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Effects of moisture content on the cyclic behavior of crushed tuff aggregates by large-scale tri-axial test

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A R T I C L E I N F O

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A B S T R A C T

The crushed rock aggregates are widely used as road base and subbase fillings of road. The moisture content of the crushed aggregates changes due to rainfalls and water infiltration from the pavement cracks during the road service period, and this usually brings detrimental effects to the performance of road base and subbase. To investigate the effects of moisture content on the resilient modulus and accumulated strain of crushed aggregates under cyclic loadings, comparative experiments on samples under optimum moisture condition and saturated condition were conducted through a large-scale tri-axial apparatus. Different cyclic stress amplitudes, confining pressures and initial deviatoric stresses were also considered in the experiments. Test results show that the change from optimum to saturated moisture content aggravates the accumulated axial strain and reduces the resilient modulus of the aggregates under cyclic loading. The influence of moisture content on the cyclic behavior of CTAs is related to the factors such as cyclic stress ratio and initial deviatoric stress.

1. Introduction

It is well known that the base and subbase layers provide the most important structural elements to support the upper loads and to transfer traffic loadings from the top surface to the subgrade. With the increase of traffic volumes and weights, the base and subbase deteriorate gradually due to the cyclic traffic loadings and the change of surrounding environment [1–3]. In most cases, rutting takes place on the road surface which causes the progressive fatigue cracking of paved layers [4–6]. This phenomenon will reduce the road service duration and increase the road maintenance costs.

The large-scale tri-axial apparatus is usually used in the investigation of cyclic behavior of coarse granular materials under cyclic loadings due to the requirement of ratio between the specimen and particle size [7–13]. Surker et al. [8] conducted a series of static and cyclic tri-axial tests on non-cohesive granular materials and found that the granular materials showed a strong tendency to compact even if the applied cyclic stress level was close to the static failure strength. Wichtmann et al. [9] proposed a high-cycle accumulation (HCA) model which could predict the permanent deformations of base and subbase materials in pavements. Anhdan and Koseki [10] investigated the effects of cyclic loading on the deformation behavior of dense gravels and found a threshold value of cyclic stress amplitude under which the dense granular materials would become stable even under a very large number of cyclic loadings. Thakur et al. [11] and Sun et al. [12,13] examined the effects of confining pressure and loading frequency on ballast deformation (permanent and resilient) and degradation. The results showed that permanent deformation is found to increase with increasing frequency, and an optimum range of confining pressures exists such that degradation is minimized. These studies revealed many factors such as stress state, loading method, relative density that influenced the cyclic behavior of coarse granular materials. However, moisture content, as another important factor, was seldom researched.

The cracks of asphalt layers lead to the infiltration of water in rainy seasons and cause the fluctuation of moisture content inside the base and subbase layers. In addition, seasonal variations of groundwater level also cause water content change in the road base [3]. Therefore, it is of great significance to gain a good understanding of the cyclic behavior of the base and subbase considering the factor of moisture content. Regarding the researches about the moisture content, Cerni et al. [14] compared the permanent deformation behavior of two unbound granular materials between optimum moisture condition and saturated condition under cyclic loading, and obtained that samples under optimum moisture condition presented higher plastic shakedown and plastic creep limit than those under saturated condition. Duong et al. [15] investigated the influences of fine and water contents

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on the interlayer soils and indicated that higher fine contents led to larger permanent axial strains at nearly saturated condition, while the opposite trend was observed at lower water content. Inam et al. [3] conducted a series of laboratory tests on granular base course materials under different moisture contents, and found that the moisture content for the maximum deformation varied according to different loading methods. However, the influences of moisture content on the performance of road base under different stress paths including the factors of cyclic stress amplitude, confining pressure, and initial deviatoric stress were not presented in these studies.

The crushed tuff aggregates (CTAs) have been widely used as road base and subbase in southeast China and other places in the world as they are easily obtained and lowly cost. The tuff is a special expansive soft rock characterized by high porosity, large specific surface area, complex composition and hydrophilic lamellar structure. They are very sensitive to the change of the surrounding environment including the variation of moisture content due to its disintegration and transformation [16–18]. However, the effect of moisture content on the cyclic behavior of CTAs under cyclic loading remains unknown and few studies have been presented on this problems. Therefore, it is necessary to investigate the influences of moisture content on the cyclic behavior of CTAs under various cyclic stress paths.

In the present study, the resilient modulus and accumulated axial strain of CTAs under cyclic loading were compared between samples under optimum and saturated moisture condition using a large-scale tri-axial apparatus. The influences of moisture content were investigated under different cyclic stress amplitudes, confining pressures and initial deviatoric stresses. Test results show that the increase of moisture content increases the axial strain accumulation and decreases the resilient modulus of CTAs obviously in all three cyclic stress paths. The influence of moisture content on the cyclic behavior of CTAs becomes more significant at high initial deviatoric stress and high cyclic stress ratio.

2. Laboratory investigation

2.1. Tested materials

The material of the specimens is crushed tuff obtained from a quarry in Wenzhou, a city in the eastern China. The particle size range of the crushed tuff aggregates (CTAs) used is shown in Fig. 1. The materials comprise well-graded gravelly soils and a few non-plastic fines (less than 5% passing the No. 200 sieve), and is classified as GW groups according to the unified soil classification system [19]. Preliminary modified Proctor compaction tests were conducted on the CTAs to obtain the maximum dry density and the optimum moisture content. The detailed index properties of the CTAs are summarized in Table 1.

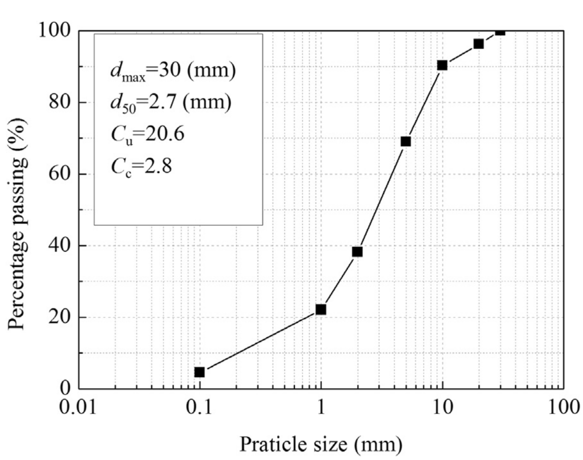

Fig. 1. Gradation curve of the tested material.

Table 1
Index properties of tested materials.

Index properties	G1
Specific weight, ρ_s(g/cm^3)	2.72
Initial void ratio, e_0	0.270
Maximum void ratio, e_{max}	0.405
Minimum void ratio, e_{min}	0.212
Minimum dry density, $\rho_{d,min}$ (g/cm^3)	1.936
Maximum density, $\rho_{d,max}$ (g/cm^3)	2.244
Optimum water content, ω_{op}(%)	5.6
Grain shape	Subangular

2.2. Test apparatus

The large-scale tri-axial apparatus (LDCTTS) used in this study was designed and manufactured by GDS Instruments Ltd,. It is mainly composed of the following parts: 64-kN axial actuator, liquid or pneumatic confining pressure controller, back pressure controller, axial load and displacement transducers, pore pressure transducer, confining pressure transducer, splitter box, signal conditioning unit and GDSDCS dynamic control unit, as shown in Fig. 2. The schematic of LDCTTS is shown in Fig. 3. This apparatus complies with ASTM D3999-91 [20] and EN12386-7 [21].

2.3. Specimen preparation

Cylindrical specimens with D=150 mm and H=300 mm were adopted in this study. The ratio between the specimen diameter and the maximum particle diameter is 5, which satisfies the requirement of the ratio between the specimen and maximum particle size. The relative density I_D of all specimens is 70%, leading to a compaction degree of D_c=95.4%, which meets the requirements of base and subbase materials in Chinese road specifications [22].

A standard routine sample preparation procedure was employed to guarantee the consistency of the sample quality. Firstly, the CTAs were placed with optimum moisture content and then stored in a plastic bag for 24 h to improve the uniformity of moisture distribution. The CTA specimens were prepared in a split mold by moist tamping. In the moist tamping procedure, the specimen was tamped at optimum moisture content in six layers and the weight and height of each tamped layer was controlled to be the same. For each blow, the miniature hammer was used with constant drop height to impose the same impact energy each time. The soils were tamped until it reached the setting height. Before placing the material for the next layer, the surface of the previous compacted layer was scraped to a depth of about 2 cm to ensure good interlocking between the vertical adjacent layers

Fig. 2. The overall system of LDCTTS.