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Seismic Performance and Design of Bridge Foundations in Liquefiable Ground with a Frozen Crust
Final Report

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Two major earthquakes in Alaska, namely 1964 Great Alaskan earthquake and 2002 Denali earthquake, occurred in winter season when the ground crust was frozen. None of the then-existing foundation types was able to withstand the force from the frozen crust overlying liquefied soils. This project aims to study how the frozen ground crust affects the performance of bridge pile foundations and how one can estimate the loads imposed by the frozen ground crust. A shake table experiment was conducted to gain in-depth understanding of the mechanism of frozen ground crust-pile foundation interaction and collect data to validate a solid-fluid coupled finite element (FE) model and a simplified method, i.e. the beam-on-nonlinear-Winkler-foundation (BNWF) or p-y approach. Loads imposed on pile foundations by the frozen crust were studied through solid-fluid coupled FE analyses of a typical Alaskan bridge foundation under two soil conditions–one with an unfrozen crust and the other with a frozen crust–and by comparison of results obtained from these two cases. The effectiveness of the p-y approach in predicting the response of piles subject to frozen ground lateral spreading in liquefiable soils was evaluated by comparing the analyses of results with those obtained from the FE modeling. Finally, guidelines were proposed for design practitioners to analyze the performance of pile foundations embedded in liquefiable soils subject to frozen ground crust lateral spreading with the p-y approach.

14- KEYWORDS: Earthquake engineering (Ttkfre), Foundation engineering (Ttkfh), Bridge foundations (Pdybbff)

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ABSTRACT

Two major earthquakes in Alaska, namely the 1964 Great Alaska Earthquake and the 2002 Denali earthquake, occurred in winter season when the ground crust was frozen. None of the then-existing foundation types was able to withstand the force from the frozen crust overlying liquefied soils. This project aims to study how a frozen ground crust affects the performance of bridge pile foundations and how to estimate the loads imposed by a laterally spreading frozen ground crust during earthquake-induced liquefaction. A shake table experiment was conducted to gain an in-depth understanding of the mechanism of frozen ground crust-pile foundation interaction, and to collect data to validate a solid-fluid coupled finite element (FE) model and a simplified analysis method, that is, the beam-on-nonlinear-Winkler-foundation (BNWF) or *p*-*y* approach. Loads imposed on pile foundations by a frozen crust were studied through solid-fluid coupled FE analyses of a typical bridge foundation in Alaska under two soil conditions—one with an unfrozen crust and the other with a frozen crust—and by comparison of results obtained from these two cases. The effectiveness of the *p*-*y* approach in predicting the response of piles subjected to frozen ground lateral spreading resting on liquefied soils was evaluated by comparing the results obtained from the p-y approach with results from FE model. Finally, guidelines are proposed for design practitioners for performance analysis of pile foundations embedded in liquefiable soils subjected to frozen ground crust lateral spreading with the *p*-*y* approach.

EXECUTIVE SUMMARY

This study investigates the effect of frozen ground crust on the seismic response of pile foundations in liquefiable soils. A shake table experiment was conducted to gain an in-depth understanding of the impact of frozen ground crust on a model pile. The results were used to validate two numerical approaches: solid-fluid coupled finite element (FE) modeling and the *p-y* approach. Loads imposed on pile foundations by the frozen crust were studied through solid-fluid coupled FE analyses of a typical Alaska bridge foundation. The effectiveness of the *p*-y approach in predicting the response of piles embedded in liquefiable soils subjected to laterally spreading frozen ground was evaluated. The main findings from this project are summarized below:

1. The shake table experiment shows that laterally spreading frozen ground crust forms two plastic hinges on the model pile: one near the frozen crust-loose sand interface and the other within the medium dense sand layer. The plastic hinge at the frozen crust-loose sand interface is formed because of the large distributed load (soil resistance) induced by the frozen ground crust; the plastic hinge in the medium dense sand layer is the direct result of lateral spreading of the ground crust.
2. Two approaches—the solid-fluid coupled FE modeling and the *p-y* approach—were confirmed as being quite effective in predicting the response of piles subjected to frozen ground crust lateral spreading, particularly the formation of plastic hinges.
3. Laterally spreading ground crust forms two plastic hinges on the pile for both frozen (with a frozen active layer) and unfrozen (with an unfrozen active layer) cases: one located near the frozen ground crust-loose sand interface (referred to as the upper plastic hinge) and the other within the medium dense sand layer (referred to as the lower plastic hinge).
4. The plastic deformation and hinge rotation demand are much higher in the frozen case than in the unfrozen case under similar seismic loading conditions.
5. The *p-y* approach is effective in predicting the location and plastic deformation demand at the upper plastic hinge, and the location of the lower plastic hinge. It underestimates the plastic deformation demand in the lower plastic hinge. However, with further study, this could be improved by using a different p-multipliers selection approach.

6. Guidelines are proposed for design practitioners to analyze the response of piles embedded in liquefiable soils subjected to frozen ground crust lateral spreading by the *p-y* approach. This includes how to obtain free-field displacement, select p-multipliers, model the frozen soil resistance, and account for the restraint offered by the superstructure.