Development and Validation of a Subgrade Service Performance Test System Considering Principal Stress Axis Rotation (Post-print)

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Abstract

To accurately reproduce the three-dimensional stress state and service performance evolution of highway subgrades under traffic loading, a subgrade service performance test system considering principal stress axis rotation was developed. The test system primarily consists of a loading system as its core, together with auxiliary modules including a full-digital servo control system and a data acquisition system. Based on the time-history characteristics of complete stress components (three normal stresses and three shear stresses) of subgrade soil elements under traffic loading, a loading system centered on four dynamic actuators and three static actuators was designed, which achieves the principal stress axis rotation effect for subgrade soil elements at different layers through static-dynamic coordinated loading. A three-dimensional dynamic stress reproduction theory for highway subgrades was established based on the theoretical model of subgrade dynamic response under traffic loading, combined with the mechanical structure and spatial characteristics of the loading system, and a transformation method from "stress spectrum" to "loading spectrum" was proposed. Using this test system, verification tests for the internal three-dimensional stress state of highway subgrades under vehicle loading were conducted. The results demonstrate that the actual output load deviation of each static and dynamic servo actuator is less than 1%, indicating that the developed subgrade service performance test system can accurately reproduce the three-dimensional stress state within the subgrade under traffic loading. The vertical dynamic stress within the subgrade gradually attenuates along the depth direction, the stress path experienced by soil elements exhibits an approximately "heart-shaped" pattern, and both the time-history curves of each dynamic stress component and the attenuation law of vertical dynamic stress show high agreement with theoretical calculations. Although the loading device of this test system remains stationary during the loading process, it can still reproduce the dynamic response of soil

elements at different depths in the subgrade working zone during the "far-near-far" movement of traffic loading through "seven-cylinder coordinated action and loading." Therefore, the subgrade service performance test system developed in this study provides new concepts, methods, and technologies for investigating the evolution laws of highway subgrade service performance under realistic stress conditions.

Full Text

Preamble

Development and Verification of Subgrade Service Performance Test System Considering Principal Stress Rotation

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Abstract

To accurately reproduce the three-dimensional stress state and service performance evolution of highway subgrades under traffic loads, this study developed a novel test system that considers principal stress rotation. The system comprises a loading system as its core component, supplemented by auxiliary modules including a full-digital servo control system and a data acquisition system. Based on the time-history characteristics of complete stress components (three normal stresses and three shear stresses) in subgrade soil elements under traffic loading, the loading system was designed with four dynamic actuators and three static actuators. Through coordinated static-dynamic loading, this configuration achieves principal stress rotation effects in subgrade soil elements at various depths. A three-dimensional dynamic stress reproduction theory for highway subgrades was established by integrating the theoretical model of subgrade dynamic response under traffic loads with the mechanical structure and spatial characteristics of the loading system, and a transformation method from "stress spectrum" to "loading spectrum" was proposed.

Using this test system, verification experiments on the three-dimensional stress state within highway subgrades under vehicle loads were conducted. The results demonstrate that the actual output load deviation of each static and dynamic servo actuator remains below 1%, confirming the system' s capability to accurately reproduce the three-dimensional stress state within subgrades under traffic loads. The vertical dynamic stress within the subgrade gradually attenuates with depth, while the stress path experienced by soil elements exhibits an approximately "heart-shaped" pattern. Both the time-history curves of each dynamic stress component and the attenuation law of vertical dynamic stress show high agreement with theoretical calculations. Although the loading device

remains stationary during operation, the system can reproduce the dynamic response of soil elements at different depths in the subgrade working zone during the "far-near-far" movement of traffic loads through a "seven-cylinder coordinated loading" approach.

Therefore, the subgrade service performance test system developed in this study provides new concepts, methods, and technologies for investigating the evolution laws of highway subgrade service performance under realistic stress conditions.

Keywords: Road Engineering; Highway Subgrade; Principal Stress Rotation; Model Test; Loading System; Service Performance

Note: Figure translations are in progress. See original paper for figures.