

Ultimate Horizontal Loading Capacity of Suction Piles

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ABSTRACT

An analytical solution procedure that can estimate the resistance of suction piles against horizontal loads was developed by considering the truly 3-dimensional behaviors. It considers the development of 3-dimensional normal and shear stresses along the circumference of the pile surface as well as a 3-dimensional soil failure wedge. The geocentrifuge test results were analyzed and compared to validate the analytical solution of the ultimate horizontal loading capacity of suction piles.

INTRODUCTION

An analytical solution procedure that can estimate the resistance of suction piles against horizontal loads is described. Numerous experimental and analytical studies on pile lateral resistance have been conducted in the past (Bierschwale et al., 1981; Ivey et al., 1968; Kasch et al., 1977; Matlock, 1970; Senpere and Auvergne, 1982). However, currently available solutions are either mostly expansion of 2-dimensional solutions or they do not completely satisfy general mechanical principles. This solution, however, takes into consideration the truly 3-dimensional behaviors. It considers the development of 3-dimensional normal and shear stresses along the circumference of the pile surface as well as a 3-dimensional soil failure wedge. The ultimate horizontal loading capacity is then obtained from the detailed consideration of the force and moment equilibrium conditions.

Due to the nature of the suction pile applications when used in mooring, the horizontal load on a suction pile may act at any point along the entire length of the pile. This is primarily because, when the mooring line is attached to a point near the middle of the pile, the ultimate horizontal pile loading capacity could increase substantially. The precise point at which the ultimate horizontal loading capacity becomes the maximum is one of the topics considered in this study. Thus the analytical solution of the ultimate horizontal loading capacity of suction piles must allow the variation of the point of the horizontal load application.

The solution has adopted the concept of a *progressive failure*. In other words, the solution first calculates the pile horizontal loading capacity for given material, loading, and geometric conditions by assuming that the soil element at either extreme end of the pile experiences a sufficient magnitude of movement necessary for the development of the passive failure state. This condition is referred to as the *initial failure*, where the thickness of the soil failure zone is infinitesimally thin. The thickness of the soil failure zone is then progressively increased, and resulting horizontal

loading capacities are calculated until the maximum value of the horizontal loading capacity is obtained.

Due to the complexity associated with the mode of the pile movement, various circumstances need to be considered for the solution of the horizontal loading capacity to be complete. Under a horizontal load, the pile can either rotate, translate, or experience a combination of both. The point of the pile rotation can be anywhere inside or outside the pile, depending on the values of input of geometry, material and loading parameters. The development of the analytical solution considering these details is described below.

ANALYTICAL FORMULATION

The analytical solution of the ultimate horizontal loading capacity is based on the method of limiting equilibrium, which requires an assumed soil failure wedge. This study adopted the soil failure wedge in the shape of a tetrahedron, as originally proposed by Reese et al. (1970), and modified by Bang and Shen (1989) as shown in Fig. 1. The wedge has an inclination angle of ξ to the vertical and a horizontal inclination angle of ε to the direction of loading. Typically, ξ and ε are assumed to be $45^\circ + \phi/2$ and $\phi/2$, respectively, at failure (Reese et al., 1970). Developed lateral earth pressures between the pile and the soil can be calculated with the assumed failure wedge and normal and tangential forces acting on all faces.

Lateral Earth Pressure

The limiting passive lateral earth pressure can be expressed in general as:

$$p = p_1 + p_2 + p_3 \quad (1)$$

where p_1 = lateral earth pressure due to the unit weight and the soil friction; p_2 = lateral earth pressure due to the cohesion; and p_3 = lateral earth pressure due to the surcharge.

By considering the soil wedge shown in Fig. 1, the developed passive thrust, P , due to the soil weight and the friction angle can be obtained directly from the force equilibrium along the vertical

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KEY WORDS: Suction pile, pile horizontal resistance, pile rotational movement, soil progressive failure, developed friction angle.