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Numerical analysis of permafrost effects on the seismic site response

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ABSTRACT

Some of the damage to the infrastructure observed in past earthquakes occurred in Alaska could be related to the existence of permafrost. However, only limited research has been carried out so far to investigate the effects of permafrost on the seismic site response. Permafrost with relatively high shear wave velocity (1000–1500 m/s) extensively exists in the interior of Alaska and causes anomaly in the shear wave velocity profile that may alter the site response. In current design practices, permafrost has been treated as bedrock and its potential effects on site response are ignored. A systematic investigation was conducted to understand the effects of permafrost on the ground motion characteristics using one-dimensional equivalent linear analysis for the MCE, AASHTO and IBC Design Earthquake level hazards. The average surface displacement, velocity and acceleration response spectra for a typical permafrost site were obtained and the worst case scenario was identified. The results show that the presence of permafrost can significantly alter the ground motion characteristics and it may not be conservative to ignore the effects of permafrost in the seismic design of civil structures.

1. Introduction

Permafrost, or perennially frozen ground, refers to the ground that has a temperature lower than 0 °C (32°F) continuously for at least two consecutive years [1]. Under the arctic or sub-arctic conditions, a large portion of the State of Alaska is underlain by continuous or discontinuous permafrost. The thickness of the discontinuous permafrost increases gradually from 0–15 m in South-central Alaska (Anchorage and the adjoining areas) to about 50 m in the interior. To the further north, the discontinuous permafrost becomes a continuous permafrost of 360–650 m thick [1]. Moreover, nearly the entire State of Alaska is located on one of the most active seismic zones in the world. Several large magnitude earthquakes including the Prince William Sound Earthquake of March 1964 (M_w=9.2) and the Denali Earthquake of November 2002 (M_w=7.9) have occurred in the state and caused considerable damage to its transportation system.

Many researchers have studied the dynamic properties of the frozen soil using both laboratory and field measures [2–4]. The large variation of temperature causes a drastic change in soil dynamic properties. For instance, the Young's modulus of the frozen soil is in magnitudes of tens to hundreds times higher than that of unfrozen soil [5]. Typically, unfrozen soil of low shear wave velocity (V_s) exists underneath the high velocity permafrost due to increase of ground temperature with depth. Therefore, the ground stiffness decreases with depth below permafrost, which is in contrast to non-permafrost sites where the ground stiffness generally increases with depth. Such change in ground stiffness due to the existence of permafrost may alter the seismic site response. However, only limited research has been carried out so far in this aspect. Finn and Yong [6] reported a summary of the research efforts on frozen ground including permafrost and concluded that studies on the seismic response of frozen ground were at an elementary stage and were primarily based on field data collected after the Alaska earthquake of 1964 [7,8]. They suggested that as a first order approximation, it might be reasonable to assume that the seismic response of a thick permafrost layer would be similar to that of the rock. Vinson [9] also studied the seismic response of a thick permafrost site and made a similar conclusion. A study on the Qinghai–Tibet railway embankment [10] reported that the existence of a permafrost layer would significantly affect the site response spectrum for earthquakes with high frequency components. However, this study was based on a very limited number of input motions and did not consider different levels of seismic hazard. Sritharan et al. [11] investigated seasonally frozen ground effects on the seismic performance of bridge foundations.

Current design codes, e.g. the American Association of State Highway and Transportation Officials (AASHTO) [12] and International Building Code (IBC) [13], are based on site response studies of unfrozen soils and do not include any specific recommendations to account for frozen soil effects. In current

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