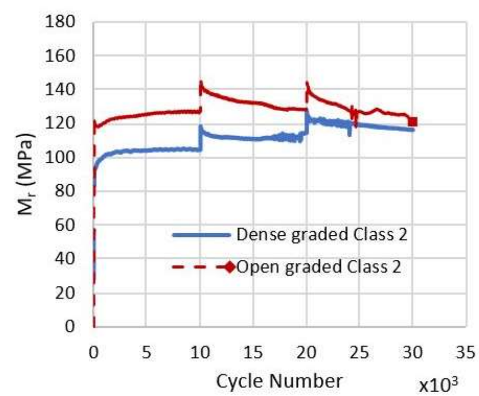

Fig. 7 Resilient modulus

3. CONCLUSION

Results from *RLTT* show that open graded Class 2 has an acceptable *PD* resistance under repeated loads for test's Stages 1, 2 and 3 followed by a significant collapse at Stage 4 as per Australian pavement design guide. Moreover, open graded Class 2 has higher M_r than dense graded Class 2 for all stages. This paper suggests that open graded Class 2 could be used as a porous base material for road pavements with low traffic volumes. Surprisingly, open graded Class 2 has high *PD* in coincidence with high M_r. Therefore, it is recommended to examine both M_r and *PD* for an accurate assessment.

4. ACKNOWLEDGEMENTS

Research material (crushed Class 2) was donated by Mountain View Quarries in Point Wilson, Victoria.

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