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Permanent deformation behavior of unbound granular base materials with varying moisture and fines content

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ABSTRACT

Specifications for unbound granular base materials vary among transportation agencies based on the availability of materials, climatic conditions, and function. Specifications aim to provide durable materials that meet design requirements and achieve the target design life with cost effective materials. This paper investigates the effect of the percentage fines (particles passing sieve No. 200) and moisture content on the plastic behavior of unbound granular materials. Plastic response of six gradations representing two types of material, 100% crushed limestone and gravel, was evaluated at two levels of moisture content. The shakedown concept was used to classify the deformation behavior of the materials. Results showed that limestone with an optimum fines content of 4.5% and gravel with an optimum fines content of 9% had better resistance to plastic deformation than other fines contents.

Introduction

Pavement materials are usually subjected to stress levels that exceed their elastic limits to accommodate the traffic loading with cost-effective design. Pavement structures fail due to gradual accumulation of permanent deformation, or degradation in materials during their service life, and not due to rapid collapse (Sharp, 1985). The mode of failure of unbound granular material (UGM) layer is governed by the applied load and the shakedown behavior of the material. Using the American Association of State Highway and Transportation Officials (AASHTO) road test data, and a case study conducted in Australia, Sharp (1985) found that pavements subjected to lighter traffic loading or with higher shakedown limits had longer service lives.

UGM response to loading is nonlinear and its behavior is affected by stress history from previous loading. Results from laboratory tests and full-scale retaining wall tests support the existence of residual stresses in compacted UGM due to compaction load and/or repeated traffic loading. Therefore, a newly constructed granular base layer is not stress-free (Uzan, 1985).

Yideti et al. (2013) presented a framework based on packing theory to evaluate the permanent deformation behavior of UGM. The framework introduced the disruption potential (DP), which is defined as the ratio of the volume of potentially disruptive fine material over the volume of voids within the coarse aggregate forming load-carrying skeleton. UGM with DP ranging from 0.5 to 0.9 showed higher resistance to permanent deformation.

Johnson (1985) presented the shakedown process that elastic–plastic materials undergo when subjected to repeated loading, as shown in Fig. 1a. If the elastic limit is not exceeded, an elastic–plastic material undergoes purely elastic behavior with no plastic deformation. When the elastic limit is initially exceeded, the material

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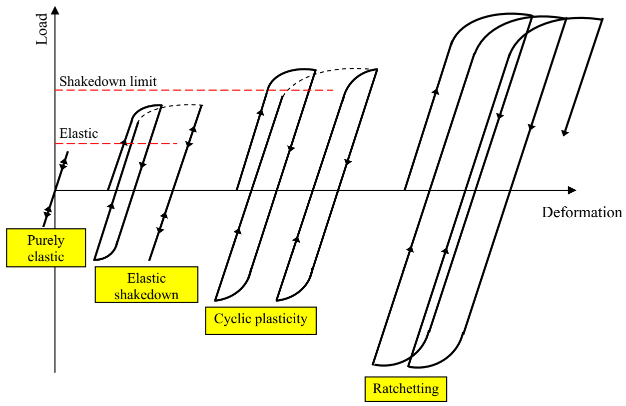
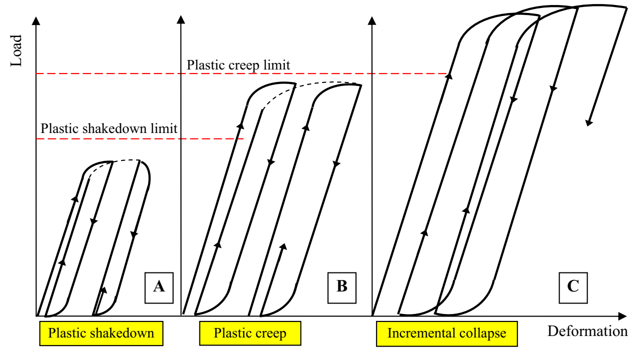


(a) cyclic compression and tension (Barber and Ciavarella, 2000; Johnson, 1985)



(b) cyclic compression only (Werkmeister, 2003)

Fig. 1. Behavior of elastic–plastic material under repeated loading.

experiences initial plastic deformation which produces residual stresses. In subsequent load applications, the behavior of the material is dependent on the combined action of the applied load and the residual stresses produced by previous load applications. After a certain number of load repetitions, the residual stresses build up to a value that leads to a steady state with entirely elastic deformation under subsequent load applications (shakedown limit). When the shakedown limit is exceeded, the material experiences incremental plastic deformation under repeated loading.

For repeated loads above the shakedown limit, an elastic–plastic material may undergo two deformation patterns: cyclic plasticity or progressive increase in plastic deformation (ratchetting), as shown in Fig. 1a (Barber and Ciavarella, 2000). It is important to determine which of these two patterns the material will undergo because the failure mode will be different. Failure is governed by low-cycle fatigue in the first deformation pattern and by exhaustion of ductility or static plastic collapse in the second pattern (Barber and Ciavarella, 2000).

Barber and Ciavarella (2000) studied the influence of friction on contact problems. According to Coulomb friction condition, the state of any point in the contact area between two bodies must be:

- Stick: there is no relative motion at the interface between the two bodies, or
- Slip: there is relative motion at the interface between the two bodies.

The frictional slip depends on the material loading history where it is an incremental process (Barber and Ciavarella, 2000). Sharp (1985) conducted shakedown analysis of different pavement structures using a reformulated Mohr–Coulomb model. Results showed that the first yield, shakedown, and static collapse loads increased with the increase of friction angle for a homogeneous half-space. The static collapse load showed more sensitivity to the increase of friction angle.

The shakedown concept was adopted in several studies to characterize the behavior of UGM under repeated loading (Garcia-Rojo and Herrmann, 2005; Nazzal et al., 2011; Tao et al. 2010; Werkmeister et al., 2001, 2005). The shakedown behavior explained in Fig. 1a was formulated for materials subjected to cycling compression and tension loading (Barber and Ciavarella, 2000; Johnson, 1985; Sharp, 1985). Werkmeister (2003) reformulated the shakedown behavior of UGM subjected to cyclic compression loading only, as shown in Fig. 1b. The deformation behavior of UGM was classified into three categories: plastic