CHAPTER 1

INTRODUCTION

The problem of a laterally loaded large diameter shafts has been under investigation and research for the last decade. At present, the p-y method developed by Matlock (1970) and Reese (1977) for slender piles is the most commonly used procedure for the analysis of laterally loaded piles/shafts. The confidence in this method is derived from the fact that the p-y curves employed have been obtained (back calculated) from a few full-scale field tests. Many researchers since have attempted to improve the performance of the p-y method by evaluating the p-y curve based on the results of the pressuremeter test or dilatometer test.

The main drawback with the p-y approach is that p-y curves are not unique. Instead the p-y relationships for a given soil can be significantly influenced by pile properties and soil continuity and are not properly considered in the p-y approach. In addition, the p-y curve has been used with large diameter long/intermediate/short shafts, which is a compromise. The SW model proposed by Norris (1986) analyzes the response of laterally loaded piles based on a representative soil-pile interaction that incorporates pile and soil properties (Ashour et al. 1998). The SW model does not require p-y curves as input but instead predicts the p-y curve at any point along the deflected part of the loaded pile using a laterally loaded soil-pile interaction model. The effect of pile properties and surrounding soil profile on the nature of the p-y curve has been presented by Ashour and Norris (2000). However, the current SW model still lack the incorporation of the vertical side shear resistance that has growing effect on the lateral response of large diameter piles/shafts. In addition, many of the large diameter shafts could be designed as long shafts and in reality they behave as intermediate shafts. Compared to the long shaft characteristics, the intermediate shaft should maintain softer response. It is customary to use the traditional p-y curves for the analysis of all types of piles/shafts (short/intermediate/long) which carries significant comprise.

The lateral response of piles/shafts in liquefied soil using the p-y method is based on the use of traditional p-y curve shape for soft clay corresponding to the undrained residual strength (S_r) of liquefied sand. Typically S_r is estimated using the standard penetration test (SPT) corrected blowcount, $(N_1)_{60}$, versus residual strength developed by Seed and Harder (1990). For a given $(N_1)_{60}$ value, the estimated values of S_r associated with the lower and upper bounds of this relationship vary considerably. Even if a reasonable estimate of S_r is made, the use of S_r with the clay curve shape does not correctly reflect the level of strain in a liquefied dilative sandy material. The p-y relationship for a liquefied soil should be representative of a realistic undrained stress-strain relationship of the soil in the soil-pile interaction model for developing or liquefied soil. Because the traditional p-y curve approach is based on static field load tests, it has been adapted to the liquefaction condition by using the soft clay p-y shapes with liquefied sand strength values.

In the last several years, the SW model has been improved and modified through a number of research phases with Caltrans to accommodate:

- a laterally loaded pile with different head conditions that is embedded in multiple soil layers (report to Caltrans, Ashour et al. 1996)
- nonlinear modeling of pile materials (report to Caltrans, Ashour and Norris 2001);
- pile in liquefiable soil (report to Caltrans, Ashour and Norris 2000); and
- pile group with or without cap (report to Caltrans, Ashour and Norris 1999)

The current report focuses on the analysis of large diameter shafts under lateral loading and the additional influential parameters, such as vertical side shear resistance, compared to piles. It also addresses the case of complete liquefaction and how the completely liquefied soil rebuilds significant resistance due to its dilative nature after losing its whole strength. The assessment of the t-z curve along the length of shaft and its effect on the shaft lateral response is one of the contributions addressed in this report

The classification of the shaft type whether it behaves as short, intermediate or long shaft has a crucial effect on the analysis implemented. The mechanism of shaft deformation and soil reaction is governed by shaft type (geometry, stiffness and head conditions) as presented in Chapter 2.

The assessment of the vertical side shear due to the shaft vertical movement induced by either axial or lateral loading is presented in Chapter 3 and 4. New approach for the prediction of the t-z curve in sand and clay is also presented. Since the lateral resistance of the shaft base has growing effect on the short/intermediate shaft lateral response, a methodology to evaluate the shaft base resistance in clay/sand is also presented in Chapters 3 and 4.

The SW model relates one-dimensional BEF analysis (p-y response) to a three-dimensional soil pile interaction response. Because of this relation, the SW model is also capable of determining the maximum moment and developing p-y curves for a pile under consideration since the pile load and deflection at any depth along the pile can be determined. The SW model has been upgraded to deal with short, intermediate and long shafts using varying mechanism. The degradation in pile/shaft bending stiffness and the effect of vertical side shear resistance are also integrated in the assessed p-y curve. A detailed summary of the theory incorporated into the SW model is presented in Chapter 5.

Soil (complete and partial) liquefaction and the variation in soil resistance around the shaft due to the lateral load from the superstructure are presented in Chapter 6. Based on the results obtained from the Treasure Island field test (sponsored by Caltrans), it is obvious that none of the current techniques used to analyze piles/shafts in liquefied soils reflects the actual behavior of shafts under developing liquefaction. New approach is presented in Chapter 6 to assess the behavior of liquefied soil and will be incorporated in the SW model analysis as seen in Chapter 8.

The nonlinear behavior of shaft material (steel and concrete) is a major issue in the analysis of large diameter shafts. Such nonlinear behavior of shaft material should be reflected on the nature of the p-y curve and the formation of a plastic hinge as presented in Chapter 7.

Several case studies are presented in this study to exhibit the capability of the SW model and how the shaft classification, shaft material modeling (steel and/or concrete) and soil liquefaction can be all implemented in the SW model analysis. Comparisons with field results and other techniques also are presented in Chapter 8.