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CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2022; 32 (3): 0133-0142
DOI: 10.2478/ceer-2022-0032
Original Research Article

MODULUS OF LATERALLY LOADED PILE IN COHESIONLESS SLOPE CREST WITH VARYING CONDITION

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A b s t r a c t

Soil - structure interaction behaviour of pile foundation is complex for heavier structures which suffer large lateral load due to wind, wave action etc., in addition to the large vertical and oblique load. The parameters involved in determining the lateral capacity of the foundation are its structural geometry, soil properties and ground condition. The behaviour is different for horizontal ground compared to the sloping ground; it is even different under loading and unloading conditions. In this study, the modulus of single pile is studied under various lengths, diameters, slope angles and loading directions. An equation is generated is developed to obtain the modulus with varying length and diameter.

Keywords: loading, unloading, slope, lateral load, diameter, length

1. INTRODUCTION

Pile subjected to lateral load is a classic soil-structure interaction problem. The behaviour is studied through elastic continuum mechanics, finite element/difference method, elastic subgrade reaction method and p-y curve. The main parameters influencing the lateral capacity are soil characteristics, ground

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condition and consistency of the soil. Apart from the above-said parameter modulus plays a vital role in determining the ultimate lateral capacity of the pile; which is defined as elastic compression of the soil under static lateral loading.

The behaviour of laterally loaded piles in the horizontal ground is explored to a maximum extent((Boominathan A & Ayothiraman R, 2006; Jiang et al., 2018; Zhang, Silva, & Grismala, 2005)). The lateral capacity of the pile reduces as the elevation of the ground changes from horizontal to any inclination(Chae et al., 2004)(Muthukkumaran K, 2014). When the pile is kept in the sloping ground to transfer the load to the soil from the structure, the pile behaves like an active pile (De Beer E.E, 1977) and the pile used to stabilise the unstable slope is called a passive pile. The ideal location of a single pile in slope is near the crest of the slope ((Muthukkumaran K, 2014),(Sivapriya S V & Gandhi S.R, 2019)).

The rigidity of the pile influences a lot in determining the lateral resistance of the pile in a slope(Begum N Almas & Muthukkumaran, 2008),(Sivapriya S.V & Muttharam, 2011). With an increase in the length of the pile, the lateral resistance increases. When the ground changes from horizontal to any inclination the reduction in passive resistance lead to deteriorating the lateral capacity of the pile (Sivapriya & Gandhi.S.R., 2011; Sivapriya S. V. & Rahul Ramanathan, 2019; Sivapriya S.V & Gandhi S.R, 2013; Sivapriya S.V et al., 2014). Even the loading pattern influences the lateral load capacity of the pile and the loaded direction has a predominant effect(Su, Ph, & Zhou, 2016). When the pile is loaded at the ground level without any eccentricity, it carries more load than loaded at the slope level.

The previous study discusses the modulus of the pile in the horizontal ground; whereas, the modulus value for pile in a slope did not gain much attention. To understand the influence of geometry of the pile and slope in determining the modulus of the pile, a study is made to calculate the modulus from the data of the laterally loaded pile extracted from the papers published by the authors and the same is used to calculate the modulus. The parameter varied is loading pattern, length, diameter and slope angle.

2. CALCULATION OF MODULUS

The modulus is defined as the lateral load per unit length for unit deformation. Beyond the critical depth (L_{cr}) the deflection of the pile is negligible such that, it is one-thousandth compared to top deflections (Krishnan R, Gazetas G, & Velez A, 1983; Kuhlemeyer R L, 1979; Randolph M F, 2009). It is represented as a combination of modulus of soil (Es), pile material (Ep) and its diameter (D) as given in equation 2.1,

$$\frac{L_{cr}}{D} = 1.45\left(\frac{E_p}{E_s}\right)^{0.21} \tag{2.1}$$

The modulus is calculated between the load/ unit length to deformation. The unit length is considered as the critical length of the pile beyond which the deflection is negligible.

The modulus of the pile is taken as the modulus of Aluminium (*Al*)70 GPa (a material property) and the modulus of the soil is 100 N/mm^2 (Joseph E. Bowles, 1997) with respect to the soil property having internal friction of 32 ^{0} and the soil is filled in a tank with a relative density of 70%. The diameter of the hollow Al pile used for the experiment is 16 mm and the length of the pile is 500 mm. By using equation 1, the critical length is calculated as 91.82 mm (≈ 92 mm); beyond 92 mm, the deflection becomes negligible.

The data is extracted from the experimental test of statically lateral load pile conducted in 1 x 1 x 0.5 m tank dimension of cohesionless soil slope. A hollow Aluminium pipe is scaled down as a model pile using Buckingham π theorem for a scaling factor of 20.

3. RESULTS AND DISCUSSION

The pile when placed in the crest of the slopes (1V:1.5H,1V:2H and 1V:2.5H) is subjected to horizontal lateral load towards and away (reverse) from the slope crest. The experiments conducted by the author (Sivapriya S. V. & Rahul Ramanathan, 2019) in their laboratory is taken as the input value. The typical load-deflection curve is converted into a load/critical depth Vs deflection curve. The initial tangent of this curve is considered as the modulus of the soil under loading and unloading conditions. The modulus under loading condition is considered as static modulus and unloading condition as post-static modulus.

The initial tangent of the load/critical length to the deformation is obtained for various conditions. Table 1 shows the various parameters involved in this study which has both static and post-static behaviour.

Table 1. Parametric Variations

Ground Condition	Length, mm	Diameter, mm	Loading pattern			
			Forward	Reverse	Loading	Unloading
Horizontal	500	16	√		√	√
1V:1.5 H	500	16	√	√	√	√
1V:2H	500	16	√	√	√	√
1V:2.5H	500	16	√	√	√	√
1V:2H	192	16	√	√	-	-
	288	16	√	√	-	-
	384	16	√	√	-	-
	300	25	√	√	-	-
	300	16	√	√	-	-
	300	12.5	√	√	-	-

The ultimate lateral load is taken as the load corresponding to a displacement equal to 20% of the pile diameter (Broms B.B, 1964). Hence the load is applied to the pile till it posses a minimum displacement of 3.2 mm (20% pile diameter); further, the load is removed in the same sequence. Thus obtaining loading and unloading load-deflection values.

Figure 1 shows the load/ critical length to deflection value of the pile embedded in the horizontal ground. The initial modulus of the curve shows a value of 725 N/mm^2 and 222 N/mm^2 in loading and unloading conditions respectively.

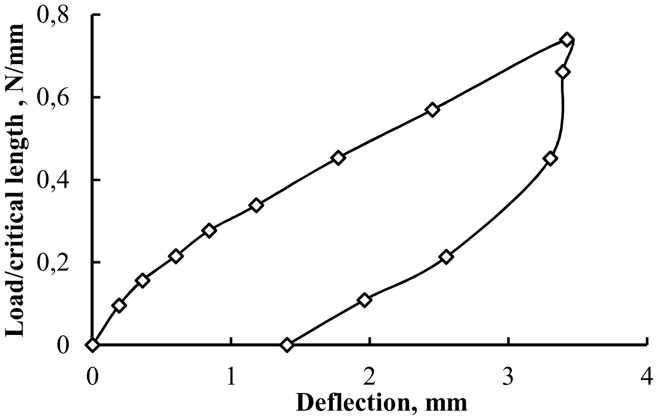

Fig. 1. For horizontal ground condition

3.1 Under forwarding loading conditions

It is observed that the modulus value increases with a decrease in the steepness of the slope. The passive resistance increases with an increase in the volume of soil present in front of the pile in a slope which leads to an increase in the modulus value. There is reduction in modulus from 725 N/mm^2 (horizontal ground) to 285 N/mm^2 (1V:2.5H), 220 (1V:2H) and 200 (1V:1.5H) N/mm^2 which is almost 60%, 69% and 72% respectively.

A volume of 0.23750, 0.3 and 0.325 m^3 of soil are removed for making the slope of 1V:2.5H, 1V:2H and 1V:1.5H respectively, leading to a reduction in passive resistance offered by the soil in front of the pile. This reduces the resistance of the soil.

While unloading, there is a minimal decrease in modulus value compared to that of the loading pattern. The modulus value for 1V:2.5H, 1V:2H and 1V:1.5H are 142,130 and 100 N/mm^2 respectively. The soil in front of the pile has already undergone deformation leading to a large reduction in modulus linearly with an increase in slope angle (figure 2).

Under unloading conditions i.e post- static; the modulus value shows an almost similar range of value. This indicates that the post- static modulus is not majorly influenced by the slope angle; as it has already deflected to a maximum during the loading condition.

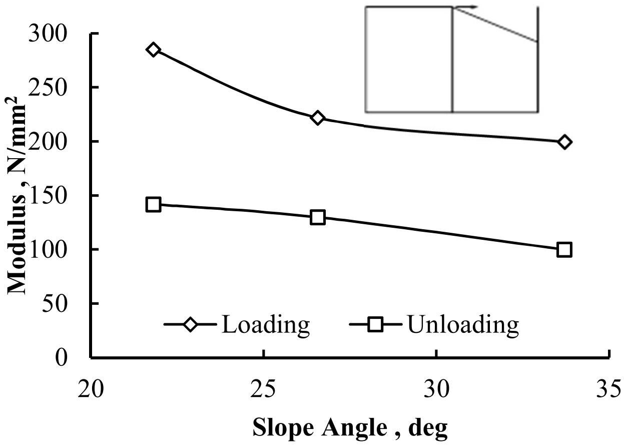

Fig. 2. Forward Loading conditions

3.2 Under reverse Loading Conditions

The modulus value for the slope 1V:1.5H, 1V: 2H and 1V:2.5H are 266, 328, 450 N/mm^2 respectively. When the load is applied against the slope, i.e towards the embankment, there is a reduction in the modulus value of about 63.31% for 1V:1.5H. This value is similar to the modulus while loading in the forward direction which was about 60.7%.With an increase in steepness of the slope, the reduction in modulus decreases. However, when the slope is reduced to 26.6 deg (1V:2H) and 21.8 deg (1V:2.5H) the modulus is reduced to 54.75% to 37.93% respectively.

While comparing it with the forward loading the modulus has increased to 33, 47.75 and 57.89% for the slopes 1V:1.5H, 1V: 2H and 1V:2.5H. The active pressure – the pressure pushes the pile due to loading in a slope; it reduces with a decrease in slope angle. The passive resistance remains the same as the slope angle in the loading direction is maintained as constant i.e the ground profile is horizontal.

The modulus value during unloading of reverse loading condition, values are 150, 165 and 200 N/mm^2; this too similar trend that of forwarding load condition with a slight increase in value. There is a reduction in modulus value which is 77 to 100% lower than that of the loading condition. The reduction in modulus value for the slope 1V:1.5H, 1V:2H and 1V:2.5H are of 32.4, 25.6 and 9.9% respectively with respect to the horizontal ground condition (Figure 3).

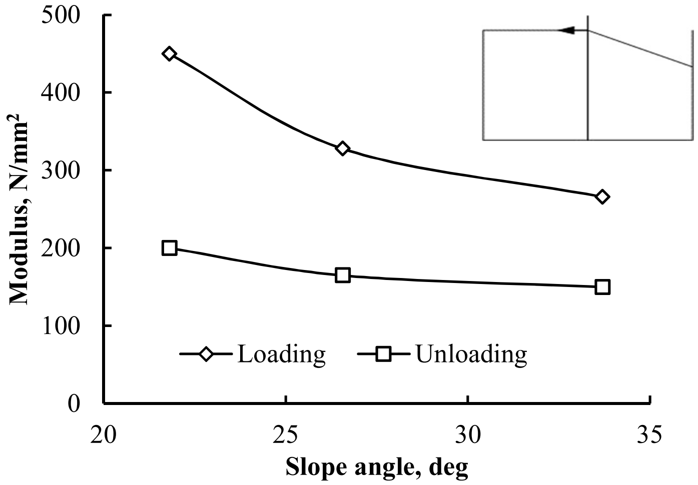

Fig. 3. Reverse loading condition

3.3 For varying length

To understand the influence of pile's length in modulus, a constant slope 1V:2H is maintained throughout the experiment. The diameter is maintained as constant – 16 mm with varying lengths of modelled pile say 192 (L/D =12), 288(L/D =18) and 384(L/D = 24) mm simulating short intermediate and long flexible piles respectively. The critical length of the pile remains the same 92 mm as there is no change in the diameter of the pile.

The modulus value of short rigid pile shows a lower value of 60 N/mm^2; this increases when the behaviour changes to intermediate and flexible pile as 115 and 208 N/mm^2 respectively. With a steep increase in the length of the pile, the modulus value increases linearly showing R^2 as 0.98(≈1). This clearly shows the structural rigidity of the pile plays a vital role in calculating the modulus (figure 4).

3.4 For varying diameter

As the critical length calculation involves 'diameter" as an important parameter, the L_{cr} values change with the change in diameter. The length of the pile is made as a constant say 300 mm with varying diameters 25 (L/D =12), 16 (L/D =18) and 12.5mm (L/D= 24) and the critical length varies as 144, 92 and 72 mm respectively.

The modulus value increases with a decrease in the diameter of the pile and the increase is very much linear. When the structure (pile) is loaded laterally, the initial load is governed by the diameter of the pile. As the cross-sectional area increases, the load-bearing increases; which make an increase in the modulus. The modulus value is 55, 105 and 140 N/mm^2 for L/D ration 12, 18 and 24 respectively (Figure 4).

4. DEVELOPING EQUATION

An attempt is made to develop an equation for various L/D various for a slope of 1V:2H (equation 4.1). Besides the slope angle, practically the length and diameter is varied to understand the lateral load behaviour for loading condition in the field. As it is the governing parameter to calculate the settlement characteristics.

$$Modulus\ \left({N}/{mm^2}\right) = 7\left[\frac{L}{D}\right] - 25 \quad (4.1)$$

Upon knowing the length and the diameter of the pile, the modulus can arrive. The equation agrees well with the obtained results (Figure 5).

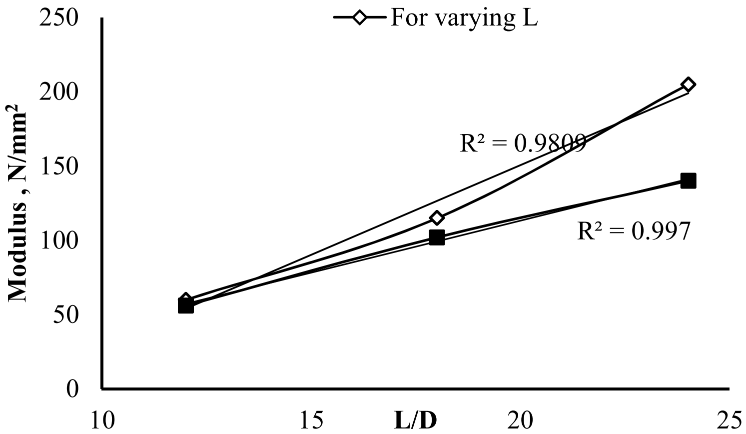

Fig. 4. Modulus with respect to varying L and D

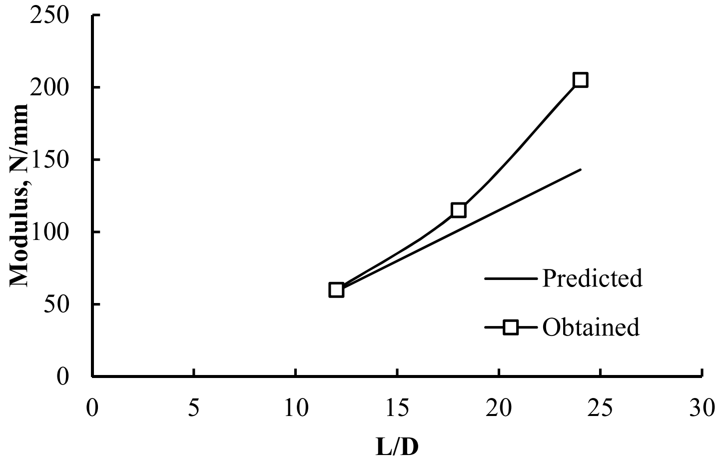

Fig. 5. Graph Generated

5. CONCLUSION

The experiment results for pile subjected to lateral load founded in slope with various slope angle loaded forward and reverse for constant L/D ratio were taken as the input parameter to understand the modulus of soil. Also, to understand the influence of Length and diameter (L/D ratio), the modulus is studied by maintaining a constant slope and varying L and D ratio; however, the L/D ratio is maintained as 12,18 and 24. The tangent of the load/ critical length to deflection is taken as the modulus and the following points are inferred.

i. With the increase in slope angle, the passive resistance offered to the pile by the soil decreases and this, in turn, reduces the modulus. There is a maximum reduction of 72% in modulus value when compared to the horizontal ground during forwarding loading. Under reverse loading, the same quantum of passive resistance is offered to the pile but there is an increase in active pressure with an increase in slope angle, which makes the pile. deflect more. It is observed, there is a maximum reduction of up to 63% compared to the horizontal modules.

ii. In order to understand the loading and unloading mechanism, the loads were removed in the same sequence as they were loaded. The R square value for forwarding loading is 0.98 and for reverse loading, it is 0.9; this shows there is a gradual change in the modulus value. The modulus in unloading i.e the post-static condition, has reduced more than 50% when compared to the loading modules. This shows that there is a drastic reduction in the resistance offered by soil to the pile.

iii. The influence of length and diameter in modulus is almost equal. With an increase in the length of the pile by maintaining the diameter, the modulus value increases. While increasing the diameter and maintaining the length as constant, the modulus value decreases. This is mainly due to the larger cross-sectional area of the pile.

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Editor received the manuscript: 30.09.2021