ABSTRACT

When a structure is subjected to an earthquake excitation, it interacts with the foundation and the soil, and thus changes the motion of the ground. This dynamic soil-structure interaction is associated with the influx and efflux of energy, which is generated by the earthquake excitation and transmitted through the soil-structure interface. The difference between the influx and efflux corresponds to the energy stored up within a structure, and thus, is closely related to the extent of damage to the structure. The South-Hyogo Earthquake of Jan. 17, 1995 caused serious damage to a number of pile foundations and pile-supported structures, and showed again the importance of accounting for the soil-pile-structure interaction.

Various tools have been developed for the analysis of pile-soil-pile interaction, among which use of a finite element method with wave transmitting boundaries is a general and direct approach to analyzing the soil-structure interaction. The direct method, however, requires a computer program that can treat the behavior of both piles and the surrounding soils with equal rigor. Moreover, variation of the soil profile in a 3-dimensional expanse should be provided for the analysis. Hence, there yet remains an important place for simple approaches even in these days of manipulative numerical solutions to problems of increasing complexity.

Konagai has developed a simplified approach to evaluating the stiffness of a rigidly capped pile group. In the approach, piles closely grouped together beneath a superstructure are viewed as a single equivalent upright beam (Single Equivalent Upright Beam analogy). The idea is based on the fact that a group of piles often traps soil among them as observed when pulled out. The stiffness matrix of the equivalent single beam, which is different from a Bernoulli-Euler or Timoshenko beam, is described in terms of two stiffness parameters. The first parameter, which dominates the lateral deflection of the pile group, is identical to the product of the bending stiffness of an individual pile and the number of piles. The second stiffness parameter, which dominates the rocking motion of the pile group, is evaluated following the same procedure as that used for the evaluation of

bending stiffness of a reinforced concrete beam. Namely, it is assumed to be equal to the sum of the Young's-modulus-weighted products of all elementary areas times their distances squared from the centroid of the overall cross-section.

This dissertation was aimed to investigate the validation of the Single Equivalent Upright Beam analogy for pile groups with different layout, number of piles and pile-to-pile spacing, and further to extend it for nonlinear behavior of soils surrounding grouped piles.

In discussing the Single Equivalent Upright Beam analogy, straightforward evaluation of pile-soil-pile interaction is first necessary to provide rigorous solutions. A program called 'TLEM1.1' was used for rigorous analysis of dynamic pile-soil-pile interaction. This program is based on the Thin-Layered Element Method, a numerical scheme presented by Tajimi and Shimomura. Parametric studies have been performed on pile groups with different layout, number of piles and pile-to-pile spacing and the tolerable limit of the Single Equivalent Upright Beam analogy has been elucidated with respect to the pile-to-pile spacing normalized by the pile diameter. As the pile spacing becomes larger than the limit, piles in the group behave as individual piles rather than behave as a whole as what has been assumed in the Single Equivalent Upright Beam analogy. For this case, instead of using the Single Beam analogy, the lateral pile group stiffness can be evaluated by the product of the number of piles and the single pile stiffness. Consequently, the lateral pile group stiffness can be well approximated by either the Single Equivalent Upright Beam stiffness or the product of the number of piles and the single pile stiffness.

Ultimate lateral resistance of soil surrounding a pile group should receive due attention in the light of seismic designs for pile-supported structures that can experience intense shakes. For evaluating the ultimate lateral resistance of soil surrounding grouped piles, it is important to consider the characteristics of the pile-soil-pile interaction or pile group effect with different pile-to-pile spacing. Patterns of stress and deformation around pile groups are considered to vary with pile-to-pile spacing. For a pile group with a sparse layout, the development of zones of plastic flow is localized in the very near vicinities of the individual piles resulting in a limited degree of overlapping of stress and deformation.

The ultimate lateral resistance of soil thus can be estimated by the sum of that for separate single piles. For pile groups with close spacing, however, the zones of plastic flow begin to overlap and develop around the pile group as a whole demonstrating relatively stronger pile group effects, and the pile group behaves as a unit, as what was observed in the lateral pushover field experiment. This supports the availability of the Single Equivalent Upright Beam analogy for evaluation of the ultimate lateral resistance of the soil surrounding a group of densely spaced piles.

In the approach to evaluating the ultimate lateral resistance of the soil surrounding a group of densely spaced pile with the Single Equivalent Upright Beam analogy, the ideas of active pile length and passively mobilized soil wedge were introduced. In practice, most laterally loaded piles are indeed 'flexible' in the sense that they are not deformed over their entire length L. Instead, pile deflections become negligible below an active length (or effective length) L_a. The active length depends largely on the ratio of the pile stiffness for flexural deformation and the soil stiffness. For grouped piles, the stiffness can be evaluated by that of the Single Equivalent Upright Beam for the lateral deflection in determining the active length L_a.

When a pile group is laterally loaded up to the ultimate state of its side soil, the piles will push up a wedge of the side soil. The weight of the soil wedge will presumably be proportional to the product of its (1) depth, (2) distance between the outermost piles to the distal end of the passive zone, and (3) out of plane width. With the concept of the active pile length, (1), (2) and (3) are assumed proportional to L_a, $K_p L_a$ and R_0, and hence, $K_p \gamma L_a^2 R_0$ is considered to be directly relevant to the ultimate soil reaction, where γ and K_p are the unit weight and the Rankine's passive earth pressure coefficient of the side soil respectively and R_0 is the radius of the equivalent single beam.

Based on above mentioned concept, investigation was done on several tests with different pile group configurations, pile-to-pile spacing and soil-profile. The results showed that the ultimate lateral side-soil resistance could be uniquely described in terms of $K_p \gamma L_a^2 R_0$. Hence, it confirms that the equivalent single upright beam analogy has a potential to be used to evaluate the stiffness of a pile group embedded in either a linear or nonlinear soil stratum in limited number of parameters.