Wedge Failure Analysis of Soil Resistance on Laterally Loaded Piles in Clay

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Abstract: A fundamental study of pile-soil systems subjected to lateral loads in clay soil was conducted by using experimental tests and a lateral load-transfer approach. The emphasis was on an improved wedge failure model developed by considering three-dimensional combination forces and a new hyperbolic *p-y* criterion. A framework for determining the *p-y* curve on the basis of both theoretical analysis and experimental load test results is proposed. The proposed *p-y* method is shown to be capable of predicting the behavior of a large-diameter pile under lateral loading. The proposed *p-y* curves with an improved wedge model are more appropriate and realistic for representing a pile-soil interaction for laterally loaded piles in clay than the existing *p-y* method. **DOI: 10.1061/(ASCE)GT.1943-5606.0000481.** © *2011 American Society of Civil Engineers.*

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Introduction

Recently, large-diameter drilled shafts have been used as foundations for long span bridges and high-rise buildings subjected to high wind loadings, with a corresponding need to resist large lateral loading. Although axial loading is a major consideration in designing such structures, large lateral loads necessitate the use of large-diameter piles. Therefore, lateral force resistance in a large-diameter pile is complex and derived from three-dimensional processes. These processes include: (1) passive lateral soil resistance along the leading face of the pile; and (2) shearing along the toe of the shaft and around the shaft perimeter. In addition, axial forces can affect the lateral behavior. A thorough analysis of such a force system requires sophisticated three-dimensional numerical methods.

Much work has been done to study laterally loaded piles by many researchers. In addition, several empirical and numerical methods have been proposed for analyzing the load-deformation behavior of piles subjected to a lateral load. Although these methods make slightly different assumptions, they can generally be classified into three groups: (1) empirical methods (Brinch Hansen 1961; Broms 1964), (2) load-transfer curve methods (Matlock 1970; Reese et al. 1975; O'Neill and Gazioglu 1984; Ashour et al. 1998; Liang et al. 2007), and (3) elastic and finite-element methods (Brown and Shie 1991; Jeremic and Yang 2002).

Jeong and Seo (2004) reported comprehensive studies on laterally loaded structures. They concludes that the load-transfer curve method for the design of laterally loaded piles is of intermediate complexity between the first and third methods mentioned previously. The lateral load-transfer curve method, often referred to as the *p-y* curve method, has been studied for many applications in engineering. A beam on a Winkler foundation is the physical model on which the *p-y* curve method is based. However, a rigorous analytical approach of the lateral pile response is difficult to achieve because the soil resistance around laterally loaded piles is a very complex, nonlinear, three-dimensional problem. The predicted results for laterally loaded piles appear to differ from their real behaviors, even though precise analyses are performed with the empirical *p-y* curve.

Generally, the *p-y* method developed by Matlock (1970), Reese et al. (1975), and O'Neill and Gazioglu (1984) for a single-pile system is the most commonly used procedure for the design of laterally loaded piles in clay soil. The confidence in this method is derived from the fact that the *p-y* curves employed have been obtained (i.e., back calculated) from a few full-scale field tests. However, most *p-y* curves used in practice are the result of lateral load tests on relatively small diameter piles [e.g., Matlock (1970): 0.33 m diameter steel-pipe piles, four cases; Welch and Reese (1972): 0.76 m diameter drilled shaft, one case; Reese et al. (1975): 0.64 m diameter drilled shaft, three cases]. Moreover, recent studies by Yang and Liang (2005) determined that the existing Reese et al. (1975) and O'Neill and Gazioglu (1984) *p-y* criteria do not work well for the lateral load tests that they performed. At the present time, few *p-y* criteria have been specifically developed for pile diameters from clay soil. For example, Ashour et al. (1998) and Ashour and Norris (2000) developed a strain wedge method for clay in which the three-dimensional soil-pile interaction behavior was modeled by considering the lateral resistance that develops in front of a mobilized passive wedge of soil at each depth. More recently, Liang et al. (2007) and Shatnawi (2008) proposed a hyperbolic *p-y* criterion for clay soil by using a three-dimensional finite element (FE) analysis.

The primary limitation of the *p-y* approach is that *p-y* curves are not a unique function. Therefore, the selection of adequate *p-y* curves is critical when using this methodology to analyze laterally loaded piles. The *p-y* relationships for a given soil type can be significantly influenced by the properties of the pile and the soil.

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