論 文 の 内 容 の 要 旨

論文題目　Ultimate lateral pile resistance characterization using active pile length
(杭の有効長を考慮した極限水平抵抗特性に関する研究)

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It is noted that the deformation of piles is predominantly governed by the soil-pile interaction. This is for the simple reason that the movement of the piles and the surrounding soil is mutually dependent. Piles subjected to lateral loads deforms relative to the surrounding soil and conversely, the surrounding soil deforms relative to the deformation of the piles. In common engineering practice, long and flexible piles are used. For this type of piles subjected to lateral loads, its deformation is not observed over its entire length as it attenuates with increasing depth. Significant pile deformation is rather observed to occur only at the upper region near the ground surface. Therefore, this length covering the region of significant deformation, called the active pile length, L_a, is important in developing solutions for laterally loaded pile. This active pile length is a parameter reflective of the soil-pile interaction as it is characterized by the stiffness of the pile relative to the stiffness of the surrounding soil.

Along this active pile length, a soil wedge in the passive region can be fully mobilized with large external lateral loading. This wedge is indicative of the ultimate side soil resistance and hence, the ultimate lateral pile resistance. Therefore, this study intends to establish relationship of the ultimate lateral pile resistance and the simple soil-pile interaction parameter, active pile length, L_a.

The active pile length, L_a, is said to be proportional to the characteristic length, L_c, which is a ratio of the pile stiffness and the soil stiffness. In this study, Konagai’s formula is used. This formula is a function of the pile stiffnes,

EI_p and shear modulus, G. The main difference with the expression commonly used in engineering (Chang's formula) is the use of shear modulus to represent the soil stiffness rather than relying on the coefficient of horizontal subgrade reaction, k_h. The substitution of the shear modulus for the characteristic length allows to capture inherently the stiffness of the soil and provide more convenient in-situ test for getting the shear modulus through shear velocity without the need for size effect correction.

The research takes off with the numerical simulation of laterally loaded piles in two-dimensional (2D) system. In this simulation, the elasto-plastic behaviour of sand is considered with elastic piles embedded in it. It is acknowledged that in reality, the soil-pile problem is innately a three-dimensional (3D) problem and having soil-pile interaction in 2D and in out-of-plane direction. Hence, in this case, piles considered is limited to capture behavior of walls, row piles or sheet piles. Nevertheless, the main intention is to simply investigate the formation of the passive soil wedge during nonlinear scenario and relate it to the active pile length. Moreover, the behavior of the active pile length can be established varying the contributing parameters such as the pile and soil stiffness. Results show a proportional relationship of the active pile length with the characteristic length. More importantly, there is a high correlation with the relationship of active pile length and the ultimate lateral pile capacity.

Hence, the concept of active pile length is applied in the three-dimensional platform for single piles embedded in sand. From the results of the rigorous solution, a simplified method to evaluate the ultimate lateral resistance of single piles in sand using the key parameter, L_a, is presented.

In the progressive formation of the active pile length, two stages are highlighted: the initial stage and the ultimate stage. First, the active pile length at the initial stage, L_0, is determined on the basis of known parameters such as the pile stiffness, EI_p, and small-strain shear stiffness, G_{max}. Capturing the elasto-plastic behavior of the surrounding soil, where there is degradation of surrounding soil stiffness, the active pile length at the ultimate stage or at larger deformations, L_{au}, can be determined by application of a correction factor. This parameter together with other pile and soil parameters that describes the mobilized passive soil wedge such as the outer pile radius, R_0, unit weight, γ, and Rankine passive earth pressure coefficient, K_p, is presented to be highly correlated with the ultimate lateral pile resistance, P_{ult}.

With these findings for single piles, the concept of active pile length is extended to closely-spaced grouped pile which could be analyzed as an equivalent single vertical pile. Grouped piles having spacing to diameter, s/d_p, equal to 1.5, 2.5, 3.5 and 4.5 is considered as closely grouped piles in this study. The relative pile stiffness to the surrounding soil stiffness is similarly the predominant driving parameter to describe the lateral deformation along the length of the grouped piles. Generally, results show that similar relationships and processes can be found with the single piles in evaluating the ultimate lateral pile resistance. Special attention must be made to the definition of parameters such as the grouped pile stiffness, EI_g and R_0 which is derived specifically for closely grouped piles. There is a difference of 13% for evaluating the ultimate lateral pile resistance of single and closely grouped pile. However, superimposing all cases considered for the single and closely-spaced grouped piles, a very high correlation (R^2=0.97) is still observed.

Thus, the determination of the ultimate lateral pile capacity using simple parameters with physical basis and reflective of the mechanisms of the laterally loaded piles provides more practical approach in the seismic design and assessment of piles and can be extended to different soil-pile configurations under more complex loadings and conditions.