CASE STUDY OF A SIMPLIFIED APPROACH TO STRUCTURAL MITIGATION OF LATERAL SPREAD BELOW A MULTI-STORY BUILDING

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ABSTRACT

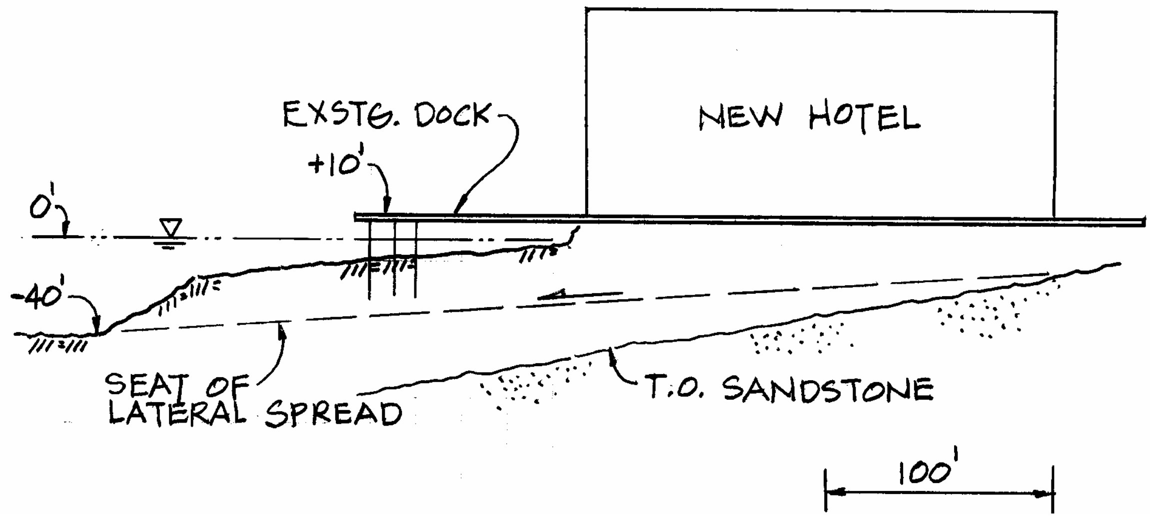
Recently published liquefaction design guidelines (MCEER/ATC-49-1, 2004) have recommended a simplified approach for using deep foundations to support structures while mitigating the effects of lateral spread. This simplified approach suggests "decoupling" the effects of lateral spread from the effects of the structural inertial loading, and recommends the use of different performance criteria for these two seismic effects.

This paper presents a case history of a new 8-story building on the Oregon coast (PBS Engineering and Environmental, 2006). A steel pipe pile foundation was designed to support gravity loads, vertical and lateral earthquake forces, and to stabilize the underlying soils against lateral spread by "pinning."

PROJECT DESCRIPTION

The project site is on the west shoreline of Coos Bay, Oregon, adjacent to a 40-foot deep dredged ship channel. A new 8-story hotel building, approximately 70-ft x 220-ft in plan, was "cut into" an existing pile-supported dock slab, which was removed and replaced with new foundations. The estimated building period was 0.6 sec, corresponding to a design spectral response acceleration of 1.0g and an un-factored base shear of 2,500 kips.

The stratigraphy beneath the building consisted of 30 to 50-ft of soft, saturated bay mud and old fill, overlying 27 to 46 feet of dense silty sand and soft siltstone, overlying competent siltstone and sandstone. The new foundations consist of 4-foot thick pilecaps supported by 24" x ½" open-ended vertical pipe piles, driven a minimum of 5-feet into the competent sandstone/siltstone stratum.



Inferred Cross-section, Looking South

LIQUEFACTION HAZARD ASSESSMENT

Based on an estimated peak ground acceleration of 0.54g resulting from a magnitude 8.5 subduction zone earthquake, we used the NCEER simplified consensus methodology (Youd and Idriss, 1997) to determine a liquefaction factor of safety of 0.11 to 0.16 for the top 27 to 46-feet of soft soils. These very low safety factors indicate that liquefaction of the soft soils should be assumed for earthquake design.

Keywords: liquefaction, lateral spread, pile pinning, deep foundations, earthquake
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STRUCTURAL INERTIAL LOADING

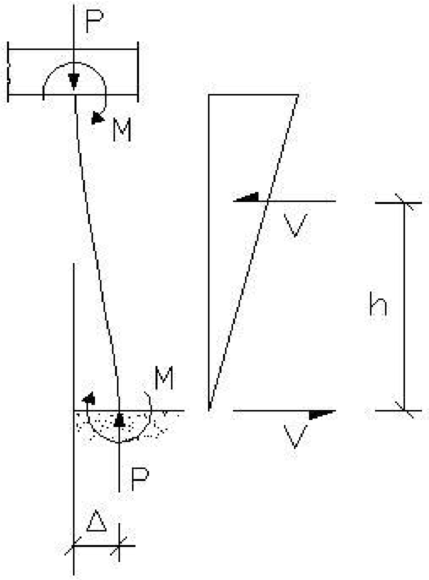
Because of the high probability of liquefaction, structure lateral load design was done assuming all the upper bay mud soils are liquefied. We made an LPILE analysis (Ensoft, Inc., 2004) assuming a fixed-head condition, with the piles embedded in liquefied soils with a residual shear strength equal to 12% of the pre-liquefaction vertical effective stress (Stark and Mesri, 1992). The analysis indicated that a lateral pilecap deflection of 4 to 5-inches corresponds to a head shear of 23 to 29-kips per pile, and bending stresses of 27 to 33 ksi.

LATERAL SPREAD EVALUATION

We modeled a potential lateral spreading block beneath the proposed building with an average thickness of 31-feet and a failure surface sloping 3 to 4-degrees. We based the lateral spreading demand on a horizontal seismic coefficient equal to one-half of the expected peak ground acceleration, and based the capacity on an estimated residual shear strength of 250 psf at the modeled failure surface. The resulting capacity to demand ratio (i.e., FOS) for lateral spread was 0.33, indicating that lateral spreading is likely during the design earthquake. To achieve a FOS of 1.0 in accordance with this analysis, a total pinning force of 7,400-kips would be required.

LATERAL SPREAD PINNING

We assessed the pinning capacity of the vertical steel pipe piles, decoupled from the effects of the structural inertial loading, by assuming the development of a mechanism consisting of plastic hinges at the pilecap and at an average depth of 40-feet below the top of the pilecap. Developing this mechanism corresponds to an $ML^2/6EI$ deflection of about 6-inches. Based on our judgment of soil stiffness variations in the upper layers, we assumed the pinning resistance to be distributed as shown at the right. We increased the calculated pile deflection by 50% to allow for inelastic deformation, and reduced the calculated pinning resistance by the P-delta moment caused by a 200-kip per pile dead load, resulting in a net pinning force of 90-kips per pile.



$$V = \frac{2M - P\Delta}{h}$$

Based on our block analysis, which indicated that a force of 7,400-kips would be required to pin the soils beneath the new building against lateral spread, a minimum of 82 piles would be necessary to achieve pinning. Because the project contains approximately 90 piles, we judged the underlying soils to be adequately pinned against lateral spread.

CONCLUSION

The MCEER/ATC simplified approach of splitting the structural loading and the lateral spreading into two independent activities is a rational technique, because the peak vibration response is likely to occur in advance of maximum lateral spread displacement. Considering both effects simultaneously would be excessively conservative and uneconomical. In addition, MCEER/ATC has judged that considering a plastic mechanism in the foundation under the action of the spreading forces is reasonable because it is unlikely to lead to structure collapse. Finally, MCEER/ATC recognizes that because considerable uncertainties exist in current methods of predicting lateral spread displacements, simple estimates of the plastic mechanism and its lateral resistance is often adequate, and highly refined accuracy of analysis is not warranted.

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