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Shakedown analysis of cyclic plastic deformation characteristics of unbound granular materials under moving wheel loads

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HIGHLIGHTS

- The coupling effect of cyclic vertical and horizontal normal stresses was studied.
- The shakedown concept was used to classify measured plastic deformation behavior.
- Plastic deformation must be assessed from plastic and resilient strains together.

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ABSTRACT

Cyclic plastic strain behavior of unbound granular materials (UGMs) exhibits significant stress path dependency. Using a customized triaxial apparatus capable of applying stress path loading, a series of laboratory repeated load triaxial (RLT) tests were conducted on two typical UGMs by varying simultaneously the axial stress and the radial stress. Effects of realistic in-situ stress paths due to a passing wheel on cyclic plastic strain behavior of unbound granular base and subbase materials were investigated and quantified. The analyses of experimental results revealed that the accumulated plastic strain responses of both UGMs subjected to different stress path loadings can be described by the shakedown approach. The amount of accumulated permanent strain, permanent strain rate, and resilient strain were used to classify the plastic deformation accumulation patterns of tested materials under moving wheel loads. Finally, the significance of the research findings on pavement analysis and design practices was highlighted to evaluate permanent deformation resistance of UGMs and their suitability for use in rut resistant and stable pavement foundation layers.

1. Introduction

A considerable portion of the permanent surface deformation of flexible pavements is contributed by the unbound pavement granular layers [12,13,25]. A better understanding of the permanent deformation mechanisms of unbound granular materials (UGMs) and further development of suitable prediction models are essential for flexible pavement designs with adequate permanent deformation resistance. The applied stress states are recognized as the primary factors influencing permanent deformation behavior of UGMs (e.g., [15,26,27,46]). Direct measurement of permanent deformation of UGMs is commonly performed using either single- or multi-stage constant confining pressure (CCP) triaxial tests. Throughout the tests, the loading direction is unchanged with the traffic loading simulated by a single vertical cyclic deviatoric stress only. However, this has been proven to be inconsistent with in-situ loading conditions and thus considered insufficient (e.g., [10,7,28,34]). On the contrary, field stresses experienced by pavement materials due to moving traffic loading consist of not only cyclic axial stresses but also cyclic horizontal stresses and cyclic shear stresses with the axes of principal stresses rotating continuously (e.g., [23,3,47,8,36]). The importance of principal stress axis rotation on the performance of pavement and railway track has been widely observed [9,6,28,33,17–19,24].

Laboratory tests associated with moving wheel load effects, which are generally performed using variable confining pressure (VCP) triaxial tests, true triaxial tests, hollow cylinder tests, or model tests, still remain quite limited on UGMs as compared to

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subgrade soils or sands. For UGMs, VCP triaxial tests are more practical to simulate the coupling effect of cyclic vertical and lateral normal stresses [43,37,8]. A common controversy between the CCP and VCP tests is whether or not they deliver similar irrecoverable and resilient strains. In accordance, several comparative studies were performed with identical initial stress, identical average

Table 1
Basic Index Properties of the Tested Base and Subbase Aggregate Materials.

Material Type	Fines Content (%)	Atterberg Limits			OMC (%)	MDD (g/cm^3)	Specific Gravity (G_s)	
		LL (%)	PL (%)	PI (%)			Plus 4.75 mm	Minus 4.75 mm
Base	4.6	NA	NA	0	4.7	2.481	2.751	2.837
Subbase	9.5	16	12.9	3.1	6.5	2.055	2.624	2.663

Note: LL = Liquid limit; PL = Plastic limit, and NA = Not available.

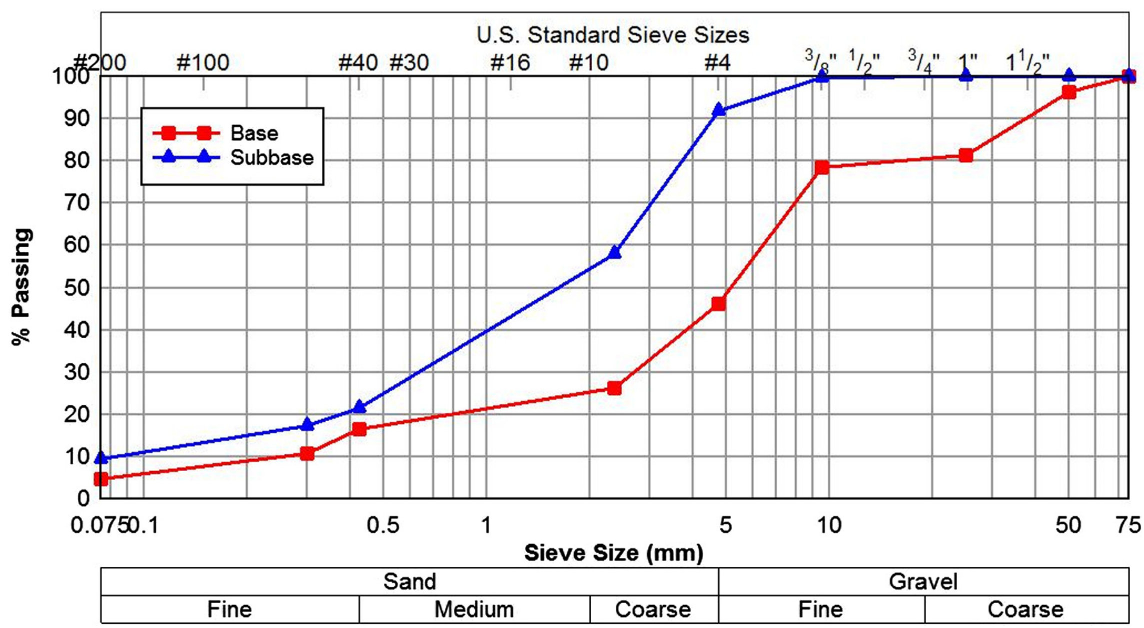

Fig. 1. Gradation Curves for the Tested Base and Subbase Aggregate Materials.

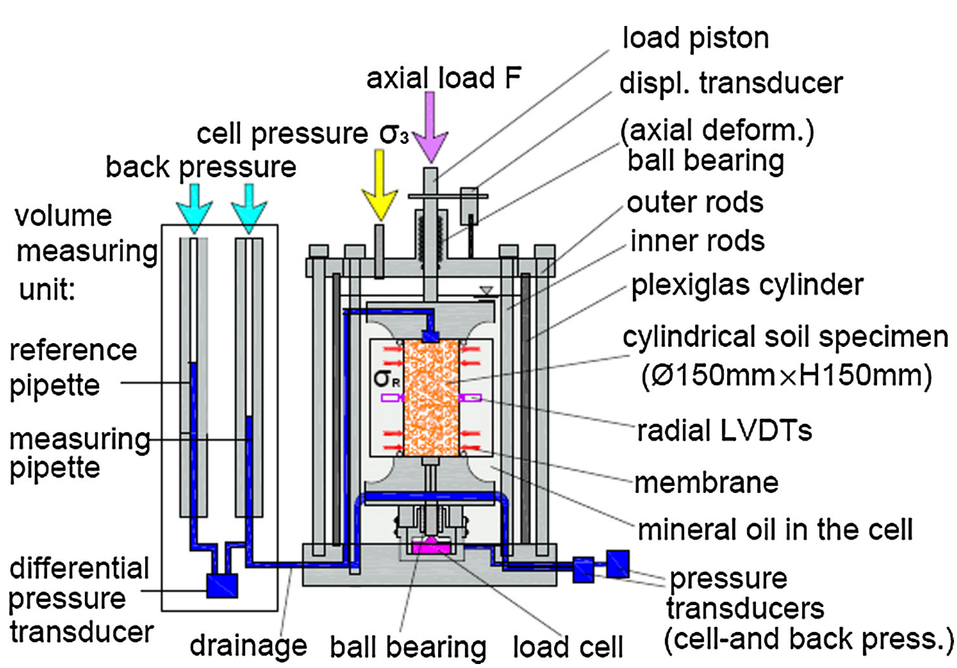

Fig. 2. Schematic Representation of the Customized Triaxial Testing Apparatus Used for CCP and VCP Tests.