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PERFORMANCE OF FOOTING WITH MULTI -LAYERED PILE STABILIZED SLOPE

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Abstract: *When a footing is located on a sloping ground, the bearing capacity of the footing may be significantly reduced. Therefore, it may not be possible to use a shallow foundation, and using uneconomic foundation types as piles or caissons becomes the only suitable solution of the problem. Therefore, over years, the subject of stabilizing the earth slope has become one of the most interesting areas for scientific research. Therefore, the use of stabilizing piles to support an active earth slope has been considered to be one of the important slope reinforcement techniques in the last few decades. These piles, which can be driven at the crest or within the slope itself, act as resisting members and are usually subjected to lateral forces by the horizontal movements of the surrounding soil. The piles have proven to be an effective means of stabilizing active landslides as well as in marginally stable slopes. Hence, it is equally important to study the performance of footing with multi-layered pile stabilized slopes.*

Keywords: *Footing, Stabilized Slope*

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INTRODUCTION

Many situations necessitates the placement of footings on sloping surfaces or adjacent to a slope crest, e.g. footings for bridge abutments on sloping embankments, small to medium rise building adjacent to slope crest. When a footing is located on a sloping ground, the bearing capacity of the footing may be significantly reduced. Therefore, it may not be possible to use a shallow foundation, and using uneconomic foundation types as piles or caissons becomes the only suitable solution of the problem. Therefore, over years, the subject of stabilizing the earth slope has become one of the most interesting areas for scientific research and attracted a great deal of attention. Slope stability can be increased in different ways, such as modifying the slope surface geometry, using soil reinforcement.

The logical prevention of all types of landslides in case of natural or man-made slopes may be accomplished by one or more of the methods: (a) reduction of the activating forces, (b) increasing the resisting forces, and (c) avoidance or elimination of the slide. The reduction of the activating forces typically takes the form of flattening the slope by excavating material from the top of the slope or reduction in the water level in the slope. The resisting forces can be increased by: (a) increasing shear strength by drainage, (b) removal of weak zones or potential failure zones, (c) building retaining structures or supports or earth buttresses, and (d) providing in situ reinforcement of the ground. An often used method of in-situ reinforcement has been the use of piles to stabilize slopes. The use of piles to stabilize a slope is a laterally loaded pile problem in addition to a slope stability problem.

The use of stabilizing piles to support an active earth slope has been considered to be one of the important slope reinforcement techniques in the last few decades. These piles, which can be driven at the crest or within the slope itself, act as resisting members and are usually subjected to lateral forces by the horizontal movements of the surrounding soil. The typical pile stabilized slope profile can be seen as shown in figure 1.

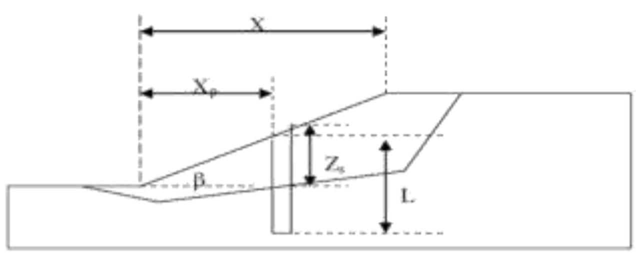

Figure 1: A profile of pile stabilized slope

The piles have proven to be an effective means of stabilizing active landslides as well as in marginally stable slopes. Many practical empirical design and analysis methods of slope stability and piled-slope stability have been proposed. The pile stabilized slope may invariably will be used for erecting or supporting the structure. The construction of structure on or near to pile stabilized slope may influence its behavior. Hence, it is equally important to study the performance of footing on pile stabilized slopes. The present work will give the understanding with regards to performance and stability of footing and slope both.

LITERATURE REVIEW

Introduction

The study regarding the effect of provision of piles for reinforcing the natural and manmade slopes had been carried out by various authors. Several experimental, analytical and numerical analyses were performed on behaviour of slope reinforced with piles. These works are reviewed keeping in view of their methodology, principles and various aspects of behaviour of pile stabilized slopes.

Numerical Studies on Pile Stabilized Slopes

Rowe and Poulos[1] (1979) proposed a finite element technique for the analysis of undrained behaviour of soil slopes reinforced by pile groups by varying the pile boundary conditions and concluded that the best arrangement is when there is no lateral displacement at top and bottom end is pinned.

Cai and Ugai[2] (2000) analyzed the slope reinforced with piles using the finite element method with varying parameters such as ratio of centre to centre distance between piles to that of diameter of pile (0-8), ratio of distance of pile from toe to that of slope length (0-1) and pile head conditions as free, hinged, unrotated and fixed. It was concluded that the maximum safety factor for the slope can be achieved when the piles are located in the middle of the slope and the pile head restrained.

Jeong[3]*et al.* (2003) proposed a simplified numerical approach for analyzing the slope/pile system subjected to lateral soil movements with varying parameters such as ratio of spacing to diameter of pile (0-8), ratio of distance of pile from toe to that of slope length (0-1) and pile head conditions as free, hinged, unrotated and fixed. It was concluded that the pile top should be restrained when piles are used to stabilize the slopes.

Won[4] *et al.* (2005) presented the numerical comparison of predictions by limit equilibrium analysis and 3D numerical analysis for a slope–pile system with varying parameters such as ratio of spacing to diameter of pile (2-4.5), ratio of distance of pile from toe to that of slope length (0-1) and pile head conditions as free and fixed. They concluded that for stability to be improved optimally, the piles should be installed in the middle of the slope and with restrained pile head and should have optimum S/D ratio as 2.5.

Wei and Cheng[5] (2009) analyzed the slope reinforced with one row of pile with varying parameters such as spacing between piles (2D-8D), pile location from toe, critical slip surface through different section. It was concluded that when spacing is low, the critical slip surface is shallow and divided into two parts and optimum location is middle of the slope with pile and middle of the critical slip surface with no pile.

I-Hsuan[6] (2009) analyzed the pile reinforced slope using 2D FEA ABAQUS software with different cases as homogeneous slope without foundation, homogeneous slope with foundation, non-homogeneous slope with foundation and non-homogeneous slope with a thin weak layer. The parameters studied were the ratio of distance of pile from toe to that of slope length (0-1), length of pile (5-20) m , ratio of undrained shear strength of weak layer to that of remaining soil mass (0.5-2.0), ratio of depth of potential slip surface to that of true length of pile (0.4-1.0) and pile head as free or fixed. He concluded that the ratio of spacing to diameter of pile should be less than 4 to have arching effect, ratio of depth of potential slip surface to that of true length of pile should not be less than 0.5. He further concluded that based on the economical design, the fixed head pile is not always recommended.

Yang[7] *et al.* (2011) studied the effect of embedded length of piles for slope reinforced with piles by varying parameters such as pile head condition viz. free, fixed, hinged and non-rotated head, embedded pile length (5-20) m, spacing (2D-6D). It was concluded that a restrained (fixed or hinged) pile head is recommended and free head should be avoided to stabilize the slope.

Mujah[8] *et al.* (2013) analyzed the multi-row arrangement of small diameter steel piles for landslide prevention using PLAXIS 2D software. The parameters considered as ratio of spacing to diameter of pile (0-8), density of soil (30%-80%), pile size (3-10) mm and pile end as hinged and free. It was concluded that greater amount of earth pressure is yielded in a denser ground condition and resistance to both lateral and axial forces is significantly enhanced by small diameter steel piles. The materials EI value plays a significant role in ensuring the overall reinforcement capacity of pile.

Gullu[9] (2013) studied the effect of pile on slope stability by PLAXIS 2D by changing the location of pile at toe of slope, at middle, at top, two rows of pile at toe and middle of slope & at middle and top of slope. He concluded that factor of safety of slope-pile system increases with the increased the row of pile. In the single row of pile application, it was found that the factor of safety decreases as the slope was reinforced towards the top of slope. The study Suggest to use either the single row pile at the toe or two-row piles at the toe and middle of slope in practice.

I-Hsuan[10] (2014) presented the results of numerical study of slope stabilizing piles in undrained clayey slopes with a weak thin layer by varying parameters such as ratio of undrained shear strength of weak layer to that of remaining soil mass (0.2-1), ratio of width of slope to that of height of slope (0-12), ratio of distance of pile from toe to that of slope length (0-1), spacing to diameter ratio (0-12) and pile head conditions as free and fixed. He concluded that the pile should be extended half way below the weak layer. The use of fixed head piles increases the effectiveness of stabilizing piles compared with free head piles. He also stated that the middle portion of the slope is the optimal pile position for pile stabilized slope.

Analytical studies of Pile stabilized slopes

Ito and Matsui[11] (1975) proposed analytical approach to estimate lateral force acting on stabilizing piles. He also studied the effect of ratio of clear distance between piles to the centre to centre distance between them, varying cohesion value and angle of internal friction. He concluded that row of piles installed closer to the top of the slope gives the best factor of safety.

Ito[12]*et al.* (1981) analyzed the stabilizing piles against landslide using one row of piles with varying parameters as ratio of clear distance between piles to the centre to centre distance between them (0.4-0.9), pile head as free, hinged, unrotated and fixed, diameter of pile (0.6-1.0). It was concluded that safety factor of the pile stability decreases with increase in pile length while safety factor for slope stability increases. The improvement in the safety factor for pile and slope stability with multi-row to single row pile was observed.

Poulos[13] (1995) described an approach for the design of piles to reinforce slope by varying pile lengths, spacing between piles. He demonstrated that centre to centre spacing required typically ranges between 2 to 4 times the diameters.

Hassiotis[14]*et al.* (1997) proposed a method for design of slopes reinforced with a single row of piles based on the theory of plasticity. The lateral forces acting on pile above the critical surface was determined by varying parameters such as pile location from toe. He concluded that for maximum FOS, the piles must be placed in the upper middle part of the slope, generally closer to the top.

Ausilio[15]*et al.* (2001) proposed a approach of limit analysis to analyze the stability of earth slopes reinforced with piles by varying the slope angle. The results concluded that optimal location of piles within the slope was near the toe of the slope.

Zhang and Wang[16] (2010) proposed an approach for stability analysis of strain-softening slope reinforced with stabilizing piles. The results show that the geometry of the slope and the pile layout has a significant effect on the safety factor and critical slip surface of the reinforced slope.

Ashour and Ardalan[17] (2011) analyzed the slopes based on soil-pile interaction with effect of ratio of distance of pile from toe to that of slope length (0.2-1.0) & Spacing to diameter ratio (1-5). The results showed that the position of the pile into the slope, the depth of the failure surface at the pile position, soil type, pile diameter and pile spacing have a combined effect on the maximum driving force that the pile can transfer down to the stable soil.

Haghbin and Ghazavi[18] (2013) proposed analytical approach to calculate the bearing capacity of a footing supported on one or two rows of piles stabilizing slope with the effects of fixity of pile head, crest distance, ratio of distance of pile from toe to that of slope length. He concluded that the maximum footing bearing capacity is achieved when non-fixed piles in the stable layer are installed at middle of the slope and fixed piles in stable layer are installed near the slope crest at various positions and the restrained pile head (hinged or fixed) was recommend for slopes.

Experimental studies of Pile stabilized slopes

Mostafa and Sawwaf[19] (2005) studied the behaviour of strip footing on pile and sheet pile-stabilized sand slope. The parameters studied were pile diameter, pile length, ratio of c/c spacing and footing width, pile diameter to footing width, height of sheet pile, location of sheet pile, length to width of pile. It was observed that the bearing capacity was found maximum when pile spacing was minimum and pile length was maximum. The pile spacing had greater significance than pile length or diameter. The optimal location of pile for maximum bearing capacity ratio was pile crest. However sheet pile stabilized slope shows better results as compared to pile stabilized slope.

Munawir[20]*et al.* (2013) modeled the slope with composite bamboo pile reinforcement by varying pile length, pile location from toe, relative density. The maximum improvement in the bearing capacity was with a bamboo pile of length 45 cm and located at (0,69) cm from toe.

CONCLUSION

The pile stabilized slope was analyzed by various researchers using analytical, numerical or experimental approach. A very few researcher work on performance of footing on pile stabilized slopes with multiple layer. The work carried out by various author shows that the study on pile stabilized slope with multiple layer is lagging. Hence there is a need to study the effect of various parameters like edge distance, slope angle, no. of layers, location of pile, diameter of pile, spacing of pile, type of pile, width of footing, etc. on stability of pile-reinforced slope.

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