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An investigation of mechanical behavior of cement-stabilized crushed rock material using different compaction methods

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HIGHLIGHTS

- Mechanical behavior of cement-stabilized crushed rock material was investigated.
- Effects of different compaction methods on mechanical behavior were evaluated.
- Effects of cement content and curing time on mechanical behavior were analyzed.
- Field tests were carried out to validate laboratory compaction methods.

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ABSTRACT

The mechanical behavior, e.g. compressive strength, tensile strength and resilient modulus, plays an important role in the performance of cement-stabilized crushed rock material (CCRM). This paper presents an investigation on the mechanical behavior of CCRM based on the quasi-static compaction method (QSCM) and the vertical vibration compaction method (VVCM), respectively. The unconfined compressive strength, splitting tensile strength and resilient modulus of laboratory produced CCRM using QSCM and VVCM are measured and compared. The effects of cement content and curing time on the mechanical behavior are studied. Field measurements are subsequently carried out to validate the laboratory investigations. The results show that the compressive strength, tensile strength and resilient modulus of CCRM by VVCM are 2.5, 1.9 and 1.6 times of the CCRM by QSCM, respectively. In addition, the compressive strength, tensile strength and resilient modulus all increase as the cement content and curing time increase, while the ratio of compressive strength to tensile strength decreases as the curing time increases. The results also show that the mechanical behavior of laboratory produced CCRM by VVCM has a better agreement with the field measurements than the laboratory produced CCRM by QSCM. The laboratory produced CCRM by VVCM can be used to imitate the practical CCRM for approximate calculation.

1. Introduction

The cement-stabilization is commonly used to enhance the performance of geo-materials in road construction [1]. However, the mechanical behavior of cement-stabilized crushed rock material, which is the primary component of composite rock base, has not been fully understood for wide application in the construction of national highway network system in China [2]. It is of significant importance to understand the mechanical behavior, e.g. compressive strength, tensile strength and resilient modulus, of cement-stabilized crushed rock material (CCRM) for the precise road construction analysis and design.

Extensive attentions have been paid to investigate the mechanical behaviors of CCRM [2–7], such as the studies on the compressive strength [8,9], shear strength [10–12], resilient modulus [13,14], permanent deformation and shrinkage behavior [15–17], which are regarded as the primary characters of CCRM. These mechanical behaviors of CCRM are affected by the density of CCRM, which has been regarded as significantly important for the long-term behavior of granular materials. The density of CCRM is directly influenced by the compaction [18]. Therefore, the compaction method of CCRM is important for the enhancement of mechanical behavior of CCRM.

Moreover, the laboratory testing of CCRM can only be an imitation of the practical conditions. It is uneconomical to drill cores from the road construction for mechanical behavior testing. Therefore, the CCRM samples are compacted and molded in the laboratory with the same compaction level as in the field [3].

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Whether the laboratory compacted CCRM samples can be used for the practical CCRM evaluation is still under consideration. In addition, the CCRM specimens for most of the previous studies are compacted and cured both in the laboratory. Therefore, the mechanical behavior will also be influenced by different environmental curing conditions from the field. In order to precisely evaluate the effects of compaction method on the mechanical behavior of CCRM, it is necessary to prepare the specimens respectively in the laboratory and field, and to cure under the same environmental condition.

Two types of compaction methods have been utilized in the Chinese Construction Specifications on the CCRM base layer. The QSCM is a commonly used method for the CCRM compaction for its easy operation and economical testing equipment requirement. However, the compaction in the field with a heavy roller is often associated with the vibration and oscillation, which is different from the QSCM loading condition. The VVCM is another compaction method for a better simulation of the field compaction. The previous researches showed that this method can be used to simulate the vibration loading condition in practical engineering [19]. However, previous researches [3] also indicated that the CCRM behaved differently with different compaction methods even for the same compaction level, e.g. the same dry density. Therefore, it is of significance to evaluate the mechanical behaviors of CCRM by using different compaction methods. Moreover, it is important to assess these laboratory compaction methods by comparing the results with the field measurements.

This paper reported an investigation of the mechanical behavior of laboratory produced CCRM using QSCM and VVCM, respectively. The unconfined compressive strength, splitting tensile strength and resilient modulus were evaluated. Subsequently, field measurements were carried out to validate the practicability of QSCM and VVCM.

2. Laboratory testing

The general specifications of the cement used for the present CCRM are shown in Table 1. The crushed rock used in this study is limestone obtained from a quarry in Liuling city, Shanxi province of China, with a crushing value of 13.9%. Suspended dense structure and skeleton dense structure are applied for the present CCRM, respectively. The definitions of suspended dense structure and skeleton dense structure are according to the coarse mineral aggregate distribution in the mixture. The skeleton dense structure reveals the state that the coarse mineral aggregates in the CCRM are sufficient to form a frame, while the suspended dense structure reveal the state that the coarse mineral aggregates in the CCRM are insufficient to form a frame [20].

Fig. 1 shows the particle size distribution of the crushed rock through a sieve analysis. The cement content rates of 2–5% by dry weight are applied in this study in accordance with technical specification for construction of highway asphalt pavements (JTG F40-2004), China [21].

The standard method of Ministry of Transport of the People's Republic of China-Test methods of materials stabilized with inorganic binders for highway engineering (JTG E51-2009) are followed for the present tests [22]. According to the standard, the CCRM

Table 1
General specifications of cement used in this study.

Fineness (mm)	Compressive strength (MPa)	Flexural strength (MPa)	Setting time (min)
1.3	20.8	5.1	52

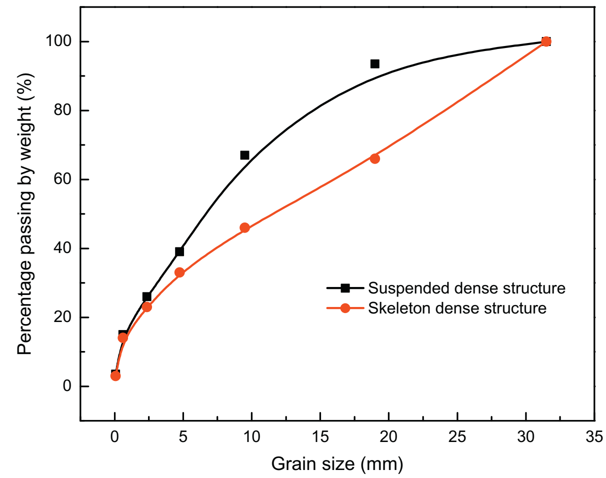

Fig. 1. Particle size distribution of the crushed rock.

specimens were compacted at a displacement loading rate of 1.0 mm/min by a compression testing machine for the QSCM. For the VVCM, the specimens were compacted by a vibrate compression machine. A vertical sinusoidal force with a frequency of 30 Hz and an amplitude of 7.6 kN was applied. The CCRM specimens by QSCM and VVCM were both with the final compaction level of 98%.

3. Testing results and discussion

3.1. Unconfined compressive strength

Table 2 shows the unconfined compressive strength of the laboratory produced CCRM compacted by QSCM and VVCM, respectively. The CCRM is with suspended dense structure and skeleton dense structure, respectively. The cement contents of CCRM are 2.0%, 2.5%, 3.0%, 3.5%, 4.0%, 4.5% and 5.0%, and the curing times for CCRM are 0, 3, 7, 14, 28, 60, 90, 120 and 180 days, respectively.

Fig. 2 shows the compressive strength of CCRM at a curing time of 28 days. It is observed from Fig. 2 that the CCRM with skeleton dense structure has a larger compressive strength than the CCRM with suspended dense structure. The compressive strength increases as the cement content increases. The VVCM is a better method to get a larger compressive strength of CCRM than the QSCM for both suspended dense structure and skeleton dense structure. The increasing tendency of compressive strength with the increasing cement content of CCRM by the VVCM is larger than that of CCRM by the QSCM, which means the cement content has more significant stabilization effects on the compressive strength of CCRM compacted by the VVCM than by the QSCM.

Fig. 3 shows the compressive strength of CCRM with 4% cement content. It is obtained from Fig. 3 that the compressive strength increases sharply at the initial stage, such as curing time of 0–14 days. Subsequently, the increasing tendency decreases and the compressive strength of CCRM keeps stable after a curing time of 180 days. Similarly as the results in Fig. 2, it also can be observed from Fig. 3 that the compressive strength of CCRM with suspended dense structure is smaller than that of CCRM with skeleton dense structure, and the VVCM is a better way to obtain a larger compressive strength of CCRM than the QSCM during the entire curing process. Moreover, it also can be observed from Fig. 3 that the compressive strength of CCRM by VVCM increasing much faster than that of CCRM by QSCM, especially in the initial curing period.