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Preliminary Testing on High-Speed Railway Substructure due to Water Level Changes

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Abstract

Water infiltration into railway subgrade due to heavy rainfall or flood is one of major factors leading to performance degradation in railways. This paper reported a full-scale physical model test on the performance degradation of a ballastless high-speed railway caused by water level changes. The tests were conducted in a dynamic testing apparatus (5 × 15 × 6 m) developed at Zhejiang University. A portion of a real high-speed railway was constructed in the testing box. Train moving loads were simulated by eight high-performance actuators acting in a predefined sequence. The water levels in the railway substructure were controlled in the testing box by a water storage tank. Both dynamic responses and accumulative settlement of the slab track-subgrade system were monitored. Test results showed that water level rising in subgrade could cause significant performance degradation of the railway. Vibration velocities at the track structure and roadbed increased faster and larger with the train speed after water level rising, as well as the dynamic soil stresses in soils. Accumulative settlement of railway subgrade grew remarkably due to water level rising in subgrade soils. That meant for the high-speed railways in service, reducing water infiltration in railway subgrade was very important to keep railway stable.

Keywords: Full-scale model test; High-speed railway; Water level; Vibration velocity; Accumulative settlement

1 Introduction

With the increase of traffic volumes, axle loads and train speeds, higher dynamic wheel loads are exerted on the track structure and underlying subgrade with more repetitions. At the same time extreme weather and intense precipitation have become more frequent and severe intensive. For example, the amount of rainfall in the heaviest 1% of rain events has increased 20% in the United States (Karl et al. 2009). Therefore, railways are likely to be exposed to more rain and even flood that

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can cause subgrade submerged in water. Subgrade failures, such as mud pumping, progressive shear failure and excessive plastic deformation, are more easily to occur due to the combined effect of pore water and train loads (Li and Selig, 1998). This will greatly increase the cost of track maintenance and jeopardize the running safety of trains. Based on data derived from Federal Railroad Administration (FRA) statistics, Rossetti (2007) reported that at least 861 railroad incidents were associated with weather conditions over the period 1995~2005. About 23.1% of these incidents were resulted from water infiltration, causing over $48 million losses.

Pore water plays an important role on the performance of railways since it strongly affects the mechanical behavior of the soil-water mixture for saturated soft soils with low permeability, e.g. clay and silt, while in more high-permeable materials water flow may cause internal erosion and material transport (Kettil et al. 2008). This will result in lower strength, lower stiffness, and higher deformation of railway subgrade. As trains run along the saturated soft soils, the speed of the vehicles may approach the Rayleigh wave velocity of the ground, leading to large vibrations and displacements of train-track system. This "resonance-like" condition was observed during the X-2000 high-speed trains running along the West Coast Line in Sweden (Madshus and Kaynia, 2000). The displacements increased drastically when the train speed reached 202 km/h, almost three times larger than the quasi-static displacements. Accumulative settlement would further develop under the long-term running of trains. For example, in the Tokaido Shinkansen line in Japan, whose design speed was 210 km/h, only reinforcement to the track was adopted and reinforcement to the soft clay embankment was neglected. Excessive settlement was accumulated due to the coupled effect of water infiltration and traffic loads, and its running speed was forced to reduce to 110~180 km/h. Moreover, ballast puncture and fine particles divorced from ballast and subgrade may create conditions of poor drainage and retention of water at the bearing surface. Track sleepers start moving up and down in grooves with the movement of wheel loads, leading to suction of fines into the groves and pumping out. The mud pumping occurred in more than 13% mileages of railways in China. A Japanese survey carried out in 1975 found that out of 17,000 km of frequently used rails in Japan, more than 700 km suffer from mud pumping. When the pore water pressure is high enough (usually caused by heavy rainfall and dynamic loadings), the effective stress in the soil decreases, which may reduce its ability to transfer shear stresses by friction. The shear failure of subgrade will occur, and the subgrade may even collapse. For example, large deformation up to 64.2 cm was observed in the Shitai railway in China during continuous heavy rainfall. Subgrade collapses were also reported in Xiaoyong and Jingjiu railways in China due to the water infiltration.

As water infiltration is one of the main causes of deterioration and premature distress of the geotechnical structures, a study team from 18 European countries carried out a 3.5 years program to investigate the effect of water infiltration on the road pavements and earthworks (Dawson 2009). It was reported that clear and significant variations of moisture in subgrades were observed in the field. The mechanical behavior, as observed in situ, was strongly affected by moisture variations: the wetter the state the lower the stiffness (up to a factor 2 or more), the lower the strength and the higher the deflection. Accelerated pavement tests showed that rutting depth increased fast after the soil was added by water, which accelerated deterioration by a factor of 4.0.

To investigate the combined effect of traffic loads and water infiltration on the performance of railways, a new research study sponsored by the National Natural Science Foundation and the Ministry of Railway has been undertaken at Zhejiang University. The research project scope involves conducting triaxial tests on the mechanical behavior of soil-water mixtures, carrying out full-scale physical model tests on the dynamic performance of high-speed railways under the coupled effect of water infiltration and traffic loads, and modeling a vehicle-track-subgrade dynamic interaction model. This paper presented first a summary of previous research studies on the degradation mechanism of railways under the coupled action of water infiltration and traffic loads. Then a full-scale physical model for ballastless railways was constructed, and a loading system with eight actuators was used to simulate train moving loads at various speeds. The water levels in the subgrade were lifted or lowered