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Acceleration responses of an immersed tunnel on soft clay deposit under horizontal excitation using centrifuge shaking table test

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ABSTRACT: To investigate the seismic response of immersed tunnels on soft clay deposits, a centrifuge shaking table model test was conducted. The centrifuge model was designed according to similitude principles, considering the model geometry, shear strength of soft clay, and flexural rigidity of tunnel structure. The model was subjected to horizontal excitation with peak acceleration of 0.1g. Results indicated that horizontal accelerations in soft clay deposit first increased and then decreased with decreasing depth under horizontal excitation. For the immersed tunnel, the acceleration increases with elevation due to the high stiffness of the tunnel structure.

1 INTRODUCTION

Immersed tunnels are used as crucial transportation infrastructure connecting coastal cities. However, large areas of soft clay deposits are commonly encountered in coastal regions (Zhou et al., 2021), and immersed tunnels are inevitably constructed on these weak deposits. Seismic excitations could cause damages on immersed tunnels due to the unfavourable engineering properties of soft clay. Therefore, understanding the seismic response of immersed tunnels on soft clay deposit is of utmost importance.

This paper presents a centrifuge test to investigate the dynamic response of an immersed tunnel on soft clay deposit subjected to horizontal excitation, with the focus on the acceleration responses.

2 TESTING PROGRAM

The centrifuge shaking-table test was conducted at the Institute of Engineering Mechanics (IEM), China Earthquake Administration, using the IEM-40-300 geotechnical centrifuge equipped with a uniaxial horizontal shaking table. The test was performed at a centrifugal acceleration level of 50 g, corresponding to a scaling factor of 1/50. Figure 1 presents a schematic view of the centrifuge model to simulate an immersed tunnel on soft soil deposit. From bottom to top, the model comprises soft clay deposit, gravel bed, immersed tunnel, backfill layer, and water. The soft clay deposit and backfill layer have thicknesses of 21 m and 9.5 m, respectively. The tunnel was designed based on the Yongjiang Immersed Tunnel, with dimensions of 12 m (length) × 7.5 m (height). A 12.5 m-deep de-aired water was placed above the backfill layer to simulate the seawater in the field.

The gravel bed and backfill layer were constructed using coarse sand through pluviation to achieve a target relative density of 85%. The soft clay deposit was composed of Suzhou kaolin, characterized by a liquid limit of 54.7, a plastic limit of 30.1, and a plasticity index of 24.6. The preparation process consisted of two stages: 1g pre-loading consolidation and subsequent centrifugal consolidation (Lan et al., 2024) to replicate the in-situ stress states of normally consolidated marine clay.

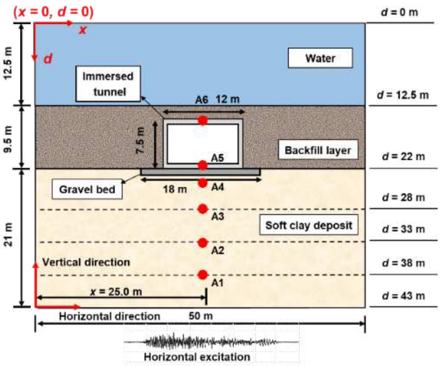

Figure 1. Schematic view of the immersed tunnel on soft clay deposit (dimensions in prototype scale) and accelerometer layout in the centrifuge model.

The instrumentation layout of the model is illustrated in Figure 1. In the model, a total of six accelerometers were installed in the model to obtain the acceleration responses of in the soil and the tunnel structure. Four accelerometers were embedded in the soft clay deposit at the depths of d = 38 m (A1), 33 m (A2), 28 m (A3) and 23 m (A4), respectively. Furthermore, to investigate the structural response characteristics, two additional accelerometers (A5 and A6) were mounted on top and base of the tunnels at the depths of d = 14.5 m and 22.0 m, respectively.

The horizontal acceleration time histories used in the centrifuge shaking table tests are presented in Figure 2, with a peak acceleration of 0.1g. During the test, the earthquake excitation was applied in the horizontal direction (as illustrated in Figure 1).

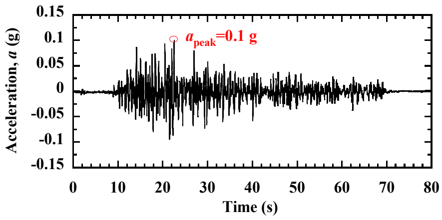

Figure 2. Time histories of input earthquake motion in the horizontal direction.

3 RESULTS AND DISCUSSION

To illustrate the upward propagation of horizontal accelerations under horizontal excitation in the model, the peak horizontal acceleration at each depth is normalized by the measured peak horizontal acceleration at the base of the shaking table to obtain the horizontal acceleration amplification factor. The profiles of the horizontal acceleration amplification factor in the vertical direction are shown in Figure 3. The horizontal acceleration amplification factor increases with decreasing depth from d = 38 m upwards to d = 23 m. This observation is consistent with the amplification of acceleration responses in soft clay deposit observed in centrifuge studies (Zhou et al., 2021). In addition, the horizontal acceleration amplification decreases from d = 28 m upwards to d = 23 m. As the seismic waves propagate upwards, the shear strain induced in the shallow region of the soft soil deposit increases significantly. This leads to a pronounced degradation of dynamic shear modulus, causing soil softening, reduced stiffness, and increased damping, which collectively result in the observed decrease of acceleration amplification factor. For the immersed tunnel, the response at the top is greater than that at the base. This occurs because acceleration is noticeably amplified along the height of the rigid tunnel structure due to the high stiffness.

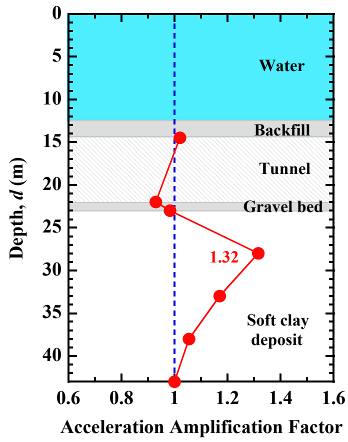

Figure 3. Peak horizontal acceleration amplification factors in the vertical direction during horizontal excitation.

4 CONCLUSIONS

A centrifuge shaking table test was conducted to investigate the acceleration responses of an immersed tunnel on soft clay deposit subjected to horizontal excitation. Results indicated that horizontal accelerations in the soft clay deposit first increased and then decreased with decreasing depth. For the immersed tunnel, the acceleration increases with elevation due to the high stiffness of the tunnel structure. Results provide valuable insights into seismic design of immersed tunnels on soft soil deposit.

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REFERENCES

Lan, J.Y., Xian, G.L., Wang, Y.Z., Wang, T.Q., Liu, X.Y., Ren, H.Y., Tang, Z.G. (2024). A combined preparation method of stratified preloading and centrifuge operation for soft clay foundations. *Chinese Journal of Rock Mechanics and Engineering* 43(5): 1282-1290. https://doi.org/10.13722/j.cnki.jrme.2023.0750

Zhou, H.Z., Xu, H.J., Yang, P.B., Zheng, G., Liu, X.N., Zhang, W.B., Zhao, J.P., and Yu, X.X. (2021). Centrifuge and numerical modelling of the seismic response of tunnels in two-layered soils. *Tunnelling and Underground Space Technology* 113: 103980. https://doi.org/10.1016/j.tust.2021.103980