# CHAPTER I.

## INTRODUCTION

### Problem Statement

For a pile situated in a soft soil stratum subjected to horizontal soil movements, horizontal pressures are developed between the pile and the surrounding soil resulting in horizontal movements or sway of the pile. The pile head may be displaced horizontally from its specified location by a distance which exceeds the tolerance in the foundation construction specification. This phenomenon contributes to development of bending moments or initial curvatures in the pile, with a consequent reduction of the axial load capacity from that predicted for a straight pile under concentric loading (1,2,3). The sway of the pile caused by horizontal soil movements is frequently found some time after its installation or during the foundation construction. Such horizontal soil movements may be induced by a surcharge of heavy construction equipment or embankment placed in the vicinity of the pile and by excavation for foundation construction without sufficient prevention of soil movements.

When this problem takes place in building or bridge constructions in which driven or bored piles are used to transmit loads from the superstructure to a lower stiff soil stratum, it usually leads to conflicts among the concerning construction parties

since the presently available theories, guide lines, design codes or standards can not be employed to produce a definitive solution to the problem. The method selected is dependent on the judgement of the individual engineer.

Thus there is a great need to make a comprehensive study to obtain formulations capable of solving the capacity of axially loaded sway piles.

Objectives and Scope of Research

The objectives of this research are to develop a computational method to analyze of the behaviour of sway piles under horizontal soil movements, to predict the loading capacity and limits on sway of piles, and to suggest the appropriate guide lines for engineers to solve this controversial problem.

The scope of this research is to formulate a method of predicting the capacity of axially loaded sway piles under horizontal soil movements using structural and geotechnical engineering techniques. Attention is confined to the case of a long sway pile situated in a soft soil stratum with the pile tip embedded in an underlying stiff soil stratum, in which failure occurs when the maximum bending moment in the pile is equal to the plastic or yield moment of the pile section. The case of a short sway pile, in which failure occurs when the soil yields along the total length of the pile, and the pile rotates as a unit around a point located at some depth below the ground surface, is not taken into account. Batter

piles, badly misaligned piles, and piles swayed by earthquakes, by wave or wind forces, and by other effects are excluded from the scope of this research.

## Literature Review

A method of analysis of sway piles under horizontal soil movements was initially developed using the concepts of beams on elastic foundations and laterally loaded piles. Solutions for beams on elastic foundations, in which the foundations are assumed to be Winkler medium, were proposed by Hetenyi in 1946 (4). Based on his assumptions, analyses of laterally loaded piles were proposed by a number of authors (5,6,7,8,9,10). These analyses do not account for continuity of the soil mass and, therefore, the results cannot be ralated directly to any of the material properties of the soil. To improve these analyses by considering the soil mass as a continuum, Spiller and Stool (11) presented the response analyses of the elastic pile in elastic and elastic-plastic soils subjected to lateral loading or externally applied moment. Later in 1971 and 1972 Poulos (12,13,14) presented the elastic analyses of the behaviour of piles subjected to horizontal load and moment using a finite difference technique. The consequences of local yield of the soil on the behaviour of piles are also incoporated in his formulation. It is interesting to note that the elastic continuum approach used in those analyses represents a more satisfactory idealization of a real soil mass than the Winkler or spring approach. In recent years the method for determination of the ultimate bearing capacity of rigid piles under eccentric and inclined loads was proposed by Meyerhof and Sastry (15).

Broms (2) proposed a method for predicting allowable axial loads of initially bent piles. By assuming the soil to be Winkler medium, representing the deflected shape of a pile as a Fourier sine series, and limiting the maximum soil pressure to one third of the ultimate lateral resistance of the soil, a simple equation for buckling load of the pile can be derived and the allowable axial load can then be computed. It was suggested that the maximum stress in the pile should not exceed the allowable value of the pile material.

As an extension to the methods developed for the case of laterally loaded piles (12,14), Poulos (16) proposed a theoretical analysis of a single pile in a soil undergoing horizontal movements arising from an external cause. The analysis is carried out using the same assumptions as for the laterally loaded piles. Additionally, the assumptions regarding real soil behaviour, which are the variation of Young's modulus and soil-yield pressure along the pile, are also employed. By deriving the equation for flexure of a thin strip in a finite-difference form for each node point along the pile with an iterative scheme to limit lateral soil resistance, the pile displacements and pressures can be calculated. Finally, the slope, moment and shear-force distributions along the pile can then be calculated. Parametric solutions for a number of idealized cases are examined to investigate the effect of various factors on pile behaviour. These factors are relative pile flexibilities, the boundary conditions at pile head and pile tip, soil movement distribution along the pile and its magnitude, pile diameter, soil modulus and soil-yield pressure distributions. Comparisons between predicted and observed pile displacements, moments, and head reaction

show reasonably good agreement.

In 1979 Wu and Fox (3) attempted to make an analysis for predicting the ultimate axial load of bent piles driven into a very soft sensitive clay with pile tip embedded in a competent gravelly sand stratum. Case studies of four pipe piles were conducted to verify the proposed analysis. The solution has been carried out using conditions of equilibrium and Terzaghi's basic equation of end bearing capacity for a straight pile. Comparisons between predicted and measured values show reasonable agreement.

At present, finite element method can be applied successfully to a variety of problems in soil mechanics and has been found to be more versatile and accurate scheme when campared with conventional theories as investigated by Girijavallabhan and Reese (17), Poulos (18) and Chandrangsu and Samphandharaksa (19). Therefore, the problem of sway piles in this research should be studied effectively by using the finite element technique.

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