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Contributed Papers: Discussions and Replies

T. Kagawa
Wayne State University, Detroit, MI

Discussion on
"Soil-Pile-Structure Interaction during Liquefaction"
by
S. Nomura, Y. Shamoto and K. Tokimatsu
(Paper No.5.16)

By T. Kagawa
Wayne State University
Detroit, MI 48202 U.S.A.

The paper presented valuable experimental and numerical investigations on the seismic response of piles in liquefying sand. The discusser would like to share with the authors his experience on this subject.

Liquefaction of sand around a pile can impact the performance of the pile in various ways, leading to: 1) Alteration of the dynamic response behavior of the pile, 2) Uniform and differential settlements due to the temporary reduction of bearing capacity of the pile, and 3) Excessive lateral movements due to the flow of liquefied sand. The major objective of the paper is to provide an improved insight into the first problem.

Soil-pile interaction in liquefying sand is a very complex problem that requires due considerations on: 1) Free-field soil movements due to earthquake shaking, 2) Nonlinear soil reaction to piles, 3) Excess pore pressure buildup and redistribution in the free field, and 4) Excess pore pressure buildup and redistribution in the near field.

Various numerical tools are readily available to assess the soil movements and the excess pore pressure generation and redistribution in the free field during an earthquake. Most piles in practice are sufficiently flexible, and the movement of a pile during an earthquake is often very similar to that of the free field. Exceptions may occur near the ground surface where the soil stiffness is small. Therefore, the pore pressure buildup and redistribution in the free field can have a controlling effect on the pile response during an earthquake.

In certain situations, however, the excess pore pressure buildup and redistribution in the near field can control the dynamic response of piles. A relatively small differential movement between the pile and the soil can produce excess pore pressures that are sufficient to dramatically reduce the lateral soil stiffness to the pile. Such excess pore pressures have large gradients in the radial direction of the pile, and the excess pore pressures tend to dissipate in that direction rather than vertically. The rate of dissipation is controlled by a number of factors including pile radius, permeability and compressibility of sand.

An assessment of the accumulative excess pore pressures adjacent to the pile is a very difficult task. Such pore pressures may be determined by considering the interaction of the pore pressure generation and redistribution in both the free field and the near field. No proven numerical methods and observational data are available to accomplish this task. The dynamic response of piles in liquefying soils should be studied both analytically and experimentally.

Development of numerical methods for the present purpose is still in an embryonic stage. For example the discusser reported numerical methods that employed nonlinear Winkler springs and dashpots[3,4,5]. These methods are somewhat similar to the one presented in this paper. These methods, however, can assess in an approximate manner the effects on pile responses of the excess pore pressure buildup and redistribution in both the free field and the near field. Unfortunately these methods have not gone through extensive calibration with measured pile responses since virtually no experimental data have been available for such calibration studies.

Experimental studies on the dynamic response of piles in liquefying sand may be conducted in various ways: 1) Small-scale tests under a 1g environment, 2) Small-scale tests in a centrifugal environment, and 3) Field tests and earthquake-response observations. Small-scale laboratory tests have distinct advantages over field tests and earthquake-response observations due to their repeatability and ease of controlling test conditions.

Almost all small-scale tests, however, need careful considerations for similitude requirements[1,2] and for their true objectives and usefulness. It often becomes difficult to match the time scalings for the dynamic response of soil and piles and for pore pressure dissipation. When tests are conducted under the normal gravitational environment, such adustments are rather minor. Under the centrifugal environment, however, such adjustments may not be feasible. Therefore, it appears best to conduct "large" small-scale tests under the 1g condition to reproduce as much as possible the field behavior of soil-pile responses in liquefying sand. The test results presented by the authors are extremely valuable from this viewpoint.

Finally the discusser would like to emphasize that extensive future studies are needed both numerically and experimentally to gain further insight into the pile response in liquefying sand and to advance the state-of-the-art in this field of soil dynamics.

1. Iai, S. (1989), "Similitude for Shaking Table Tests on Soil-Structure-Fluid Model in 1g Gravitational Field," Soils and Foundations, Vol.29, No.1, pp.105-118.

2. Kagawa, T. (1978), "On the Similitude in Model Vibration Tests of Earth Structures," Proceedings, Japan Society of Civil Engineers, No.275, pp.57-67 (in Japanese).

3. Kagawa, T. (1986), "Cyclic and Loading-Rate Effects on Piles," Proceedings, 3rd International Conference on Numerical Methods in Offshore Piling, ICE, Nantes, France, May.

4. Kagawa, T. and Kraft, L.M., Jr. (1980), "Lateral Load-Deflection Relationships of Piles Subjected to Dynamic Loadings," Soils and Foundations, Vol.20, No.4, pp.19-36.

5. Kagawa, T. and Kraft, L.M., Jr. (1981), "Lateral Pile Response during Earthquakes," Journal, Geotechnical Engineering Division, ASCE, Vol.107, No.GT12, pp.1713-1731.