Modeling Lateral Soil-Pile Response Based on Soil-Pile Interaction

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Abstract: Although most designers prefer the *p-y* curve method as compared to elastic continuum or finite-element analysis of laterally loaded pile behavior, the profession has reached a state where it is time that closer scrutiny be given to the traditional "Matlock-Reese" *p-y* curves used in the analysis. The traditional *p-y* curves were derived from a number of well-instrumented field tests that reflect a limited set of conditions. To consider these *p-y* curves as unique is questionable. As important as such curves have been to advancing the practice from elastic to nonlinear beam on elastic foundation analysis, such calibrated/verified *p-y* curves reflect the specific field test conditions (particularly the pile properties) encountered. As presented in this paper, there are additional influences such as pile bending stiffness, pile cross-sectional shape, pile-head fixity, and pile-head embedment that have an effect on the resulting *p-y* curves. It is argued that strain wedge (SW) model formulation can be used to characterize such effects. SW model analysis predicts the response of laterally loaded piles and has shown very good agreement with actual field tests in sand, clay, and layered soils. The advantage of the SW model is that it is capable of taking into account the effect of changes in soil and pile properties on the resulting *p-y* curves.

INTRODUCTION

The problem of a laterally loaded pile is often solved as a beam on an elastic foundation (BEF) involving nonlinear modeling of the soil-pile interaction response (*p-y* curve). Currently employed *p-y* curve models were established/verified based on the results of field tests in uniform soils such as the Mustang Island (Reese et al. 1974), Sabine River (Matlock 1970), and Houston (Reese and Welch 1975) tests and were adjusted mathematically using empirical parameters to extrapolate beyond the soil's specific field test conditions. The traditional *p-y* curve models developed by Matlock (1970) and Reese et al. (1974) are semiempirical models in which soil response is characterized as independent nonlinear springs (Winkler springs) at discrete locations. Therefore, the effect of a change in soil type of one layer on the response (*p-y* curve) of another is not considered. In addition, the formulations for these *p-y* curve models do not account for a change in pile properties such as pile bending stiffness, pile cross-sectional shape, pile-head fixity, and pile-head embedment below the ground surface. Soil-pile interaction or *p-y* curve behavior is not unique but a function of soil and pile properties. It would be prohibitively expensive to systematically evaluate all such effects through additional field tests, and hence, it is necessary to consider such influences based on available theoretical means [strain wedge (SW) model formulation] that allows transformation of envisioned 3D soil-pile interaction response to 1D BEF parameters. The intent in this paper is to show that, as Terzaghi (1955) and Vesic (1961) stated, the subgrade modulus E_s (and therefore the *p-y* curve) is not just a soil but, rather, a soil-pile interaction (and therefore a pile property dependent) response.

It is known that *p-y* curves can be employed in a comprehensive numerical soil-structure interaction analysis (e.g., a finite-element program) to model the soil-pile response of a structural problem involving the superstructure along with the substructure. However, the lack of accountability of the influence of the points mentioned above on the characterization of the *p-y* curves results in the need to study the soil-pile interaction more carefully (Gazioglu and O'Neill 1984; Murchison and O'Neill 1984; Ruiz 1986; Dunnavant and O'Neill 1989; Gabr et al. 1994).

Some researchers have attempted to enhance *p-y* curve evaluation based on pressuremeter test (Smith 1983; Briaud et al. 1984) or dilatometer test (Robertson et al. 1989; Gabr et al. 1994) response. However, without specific consideration of the nature of the pile, such attempts focus only on the soil part of such soil-pile interaction behaviors. The SW model (Ashour et al. 1998) provides a theoretical means for developing *p-y* curves that considers the effect of soil and pile properties. The SW model not only assesses the changing, strain dependent (i.e., equivalent linear) modulus of subgrade reaction profile but also yields the *p-y* curves, if desired.

OVERVIEW OF SW MODEL BASIC CONCEPTS

The SW model parameters are related to an envisioned 3D passive wedge of soil developing in front of the pile. The basic purpose of the SW model is to relate stress-strain-strength behavior of the layered soil in the wedge to 1D BEF parameters. The SW model is, therefore, able to provide a theoretical link between the more complex 3D soil-pile interaction and the simpler 1D BEF characterization. The previously noted correlation between the SW model response (Fig. 1) and BEF characterization (Fig. 2) reflects the following interdependence [as illustrated in detail by Ashour et al. (1996, 1998)]:

- The horizontal strain ε in the soil of the developing passive wedge in front of the pile to the deflection pattern (y versus depth x) of the pile
- The horizontal soil stress change $\Delta\sigma_h$ in the developing passive wedge to the soil-pile reaction p associated with BEF analysis
- The nonlinear variation in the Young's modulus ($E = \Delta\sigma_h/\varepsilon$) of the soil to the nonlinear variation in the modulus of subgrade reaction ($E_s = p/y$) associated with BEF characterization

The reason for linking the SW model to BEF analysis is to allow the appropriate selection of BEF parameters to solve the following differential equation:

$$EI\left(\frac{d^4y}{d^4x}\right) + E_s(x)y = 0 \qquad (1)$$

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Note. Discussion open until October 1, 2000. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on August 26, 1998. This paper is part of the ***Journal of Geotechnical and Geoenvironmental Engineering***, Vol. 126, No. 5, May, 2000. ©ASCE, ISSN 1090-0241/00/0005-0420–0428/$8.00 + $.50 per page. Paper No. 19113.