SEISMIC RESPONSE OF PILE FOUNDATION IN LIQUEFIED SITE CONSIDERING THE EFFECT OF OVERLYING FROZEN SOIL LAYER

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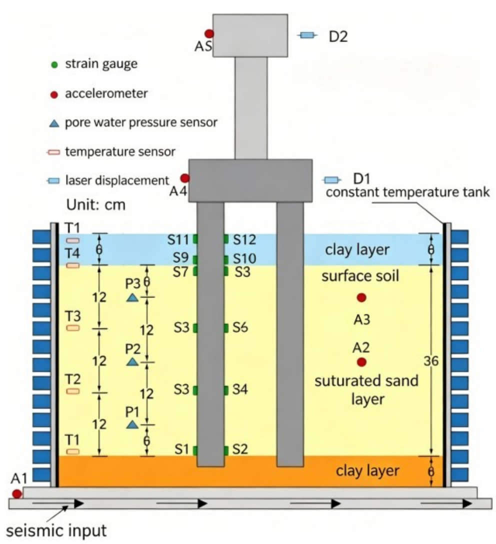
Extended Abstract

The Qinghai-Xizang Plateau region in the western part of China is home to extensive permafrost and seismic fault zones, with frequent seismic activities. For instance, there were the 7.4 magnitude earthquake in Maodu, Qinghai in 2021, the 6.9 magnitude earthquake in Menyuan, Qinghai in 2022, and the 6.2 magnitude earthquake in Jishishan, Gansu in 2023. In all these cases, the phenomenon of site liquefaction caused by earthquakes was observed. A large number of transportation infrastructure such as highways and railways in the western part of China adopt the method of using bridges instead of roads. Pile foundations are widely used due to their good bearing capacity and low thermal disturbance to permafrost.

The liquefaction of the ground caused by earthquakes is one of the main reasons for the damage to bridge pile foundations. The overlying soil layer on the liquefied ground has significant effects on the seismic dynamic characteristics of the soil and the pile foundation. When the overlying layer on the liquefied ground is frozen soil, the seismic response of the pile foundation will become more complex. Therefore, conducting research on the seismic response of bridge pile foundations in liquefied sites with overlying frozen soil layers has important theoretical and engineering significance.

The presentation content in this keynote speech covers the vibration test of pile foundations on sites with overlying frozen soil liquefaction, as well as the two-dimensional nonlinear finite element model of pile-frozen soil interaction considering the shear effects of both the overlying frozen soil layer and the liquefied soil layer. The test was based on a typical pile foundation bridge of the Qinghai-Tibet Railway in the western permafrost area. The length of the prototype pile was 15 meters, the diameter was 1.5 meters, and the elastic modulus was $4\times10^4\,\mathrm{MPa}$, and the density was $2.4\times10^3\,\mathrm{kg/m^3}$. Considering the limitations of the size of the vibration table

and the layered shear model box, the size similarity ratio of this vibration table test was determined to be 1:30. The model soil layer is divided into three layers, from top to bottom they are the frozen soil layer, the saturated sandy soil layer and the clay layer. The thickness of the frozen soil layer and the clay layer is 6 cm, and the thickness of the saturated sandy soil layer is 36 cm. The upper structure is simplified as a bridge pier plus a mass block. The bridge pier is simulated by an iron rod with a diameter of 8 cm and a height of 26.7 cm, and the mass block is a 120 mm × 100 mm × 80 mm iron block. Figure 1 shows the layout of the test sensors. The numerical model takes into account that there will be sliding and displacement discontinuity phenomena between the overlying frozen soil layer and the saturated sandy soil layer, which is known as shear localization. In the OpenSees software, the phenomenon of shear localization is simulated by establishing a soil element with a low reference shear modulus at the interface between ice and sand. The model uses dynamic *p-y* springs and dynamic *t-z* springs to simulate the horizontal and vertical interactions between the pile body and the soil, and uses dynamic *q-z* springs to simulate the vertical interaction between the pile tip and the soil. The dynamic *p-y* curve of frozen soil is determined based on the modified weak rock *p-y* curve from relevant literature. The pile-soil dynamic interaction model is shown in Figure 2.



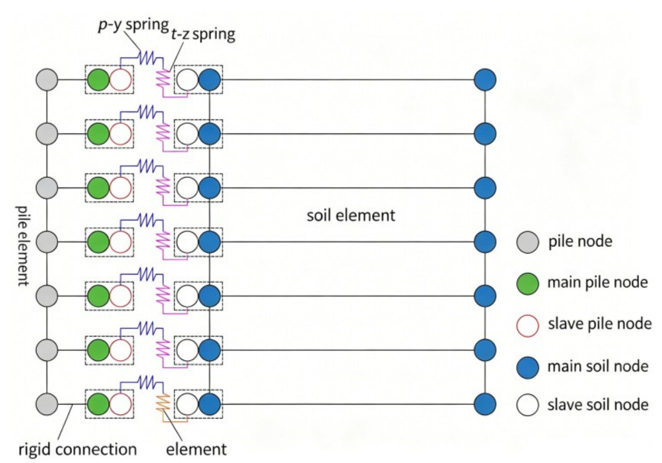


Figure 1- Test sensor layout   Figure 2- Pile-soil dynamic interaction mode

The uniqueness of this study lies in the fact that, unlike the conventional soil liquefaction vibration table tests in the past, this experiment takes into account the influence of the overlying frozen soil layer. It studies the seismic response laws of pile foundations under the coupling effect of the overlying frozen soil layer and the liquefied soil layer, and simultaneously establishes a two-dimensional nonlinear finite element model of pile-frozen soil considering the shear effects of the overlying

frozen soil layer and the liquefied soil layer. It also investigates the influence of the thickness of the overlying frozen soil layer on the seismic response of the pile foundation.

The results of the vibration test and simulation show that the curvature of the pile foundation is the greatest at the bottom of the frozen soil layer, and the pile foundation is most likely to be damaged at the interface between frozen and sandy soil. In the middle and lower part of the sandy soil layer, the curvature of the pile foundation will increase again due to the lateral flow caused by soil liquefaction. For the actual engineering of liquefied sites in the frozen area, the design at these two positions should be given special consideration. The thicker the overlying frozen soil layer, the smaller the superstatic pore pressure ratio of the soil, and the lower the probability of soil liquefaction. An increase in the thickness of the overlying frozen soil layer can to some extent enhance the bending and shear bearing capacity of the pile foundation.

Keywords: *Frozen soil; liquefaction site; pile foundation; seismic response; numerical simulation.*