Effects of Water Level Rise on Dynamic Response and Long-Term Settlement of High-Speed Railway Subgrade: Postprint

Authors: Hu Jing, Tang Yue, Zhang Jiakang, Jiang Hongguang, Bian Xuecheng, Deng Tao

Date: 2025-07-17T00:00:00+00:00

Abstract

Based on Biot' s theory, a 2.5-dimensional finite element analysis model for the coupled track-subgrade-multilayer saturated soil foundation system is established, a calculation method for subgrade cumulative settlement considering actual train cyclic loading is proposed, and the influences of water level rise, train speed, and train axle load on the dynamic response and long-term settlement of the subgrade are analyzed. The research results indicate that the amplifying effect of water level rise on soil vibration intensity is not confined to the depth range of water level change, but rather leads to enhanced vibration throughout the entire subgrade and foundation cross-section; moreover, this full-section vibration amplification effect intensifies with increasing train speed. When the water level rises into the subgrade, significant excess pore pressure develops within the subgrade, with a maximum value reaching 27.52 kPa, resulting in a substantial reduction in effective stress and causing the stress path of subgrade soil elements to approach the failure line. When the water level resides within the foundation, the cumulative deformation of the subgrade under train cyclic loading is relatively small, and track settlement primarily originates from the foundation. When the water level rises into the subgrade, the cumulative deformation of the subgrade develops rapidly with increasing load cycles, reaching approximately 54 mm after 1 million load cycles, far exceeding the allowable limit, indicating that subgrade waterproofing exerts a restraining effect on the long-term evolution process of "failure" . Furthermore, this study also examines the influence of train speed and train axle load on cumulative deformation, which increases significantly with increasing train axle load, and the effect of axle load increase on subgrade cumulative deformation is more pronounced compared to that on the foundation, warranting stringent attention in design.

Full Text

Preamble

Influences of Water Level Rise on Dynamic Responses and Long-Term Settlement of High-Speed Railway Subgrade

HU Jing[1], TANG Yue[1], ZHANG Jia-kang[1], JIANG Hong-guang[2], BIAN Xue-cheng[3], DENG Tao[1]

[1]College of Civil Engineering, Fuzhou University, Fuzhou 350108, Fujian, China
[2]School of Qilu Transportation, Shandong University, Jinan 250002, Shandong, China
[3]College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310058, Zhejiang, China

Abstract

Based on Biot' s theory, this study establishes a 2.5-dimensional finite element analysis model for a coupled track-subgrade-multi-layer saturated soil foundation system and proposes a calculation method for subgrade cumulative settlement under actual train cyclic loading. The effects of water level rise, train speed, and axle load on subgrade dynamic response and long-term settlement are systematically analyzed. The results demonstrate that the amplifying effect of rising water levels on soil vibration intensity is not confined to the depth range of water level fluctuation, but rather enhances vibration throughout the entire subgrade and foundation cross-section. This full-section vibration amplification effect becomes more pronounced with increasing train speed. When the water level rises into the subgrade interior, significant excess pore water pressure develops within the subgrade, reaching a maximum value of 27.52 kPa, which leads to a substantial reduction in effective stress and drives the stress path of subgrade soil elements toward the failure envelope. When the water level remains within the foundation, cumulative deformation of the subgrade under train cyclic loading is relatively small, with track settlement primarily originating from the foundation. However, when the water level rises into the subgrade, cumulative deformation develops rapidly with increasing load cycles, reaching approximately 54 mm after one million loading cycles—far exceeding allowable limits. This indicates that subgrade waterproofing plays a critical role in constraining the long-term evolution of "failure." Furthermore, this study examines the influence of train speed and axle load on cumulative deformation, revealing that deformation increases significantly with axle load, and that this effect is more pronounced on subgrade deformation than on foundation settlement, warranting strict attention during design.

Keywords: Subgrade engineering; Dynamic response; 2.5-dimensional finite element; Water level rise; Saturated foundation; Long-term settlement

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