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Behavior of Laterally Loaded Piles in Cohesive Soil Slopes

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Abstract- Pile foundations are slender structural elements used to transfer loads from structures into deep hard strata below the ground level. Many transmission towers, high-rise buildings, and bridges are constructed near steep slopes and are supported by piles. These structures may be subjected to large lateral loads, such as violent winds and earthquakes. The load transfer mechanism for a laterally loaded pile is very complex when it is located on the sloping ground. The available analytical methods of analysis for laterally loaded piles in level ground cannot be directly applied to such piles in sloping ground. According to the subject importance and advantage of numerical methods and computer technology to valuation the behavior of the piles, the aim of this study is that investigate the behavior of single piles under lateral loads and located adjacent soil slopes using finite difference numerical method and study the effects of some factors on the lateral load capacity of pile. A series model by a finite difference numerical software FLAC 3D on steel piles in cohesive soils is done.

Keywords- *Pile; lateral load; soil slope; Cohesive soils; FLAC 3D*

I. INTRODUCTION

Many transmission towers, high-rise buildings and bridges are constructed near slopes and are supported by piles (Figure 1). These structures may be subjected to large lateral loads, such as violent winds and earthquakes. Widely used types of foundations for these structures are pile foundations. Under these loads, the lateral resistances of piles near slopes will be small, compared with piles on horizontal ground.

In the past, the design of laterally loaded piles has been based on analytical methods in which the soil resistance is obtained empirically, mainly from full-scale tests in the field or model test studies in the laboratory. The analytical methods developed for a single pile and pile group under lateral load are the subgrade reaction method, the elastic continuum method and the finite element method.

In soil mechanics and foundation engineering one of the most widely used methods is numerical modeling. The available analytical methods of analysis for laterally loaded piles in level ground cannot be directly applied to such piles in sloping ground. According to the advantage of numerical methods and computer technology to valuation the behavior of the piles, in this paper numerical method finite difference for study the effects of soil slope on the lateral load capacity of pile is used.

The important literature reported on a single pile and pile groups under lateral loads are: Matlock and Reese(1960), Banerjee and Davies (1978), Poulos (1971), Pise (1983), Pise (1984), Budhu and Davis (1988), Alizadeh and Lalvani (2000) and Mokwa and Duncan (2001). Matlock and Reese (1960) provided generalised

solution for elastic and rigid pile under lateral load. Poulos (1971) and Banerjee and Davies (1978) reported the elastic solution for laterally loaded pile. Pise (1983) presented theoretical results for fixed head piles while Pise (1984) presented theoretical results for free head piles. Budhu and Davies (1988) reported elasto-plastic analysis of laterally loaded pile based on boundary-element method. Alizadeh and Lalvani(2000) provided useful results of full-scale, field lateral load tests on four instrumented single piles installed in sand. Karthigeyan et al. (2006) used 3-dimensional finite element program GEOFEM3D to analysis the pile – soil interaction problem. Chae et al. (2004) described the results of several numerical studies performed with a 3D FEM model test and prototype test on laterally loaded short rigid piles and pier foundation located near slope. Martin and Chen (2005) evaluated the response of piles caused by an embankment slope, induced by a weak soil layer or a liquefied layer beneath the embankment using FLAC3D program.

The aim of this study is that investigate the behavior of single piles under lateral loads and located adjacent soil slopes using finite difference numerical method and study the effects of some factors on the lateral load capacity of pile. The software used in this study was FLAC 3D version 3.00-261.

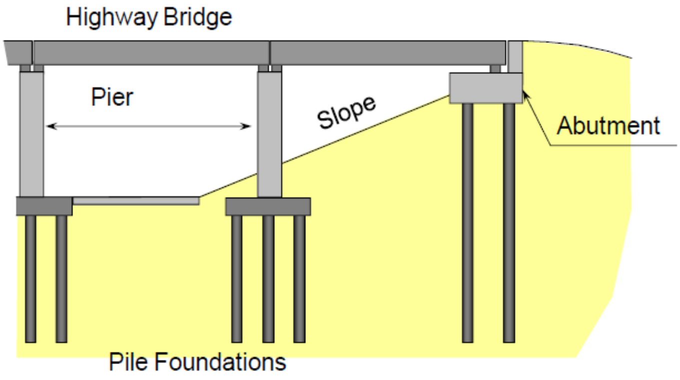


Figure 1. Pile Supported Bridge Abutments (Nimityongskul 2010)

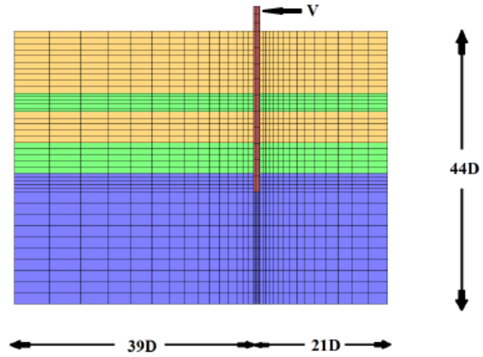
II. Numerical Modeling

FLAC is a computer software that it does analysis of Stress - Strain and Stability based on finite difference method. In this software, after building the model geometry and mesh, material properties, boundary conditions and initial conditions are defined. Then computation phases are determined and calculations are performed by the software. For laterally loaded pile under static condition, several researchers have adopted the Mohr-Coulomb (MC) soil model to represent the undrained behavior of cohesive soils.

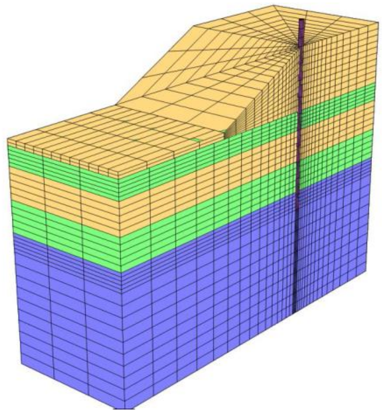
The Mohr-Coulomb model requires five parameters that are well known in most practical situations. The other two parameters, in addition to soil cohesion c, angle of internal friction ϕ and dilatancy angle ψ, are Young's modulus E and Poisson's ratio ν, based on Hooke's law for isotropic elastic material behavior.

In this study is attempted to evaluate the effects of ground slope on the lateral load capacity of the pile. To do this, at first for piles installed on flat ground (without slope), the lateral load capacity of piles is calculated (Figure 1.a). Then the pile is placed at different distances from the crest of a soil slope and comparisons between different states are done (Figure 1.b). The properties of different soil layers and pile are shown in table 1.

Many factors contributed to the reduction of the lateral capacity of the pile when it is installed on the slope crest. In the following some of them have been studied.



(a)



(b)

Figure 2. FLAC 3D Mesh for the Pile in flat ground (a) and pile at near slope (b)

TABLE I. Material properties for the MC-Soil Model

	Clay	Sand	Bed Sediment	Pile
Unit Weight (pcf)	115	130	110	500
Young's Modulus (ksf)	158	600	158	4×107
Poisson's Ratio	0.495	0.35	0.495	0.1
Cohesion (psf)	2400	-	3500	-
Friction Angle	-	40	-	-

A. *Effect of pile distance from slope crest on the lateral load capacity of the pile*

Pile is installed at different distances from the crest of the slope and curve of the load - displacement is calculated for each case. For this work, the head of pile displaced amount 4in and load – displacement curve is obtained. Comparison between the computed load-displacement curve for piles with different distances from the crest are shown in Figure 3. From Figure 3, it can be observed that the lateral load capacity of the pile increases with increase the pile distance from slope crest so that at a distance of more than 8 times the diameter of the pile can ignore the effect of slope. It was also observed that for small soil displacements (i.e., less than 0.5 inches), the proximity of slope has small to insignificant effect on the lateral pile response. At larger soil displacements, the proximity of slope adversely affected the lateral capacity of piles.

B. Effect of angel of slope on the lateral load capacity of the pile

For pile installed on the slope crest, three different angles for the slope is considered. The slopes of the model are: 2-1(63.43˚), 1-1 (45˚), 1-2 (26.56˚).

A comparison between the computed load-displacement curves for slopes with different angles are shown in Figure 4. It was observed that with increasing slope angle, the lateral load capacity of piles decreases.

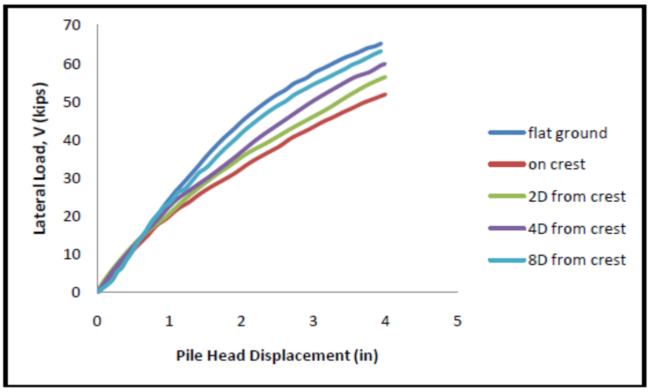


Figure 3. Computed load-displacement curve for piles with different distances from the crest

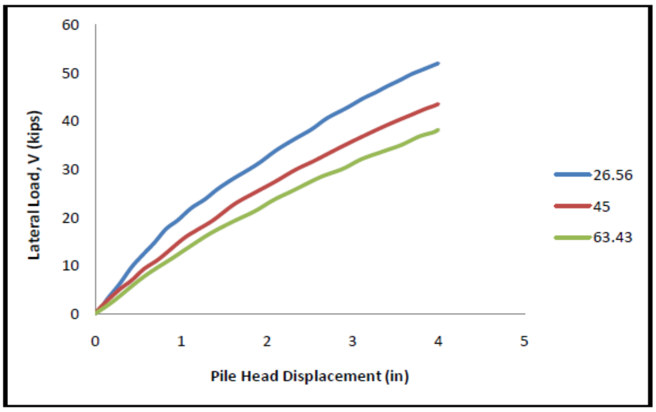


Figure 4. Computed load-displacement curve for slopes with different angles

C. Effect length of pile on the lateral load capacity of the pile

For pile installed on the slope crest, three different length of pile is considered. Computed load-displacement curves for piles with different length are shown in Figure 5. It was observed that the lateral load capacity of piles increases with increasing pile length. As a result, the slope effect can be negligible with increase the pile length for pile installed on the slope crest.

III. CONCLUSIONS

A series model by a finite difference numerical software FLAC 3D analyses were performed in order to investigate the effect of sloping ground on the behavior of laterally loaded piles in clay. Many factors contributed to the reduction of the lateral capacity of the pile when it is installed on the slope crest. In this paper some of them have been studied. The main findings of this research study on the effect of soil slope on lateral capacity of piles in cohesive soils are provided as the followings:

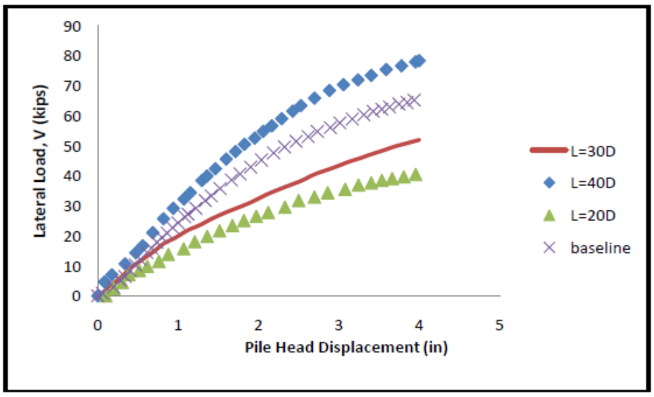


Figure 5. Computed load-displacement curves for piles with different length

(1)Lateral load capacity of the pile increases with increase the pile distance from slope crest. For small soil displacements (i.e., less than 0.5 inch), the proximity of slope has small to insignificant effect on the lateral pile response. At larger soil displacements, the proximity of slope adversely affected the lateral capacity of piles.

(2)The effect of slope on the lateral capacity was insignificant for piles installed at distances of 8D or greater from the slope crest.

(3)With increasing slope angle, the lateral load capacity decreases. So that with the increase of pile angles amounts to 70 percent, lateral load capacity is reduced as much as 18 percent.

(4)One way to reduce the effect of sloping ground on the lateral load capacity of piles is increasing pile length. With an increase of 35 percent of pile length, the pile lateral capacity of approximately 55 percent increase.

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