EARTHQUAKE RESPONSE OF PILE FOUNDATION IN LIQUEFIABLE SOIL

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By

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ABSTRACT

Liquefaction is an earthquake-induced phenomenon in soil strata with fine sand and silt. During potential earthquakes, pore water pressure increases and balances the weight of the soil, reducing the shear strength and bearing capacity in liquefiable soil. Pile foundation is the solution to this kind of failure of the structure due to earthquakes. Still, they suffer large-scale damage because of excessive bending moment and pile head deflection. The loss of shear strength of soil in liquefied soil layer due to excess pore water pressure may develop significant bending moments and shear forces in the piles resulting in buckling and flexural failure. Pile response due to liquefaction required a large setup of equipment in the laboratory. Hence an attempt has been made to investigate the response of pile under liquefaction using spectrum compatible accelerogram corresponding to maximum credible earthquake for the most severe seismic zone of Indian standard with Finite Element Model (FEM) in the OpenSess platform.

The present study explores three primary issues of the pile response on liquefiable soil namely, FEM analysis for pile response, analysis of pile response under liquefied soil using Winkler beam foundation model and pile response mitigation using rubber-soil mixtures. Two types of soil layers are considered under each cases mentioned above i.e., pile with single liquefiable soil layer and pile embedded in liquefied layer sand-witched between non-liquefied crust layers. A summary of these studies and observations are as follows:

A simple prototype model is proposed to evaluate the pile response characteristics of soil due to earthquake liquefaction. For this a model is proposed with a horizontal liquefiable soil layer above a non-liquefied bed-rock with a steel pile embedded into the soil layer. The entire model is placed on a base, moving laterally but restrained against the vertical direction. Now, the model is analyzed to obtain the pile response when shaking is applied at the base considering the pile end is fixed at the bottom. It is estimated that liquefaction deforms the piles laterally under the action of axial load leading to an increase in bending moment leading to damage. Maximum pile head deformation, Bending Moment (BM) and Shear Force (SF) are estimated to be much higher than that in non-liquefied soil layer. The proposed model is validated with the results obtained by earlier researchers, using the Kobe earthquake recorded accelerogram. It is estimated that, non-liquefied crust layer directly over a liquefied soil generates additional lateral load on the pile. A normalized comparative

plot is made to check the separated effect of axial load and crust layer. From the normalized plot, the pile head displacement due to lateral movement of crust layer is estimated to be much higher than without considering crust layer, demonstrating the twice damaging effect of non-liquefied crust layer.

Numerically pile response in liquefied soil is analyzed through force-based approach and displacement-based approach. Most commonly used is displacement-based approach, i.e., Winkler foundation. Beam on non-linear Winkler Foundation (BNFW) model can consider the non-linear soil-pile interaction through the use of non-linear springs representing the soil behavior at discrete locations. Most of the researchers used spring stiffness by assuming degree of liquefaction. However, a static equivalent approach is used without assuming degree of liquefaction. Maximum responses due to FEM in OpenSees platform and numerical modelling are in close agreement in all cases viz. liquefied soil with and without sand-witched layer substantiating the proposed model's adaptability for solving soil-pile-structure interaction in liquefiable soil due to earthquake loading.

Rubber can effectively dampen earthquake energy transmission. As a source of rubber in the mixture, the scrap tires can be used as a beneficial way to reuse used tires. Considering this effect, a pile response mitigation technique using Rubber Soil Mixture (RSM) is proposed. Further, a parametric study is done to estimate the effect of depth and width RSM around the piles for various depth and thickness RSM layers around the piles. It is observed that the RSM layer of 2 m width around the pile and a depth of 2.5 m can reduce the pile head displacement 40%, while the reduction in maximum SF and BM is estimated to be 60% and 61%, respectively. RSM layer of 1m width is applied around the pileup to crust layer depth. Results show that the use of the RSM layer proves very effective in reducing the pile responses. Pile head displacement due to RSM is reduced by 70% when compared to without RSM.

Further, a parametric study is carried to estimate the effect of depth of RSM layer on pile response reduction. The result predicts that almost 10% reduction in maximum pile head displacement is achieved with 1m depth of RSM layer, while the reduction further increased to 40% and 60% with RSM depth 2.5m and 4m, respectively. This establishes the effectiveness of the RSM technique to mitigate liquefaction potential on piles response. The effect of the volume of the RSM layer on pile response is also studied. From the result, it may be observed that reduction of pile response is increased with an increase in RSM volume. It is also estimated that placing the same volume of RSM layer depth-wise gives better control for highly spaced piles while achieving 70-80% reduction more RSM volume

to be placed along width (surface) direction. Maximum responses estimated through the proposed FEM model vide OpenSees and prediction in SAP2000 platform are in close agreement in all cases, showing the proposed model's adaptability for solving soil-pile-structure interaction in liquefiable soil due to earthquake loading.