International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 9 Issue 5 ǁ 2021 ǁ PP. 46-52

Review On The Behaviour Of Piles In Sloping Ground

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Abstract
A foundation is described as 'piled' when its depth is more than three times its breadth. Pile foundations are one of the widely used foundations, which are often used in transmission towers, high-rise buildings, bridge engineering, and other structures. These structures are often built - in or near the slope. The calculation of the pile settlement is an important part of the pile foundation design in sloping ground. However, the pile behavior in the sloping ground is different from that in flat ground. The slope effect is generated and the pile displacement in the sloping ground is larger than that in the flat ground under the same load. This literature review deals with the behaviour of piles in the sloping ground under vertical loads and lateral loads.
Keywords: *Piles, Sloping ground, Vertical load, lateral loads,*

Date of Submission: 16-05-2021 Date of acceptance: 31-05-2021

I. INTRODUCTION

Pile foundations are the part of a structure used to carry and transfer the load of the structure to the bearing ground located at some depth below ground the surface. The main components of the foundation are the pile cap and the piles. Piles are long and slender members which transfer the load to deeper soil or rock of high bearing capacity avoiding shallow soil of low bearing capacity The main types of materials used for piles are Wood, steel and, concrete. Piles made from these materials are driven, drilled or, jacked into the ground and connected to pile caps. Depending upon the type of soil, pile material and load transmitting characteristic piles are classified accordingly.

Loads on piles:

Piles can be arranged in many ways so that they can support the load imposed on them. Vertical piles can be designed to carry vertical loads as well as lateral loads. If required, vertical piles can be combined with raking piles to support horizontal and vertical forces. Often, if a pile group is subjected to vertical force, then the calculation of load distribution on a single pile that is a member of the group is assumed to be the total load divided by the number of piles in the group. However, if a group of piles is subjected to lateral load or eccentric vertical load or combination of vertical and lateral load which can cause moment force on the group which should be taken into account during the calculation of load distribution.

Pile foundations: vertical piles only

Here the pile cap is causing the vertical compression U, whose magnitude is equal for all members of the group. If Q (the vertical force acting on the pile group) is applied at the neutral axis of the pile group, then the force on a single pile will be as follows :

$$P_v = \frac{Q}{n}$$

where:
Pv = vertical component of the load on any pile from the resultant load Q
n = number of vertical piles in the group
Q = total vertical load on pile group

II. LITERATURE REVIEW

Almas Begum and Muthukkumaran [1] investigated a single model pile under lateral load in sloping ground. This study is used to develop a graphical non-dimensional relationship between the lateral loads and maximum bending moment in the pile. The behaviour of the pile was studied by its lateral load pile head displacement response and bending moment profile along the pile shaft. From the behaviour, a correction factor for the lateral load capacity and the maximum bending moment for the sloping ground was obtained.

Ameer A. Jebur [2] conducted detailed numerical modeling using Winkler theory is used to examine the behaviour of model piles in sandy soil subjected to lateral load. The moment distribution profile is calculated and is observed that from the moment profile, the model piles are non-linear. Due to the decrease in the pile stiffness, there is an increase in domain mass within the contacted soil mass.

Artak D. Mirzoyan [3] studied the lateral resistance of piles at the crest of slopes in the sand. The piles located near a sloped profile experience a reduction in ultimate strength compared to piles located in horizontal soil profiles. For the case of a pile located at the slope crest, the reduction was approximately 23%, and for the case of a pile located three pile diameters from the slope crest, the reduction was near 7%. Thus, pile proximity to slope has a significant effect on the amount of reduction in ultimate strength.

Barry J Meyer and Lyson C Reese [4] studied the behaviour of laterally loaded single piles using COM623. The results indicated that the pile head deflection was more sensitive to soil variations. The cyclic loading caused an increase in the maximum bending moment.

Brian Michael Machmer [5] conducted an experimental study to understand the behaviour of a pile foundation in unsaturated soil. The piles are subjected to horizontal loading. The experimental results show that the increase in the bearing capacity of the pile is 2.7 times the deterministic approaches using saturated soil parameters. The increase in footing size increases bearing capacity. The suction also increases the value of the cohesion term.

Brown DA and Shie CF [6] experimented to study the behaviour of laterally loaded piles using a three-dimensional finite element model in clayey slope. The p–y curves are widely used in the design due to its relative simplicity of the beam foundation. Results indicate that ground inclination noticeably affects ultimate load Pu, but has essentially no effect on the initial slope of the p–y curves.

Chandrasekaran et.al [7] studied the dynamic response of laterally loaded pile groups in clay. The effects of pile spacing and the number of piles and configuration on displacement and bending response of pile groups in clay soil were studied under dynamic lateral loading. The displacement response of the pile group in clay is strongly nonlinear due to stiffness degradation and an increase in hysteretic damping. Dynamic lateral loading increases the maximum bending moment and active pile length.

Chang. Y.L. [8] conducted a lateral pile loading test. The closed-form solutions, proposed and are used in the subgrade reaction analysis, have been adopted to predict the load-deflection for a laterally loaded pile in homogeneous soils.

Cheng-Lin et.al [9] analyzed the response of laterally loaded pile foundation in sandy soil under scouring considerations. The lateral deflection of the sand is reduced and this tends to increase the lateral deflection of the pile head. In other words, considering the stress history of the remaining sand reduced the required pile length in terms of the design of laterally loaded piles.

Chia-Cheng Fan and James H. Long [10] studied the soil response of piles under lateral loads using non-linear finite element analysis. The soil properties like stiffness, diameter, and coefficient of horizontal earth pressure are investigated. The effects of pile stiffness are not significant and the ultimate soil resistance increases the co-efficient of horizontal earth pressure. Hansen's method also provides a better way to predict ultimate soil resistance.

Chong Jiang et.al [11] conducted a series of 3D finite element analyses to study the behaviour of laterally loaded piles in the sloping ground under undrained loading conditions. For different slopes and loading conditions, the effect of slope angle and the distance of the pile from the slope crest is coupled. Further, it is said with the increase of α the effect of x on the pile is increased.

Chong Jiang and Wen-Yan [12] studied the settlement of a vertically loaded pile in sloping ground. The increase of the slope ratio will cause the position of the maximum bending moment and soil resistance at zero points of the pile to move downward. When the pile distance from slope crest B < 7D, the displacement and internal force development of the pile under toward loading are more apparent. When the pile distance from the slope crest exceeds 7D, the effect of the loading direction on the pile can be removed.

Deendayal Rathod and T.G.Sittharam [13] presented the dynamic response of a single pile of diameter 0.4 m and length of 11.5 m located on soft clay. This pile is subjected to vertical load and ground acceleration. PLAXIS 2D is used to analyze the pile. The deformation and acceleration behaviour pile is analyzed. From the experimental results, it is concluded that the top tip of the pile is suspectable for damage comparing to the bottom pile.

Deendayal et.al [14] analyzed the laterally loaded piles group using PLAXIS 3D located on sloping ground. When a group of piles is placed on a 1V:5H slope, the maximum bending moments in the back row are more compared to the middle and front rows when the same load is applied. In cohesive surfaces, lateral displacement is observed at high rates.

Dhatrak and Gaurav Bhagat [15] investigated the behaviour of a single pile in a reinforced slope under inclined loads. For short piles, two layers of geogrid reinforcement are found optimum and for long piles, three layers of geogrid reinforcement are found optimum. The maximum percentage increase in ULL is 104%

for an optimum number of geogrid layers (N=2) for short piles and 129% for an optimum number of geogrid layers (N=3) for long piles.

Fen Li et.al [16] studied the effects of scouring on laterally loaded single piles in marine clay. The relationships of the ultimate lateral capacity of the single pile with the depth, width and slope angle of the scour hole were obtained. The numerical results show that the scour depth has a more significant influence on the pile lateral capacity than the scour width. Also, the pile with a free head was more sensitive to scour than the pile with a fixed head.

Frank and Pouget [17] studied the p-y approach of the pile in a stable slope using an instrumental pile installed in the ground. Using pressure meter data in the p-y approach, soil-structure interaction analysis is made with the PILATE program, proves to be applicable for the design of piles. The experimental findings are used to understand the behaviour of piles subjected to longer thrusts.

George Mylonakis et.al [18] implemented a substructuring method for analyzing bridge piers. Analyses are performed in frequency and time domains. The method reproduces semi-analytically both the kinematic and inertial soil interaction in a simple way. The observed phenomenon helps to predict the qualitatively the response cases. Using equivalent linear results rough estimates in elastic structural response are made.

Hiroyoshi Hirai [19] used the Winkler approach for vertically and laterally loaded piles in non-homogeneous soil. Using Winkler's model approach for vertically loaded piles, the load transfer parameter adopts the maximum radius of the pile proposed. For laterally loaded piles, the relationship between the horizontal displacement and stress is produced through the displacement influence factor obtained from Mindlin's solution

Hongyu Qin Wei Dong Guo [20] has experimented to find the distance between the tested pile and source of free soil movement Sb, sliding depths, and angle of soil movement on the pile response. For instance, the axial loading P leads to extra bending moment and deflection in the passive pile the M max reduces with an increase in Sb and the M max is proportional to the angle of soil movement.

Jegatheeswaran and Muthukkumaran [21] analyzed the behaviour of piles using finite element analysis, with the influence of lateral soil movement. Due to the increase in lateral load capacity, the effect of the settlement of pile is more in sloped ground surface than the horizontal ground.

Jianwei Zhang et.al [22] experimentally analyzed a single pile response under combined loading in slope. The experimental results indicate that the soil pressure along the slope direction was smaller than the other side, resulting in an asymmetry of the slope soil around the pile and in turn introducing a horizontal thrust to the pile. With the increase of slope angle, the horizontal thrust increased while the single pile's bearing capacity decreased.

K.Georgiadis and M.Georgiadis [23] used a computer program COM624P, for analyzing laterally loaded single piles. The p-y analyses were held on sand and clay. The influence of the slope angle on both horizontal displacements and bending moments increases with slope angle. The finite element analysis results show when the applied horizontal load gets increased the values r_y and r_m also get increased.

Kasinathan Muthukkumaran [24] observed that when the piles are installed in sloping ground undergo forward loading. During this forward loading, the lateral capacity of the piles is almost reached at 8% of the pile diameter in loose to medium dense soil and 16% of the pile diameter in dense. The influence of slope and loading direction is almost negligible in the lateral load capacity of piles in 1V:1.5H slope with 70% relative density.

Kranthikumar and Ravi S. Jakka [25] studied the behavior of large diameter piles resting on or near the cohesionless soil slopes using a finite element method is studied. The effect of various influencing parameters like slope gradient, the diameter of pile, length to diameter ratio of the pile, and location of water table on the axial and lateral load-carrying capacity of the pile have been studied.

Kumar et.al [26] modeled a single pile system using FEM implemented PLAXIS 3D software. The numerical results of pile bearing capacity and pile top displacement have been compared with static load test results of a model pile. The experimental and numerical results suggest greater deflection for positive batter piles than for vertical and negative batter piles under the same lateral loading.

Leshukov [27] carried out tests on 80 and 120 cm long piles with a quadratic cross-section in silty fine sand. Oblique tension forces are applied and the effect of inclination angle on the vertical ultimate load is analyzed. The ratios of length to the diameter of the piles (L/D) were also varied. The maximum increase was obtained with inclination angles between 20̊ and 30̊.

Liyanapathirana and Poulos [28] used a numerical-based finite element method to analyze the pile behaviour in liquefying sloping ground. Using free-field ground response analysis ground displacement and degraded soil stiffness were obtained. Using the Winkler model the spring coefficients are derived. The performance of pile groups is observed during centrifuge tests and the response of the piles is studied.

Luc Thorel et al. [29] studied the static and dynamic behaviour of pile-supported structures in soft soil. The results were obtained in terms of movements and stresses in soil. This shows different responses in accelerations, displacements of evaluated systems.

Martin Achmus and Kiaus Thieken [30] studied the behaviour of piles in non-cohesive soil under combined loading. The results indicate a reduction in both vertical and horizontal system stiffness. It is caused by a negative skin friction effect. If the vertical load becomes larger there will be an increase in ultimate load due to large normal stress acting on the pile shaft.

Martin and Chen [31] studied the response of piles due to lateral slope movement. The pile response caused by an embankment slope is studied using the FLAC3D program. It is induced by a weak soil layer on a liquefied layer under the embankment. Sensitivity studies on soil and pile parameters show that the relative stiffness between the pile and soil are important factors in determining the failure modes of the pile and the pressure on the pile.

Mezazigh.S and D. Levacher [32] studied the effects of slope on p-y curves in dry sand under centrifuge tests. The displacements of the pile and the internal forces are increased as the pile is installed closer to the crest. Concerning the case of the horizontal soil surface, for the same load, the displacement at the head of a pile at the crest of a slope cut to 2 in 1 is 1.6 times greater and the maximum moment is greater by 1.25.

Muthukkumaran and Almas Begum [33] studied the behaviour of laterally loaded piles on the sloping ground using FEM and model tests. It is analyzed for various slopes and relative densities. From load deflection and bending moment behaviour, a correction factor for the load capacity for the sloping ground is obtained and used for further development.

Mylonakis [34] analyzed axially loaded piles using Winkler modulus, the modulus of the subgrade reaction on the axially loaded piles is investigated. The pile is subjected to lateral loads which are governed by the simple theory of bending of beams. The analytical solutions of the governing equation for the deflection of a laterally loaded pile have been obtained and studied.

Nima Ghashghaee Zadeh and Behzad Kalantari [35] experimentally studied the performance of a single pile under vertical and lateral loads. The maximum design bending moments in the laterally loaded piles under combined loading were found to increase with the increase in vertical load levels in both types of soils. Also as the L/B ratio increases, the influence of combined loading on the lateral capacity reduces.

Patra and Pise [36] analyzed model pile groups under oblique pull-out loads. The model test was conducted by using aluminium piles in medium dense fine sand under oblique pull. It was found that for both single piles and pile groups the ultimate vertical load can be significantly increased by a horizontal load acting simultaneously. Deflection curves were also reported. However, it should be noted that very large horizontal deflections of up to 15 mm i.e. 75% of the pile diameter were realized in these tests and used in the determination of ultimate loads.

Poulos. H.G. [37] analyzed to study the effect of slope or cut on the load-deflection behaviour. This experiment uses the elastic theory but allows for the yield of the soil. Under elastic loading, the direction of loading does not affect the deflection of the pile and the load-deflection relationship depends on the direction of loading.

Prakash and Kumar [38] developed a method to predict the load-deflection relationship for single piles embedded in sand and subjected to lateral load, considering soil non-linearity, based on the results of 14 full-scale lateral pile load tests. All these studies have been directed towards the response of a single pile or group of piles subjected to lateral load in the horizontal ground with little attention being paid to piles in sloping ground subjected to lateral loads.

Randolph [39] studied the load transfer parameter of a single pile subjected to vertical loads in non-homogeneous soils. Second, to combine the elastic continuum approach with the subgrade reaction approach, the modulus of the subgrade reaction along the pile in non-homogeneous soils is expressed by the displacement influence factor related to Mindlin's equation for an elastic continuum analysis. Third, the relationship between settlement and vertical load for a single pile in non-homogeneous soils is obtained by using the recurrence equation for each layer.

Sawant and Shukla [40] conducted a three-dimensional finite element analysis to investigate the effect of edge distance from the slope crest of laterally loaded piles. The response of the pile in the sloping ground is compared with the level ground. This comparison develops a simple methodology for estimating the displacement and maximum moment.

Sharour and Meimon [41] analyzed the behaviour of off-shore piles under inclined loads. For the piles under combined tension loading in sand based on numerical simulations, the horizontal load-deformation behaviour of a pile is hardly affected by an axial load, where a horizontal load leads to a stiffness reduction in the axial direction.

Sivapriya S.V and Rahul Ramanathan [42] conducted an experimental study to find out the load-displacement behaviour of a pile on a sloping ground for various L/D ratios. Due to the resisting volume of a passive wedge, there is a reduction in capacity. As the inertial force is larger, the effect of diameter is high in the lateral load.

Sumanta Haldar and Sivakumar Babu [43] made a comparative study to analyze the allowable capacity of laterally loaded piles fixed in the undrained clay soil. Due to the effect of COV and δz, there is a change in allowable load and bending moment. The increase in correlation distance decreases the strain level.

Teja Munaga et.al [44] studied the behaviour of pervious concrete piles under axial and lateral loads. The maximum bending moment experienced by the pile decreased by 30% as the aspect ratio of the pile increased from 6 to 14. This is due to the increase in the resistance offered by the pile, thus leading to a decrease in the bending moment experienced by the pile.

R.M.Verhoef [45] performed an analysis with a finite slope, where the pile is located at the crest, in the middle, and at the toe of the slope. The most important observation of this analysis is the fact that the capacity of a laterally loaded pile in a sand slope is much more affected by the angle of the slope than the capacity of a laterally loaded pile in a clay slope.

Wenzhe Peng et.al [46] studied the behaviour of laterally loaded piles is analyzed using the modified strain wedge model which is divided into an upper soil wedge and a modified lower strain wedge. The accuracy of this wedge model is verified using many in-situ tests and the results are calculated.

Youngho Kim and Sangseom Jeong [47] made an analysis of soil resistance on laterally loaded piles based on 3D interaction. The lateral load transfer curve is investigated in Korean offshore deposits. The simulation techniques and analysis results were validated in the full-scaled field load test in marine clay in terms of pile deflection, bending moment, and p–y curves along the length of the pile. The realistic representation of the lateral load transfer characteristics of large diameter piles in clay soil provides good agreement results with the field test results.

Zhang et.al [48] evaluated the effects of slope inclination and sleeving thickness on the behaviour of piles using a series of 3D analyses. Empirical relation of piles in the sloping ground is proposed. The effects of inclination in the sloping ground are generally minor for very small lateral loads and for larger loads it will develop larger horizontal displacements and bending moments.

Zhi Yong Ai Yuan et.al [49] analyzed the laterally and vertically loaded piles in multi-layered transversely isotropic soils. The pile shaft surrounding with soft soil layer at the shallow depth has a higher internal force and deformation. The behaviour of piles is analyzed under small deformation and the pile is modeled by combining the 1D compression bar and Euler Bernoulli beam theory.

Zhong-Miao Zhang et.al [50] conducted a destructive field study on the behaviour of piles under tension and compression. The measured skin frictions for the piles under compression were about 6% to 42%. Four destructive full-scale pile loading tests were conducted to find the field performance of piles under tension and compression.

III. CONCLUSION

Piles are generally used to support superstructures such as bridge abutments, high-rise buildings, and transmission towers, which are subjected to heavy axial forces as well as lateral forces. From this study, we can able to understand the behaviour of piles under lateral and vertical loadings. Numerous studies have been conducted to study this behaviour. Compared with a pile on level ground, there are many particular characteristics in a pile that is on sloping ground. These characteristics depend on the combined loading and the magnitude of the soil lateral displacement can be analyzed and studied.

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