CONIC SOIL WEDGE CHARACTERIZATION OF LATERALLY LOADED PILES IN MEDIUM DENSE SAND BASED ON ACTIVE PILE LENGTH

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1. INTRODUCTION

The deformation of a flexible pile due to a lateral load is largely significant near the ground surface and becomes negligible with increasing depth (Konagai, 2003). The length of this region of significant deformation down to the negligible point is called the active pile length, L_a. In this study, the point of negligible deformation is when it is equal to 3% of the pile head displacement. In a nonlinear scenario, a soil wedge in the passive region is developed and being pushed up. From the X-ray experiment of Otani (2006), he investigated the soil failure pattern around a laterally loaded pile. It was found out that the shape of the failure wedge is a cone contrary to the conventional pyramidal shape. In this study, an attempt is made to relate conic shape to the mobilized failure wedge indicative of the ultimate side soil resistance. More so, since the soil wedge appears along the L_a, it can be inferred that the parameter L_a can be used to describe the ultimate side soil resistance. To investigate if the active pile length can describe the ultimate side soil resistance, a numerical simulation of single pile embedded in homogeneous medium dense sand was conducted using the 3D OpenSeesPL. The elasto-plastic behavior of the soil is modeled using the multi-yield-surface plasticity (Prevost, 1985) while the pile is modeled using elastic beam-column elements. From the results of the rigorous solution, a simplified method using the key parameter, L_a, to define the ultimate lateral resistance of single piles in medium dense sand is presented for more practical approach in the seismic design and assessment of piles.

2. METHODOLOGY

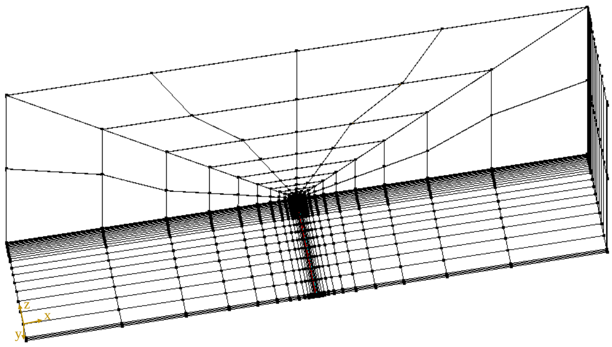

Fig. 1 3D Soil-Pile Configuration System

The nonlinear finite element method using the freeware OpenSees PL (Lu et. al, 2006) is used to simulate the response of a single laterally loaded pile in medium dense sand in three dimension. The 3D soil-pile configuration system is shown in Fig. 1. A half mesh is used in view of the symmetry. The dimensions of the soil box are the following: 156.76m (along the x-axis) x 79.38m (along the y-axis) x 31m (along the z-axis). A single end bearing pile of with length, L_p = 30m is embedded in the soil taken as medium dense. Additional 0.03m of pile is added above the ground surface for application of load. The boundary conditions at the bottom of the soil domain are fixed in all axes (x, y and z), while the sides and the back planes are fixed in the x and y axes but free in the z axis. In the plane of symmetry, all axes are free except for the y-axis to simulate a full mesh.

3. CASE STUDY

In this study, static pushover tests for the single end bearing pile embedded in a homogeneous medium are simulated. A displacement control was used where a 0.001m displacement is incrementally applied at the pile head (considered fixed) until it reaches 1.0m. There are a total of 9 cases used in this study where the diameter of the pile is varied from 0.30m to 1.0, and the Young's modulus considered are: 30GPa, 70GPa, and 200GPa. The geometric and material properties of the piles are summarized in Table 1. On the other hand, the material parameters of the corresponding medium dense sand are given in Table 2 calibrated and inherent in the OpenseesPL library.

Table 1. Pile Parameters

Diameter, d (m)	0.30	0.40	0.40	0.40	0.50	0.50	0.60	0.80	1.00
Young's modulus, E_p (GPa)	200	30	70	200	30	200	30	30	30

Keywords: Active Pile Length, Ultimate Lateral Pile Resistance, Piles, Sand, Soil-Pile Interaction
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Table 2. Soil Parameters

Reference Confinement	Shear Modulus, G_s	Bulk Modulus, B_s	Mass Density, ρ	Friction Angle, ϕ
80kPa	75MPa	200MPa	1.006Mg/m^3	32deg

3. ANALYSIS

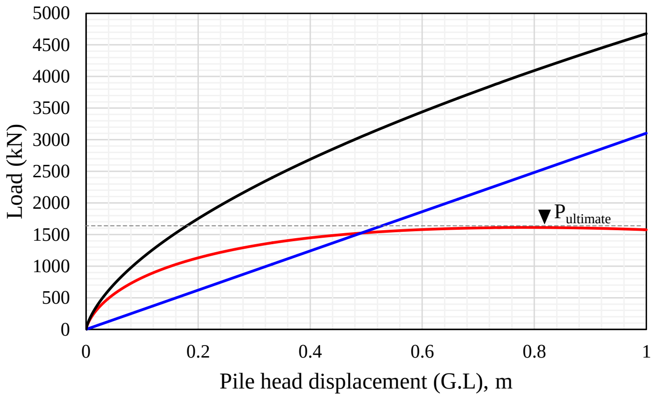

Fig. 2. Load-Deformation Curve for d=0.30m E_p=200GPa

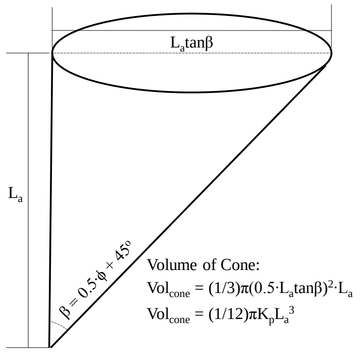

Fig. 3. Relationship of $P_{ultimate}$ with $\gamma K_p L_a^3$

In this study, an approach to estimate the ultimate lateral resistance of piles embedded in medium dense sand is presented. Fig. 2 shows a sample load deformation curve of one case (d=0.30m and E_p=200GPa). The black line is the lateral force applied at the pile head. The blue line is the pile resistance based on the active pile length at 1.0m pile head displacement, where the soil wedge is deemed to be formed. The red line indicates the side soil reaction which is derived from the difference of lateral force at the pile head and the pile resistance. Looking at the red line, it can be observed that the line becomes constant. The value of the load, where the line becomes constant is considered the ultimate lateral resistance, P_u. This is how P_u is derived for all cases. To relate this to Otani's (2006) study, the ultimate side soil resistance is equal to the weight of the mobilized failure wedge equivalent to the product of the unit weight and volume of the cone. Since the mobilized wedge is formed along the L_a, the height of the cone is designated as L_a and the other corresponding dimensions are shown in Fig. 3. The weight of the soil and the corresponding P_u for all cases are plotted and shown in Fig. 4. It can be seen that there is indeed a high correspondence and a linear relationship with these two variables. Hence, P_u can be expressed as below, where, γ: unit weight of the soil and K_p: Rankine passive earth pressure coefficient.

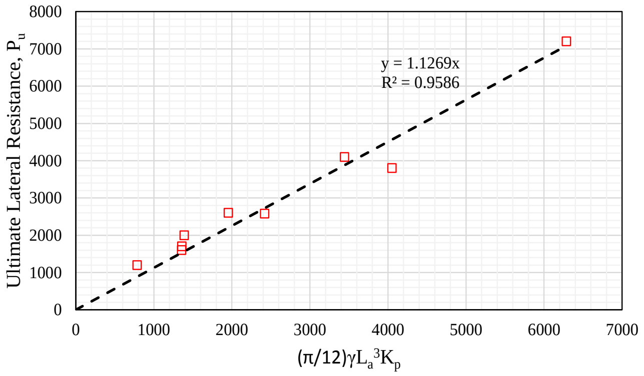

Fig. 4. Relationship of P_u with $\gamma K_p L_a^3$

$$P_u = \frac{\pi}{12}\gamma K_p L_a^{\ 3} \quad (1)$$

4. CONCLUSIONS

The soil wedge in the passive region along the active pile length can indeed be described by a conic shape. The L_a can be a key parameter to describe this wedge, indicative of the ultimate side soil resistance for piles embedded in medium dense sand. Practicality wise, this simplified expression can be useful in the seismic and assessment of piles. This idea shall be extended to deal with more complicated various soil-pile configuration.

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