"A Review Paper on Tension Pile"

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Abstract – An analysis of the tension pile for different angles is presented here because it was to be found that the numerical model assessed the actual pile bearing capacity more closely by the empirical calculation rules. The bearing capacity of tension piles involves interactions between the tension-pile with the neighbouring sediments, often use is made of empirical relations between soil properties, skin friction, L/D ratio and angle of uplift loading.

Keywords – Tension Pile, Study and Behaviour, Inclined Loading, Lateral and Uplift Capacity, Pile Surface Roughness, Length and Diameter, Unit Skin Friction, Earth Pressure and Soil Type.

I. INTRODUCTION

General – In this paper an attempt has been made to present a review of the literature to identify the important and useful analysis of tension pile with the basic concept. Generally, tension piles are used to provide sufficient lateral but Nowadays, with the increasing need for infrastructures and the decreasing availability of space, both structural and geotechnical engineers are challenged to design, analyse, and evaluate more expensive and strategic structural systems (offshore platforms, high-rising buildings, multi-story highways, etc.) submitted to extreme lateral loadings (terrorist attacks, earthquakes, gusty winds, etc.). But also, in structural engineering and bridge construction piles are often used as foundation elements.

Foundations of Tension pile are widely used in the geotechnical engineering to sustain uplift load from the superstructure. In the past decades, a few studies have been conducted to investigate the capacity of tension pile foundations, but the design of tension pile foundations still needs much empirical treatment. As most common buildings will experience horizontal loads, whether it is from wind loads on a building or hydrostatic loading on a quay, the slender piles used must be inclined as the lateral resistance of the vertical piles is extremely low. However, if the soil settles the relative movement of the soil and the inclined pile will result in a lateral force against the pile. This force causes bending moments that reduce the carrying capacity of the inclined pile. Some other countries use inclined piles (Tomlinson and Woodward, 2008). The use of Tension piles should be installed at the largest possible angle is an efficient way to handle lateral and uplift forces in constructions. However, if the soil take place of any type settles the structural bearing capacity of each pile is decreased because of induced bending moments in the pile. There are several reasons for a soil to settle, if an embankment is built on top of a clay settlements will occur. The behaviour of the interface between pile and soil significantly influences the behaviour of the tension pile.

There is currently no validated method to analyse horizontal loading from a settling soil. However, recent studies have pointed out that in several configurations, the large forces induced onto the pile cap connection during the earthquake. It indicates the possible tensile or compressive failure at the connection with the cap when the pile is embedded or the extraction of the pile because of cyclic axial distress in case of floating piles. The main problems that appear during an earthquake loading are summarized hereafter:

• Tension piles induce large axial forces translated to the pile cap,

• The bending capacity of Tension piles is reduced due to important tensile stress,

• Tension piles are subjected to bending stress due to soil densification or soil consolidation,

• The spatial configuration of Tension piles has significant influence on the dynamic response of the super-structure.

These findings imply that piles at different angles can be used in a far greater extent than previously expected and may have a beneficial behaviour, hence decreasing the cost for the project.

Numerical analysis pointed out that the presence of Tension piles at different angle was one of the reasons why the quay wall managed to withstand the severe seismic motion and experienced only small displacements.

II. THE PAPER OBJECTIVES

- To study of Tension Capacity and Behaviour of tension pile by Numerical method in a homogenous and a non-homogenous soil.
- To study the Importance of unit skin friction between soil and surface of pile, and
- To examine the benefits and barriers of tension pile.

III. LITERATURE SURVEY

The research paper related to "A study on tension pile" from various reputed journal have been considered for the review. After doing thorough study of tension pile the results of the research papers considered for the review. There are quite a good number of studies available in the body of literature focusing on the awareness and Potential for implementation of tension pile for different sector. The one important such study is discussed below.

Ireland (1957) - He reported uplift test results of five step tapered Raymond piles, cast-in-situ, depths varying from 4.75 m to 5.29 m in fine sand of marine origin. Water table was near the ground surface. The values of Ks may be more than the coefficient of Rankine's passive earth pressure coefficient Kp.

Broms (1964) – In his studies was to be found of different failure modes. Failure modes was described depending on the length of the pile. for calculating the deflections and moments of piles in a cohesive soil under undrained loading using the theory of subgrade reaction. Deflections to the "working" load range, which is normally considered to be 1/2 of the computed ultimate pile capacity. In the working load range, he also assumed that the soil was linearly elastic.

Begemann (1965) - Begemann suggests that the calculated skin resistance for downward loading be adjusted by a reduction factor dependent on the soil and pile type. He also suggests reduced values of skin resistance be used if the uplift load is oscillating.

Meyerhof and Adams (1968) - They have developed a theory of uplift resistance capacity of foundations embedded in soil. On the basis of model test results, an approximate non dimensional uplift load displacement relationship is developed. This relationship is useful in the determination of the allowable anchor holding capacity at a given level of vertical displacement of the anchor. The experimental ultimate uplift capacity of rectangular anchor plates is generally in good agreement with those predicted.

Vesic (1970) – He considered the cavity-expansion model. His study indicated that the ultimate skin friction on the piles is same both in compression and tension. He proposed a method for estimating the pile point bearing capacity based on the theory of expansion of cavities. According to this theory, based on effective stress parameters.

Das and Seeley (1975) - They investigated the ultimate capacity in loose granular soil of vertical piles under axial pull. It is concluded that the unit uplift skin friction for piles is approximately linear with depth up to a critical embedment ratio.

Das, Seeley and Smith (1976) - They investigated the variation of uplift capacity of pile groups considering various parameters like shape, size and spacing. They found that for all groups in general the efficiency increases with increase in spacing and also decreased with number of piles in the group.

Sulaiman and Coyle (1976) - The study describes correlations achieved for piles subjected to uplift loads by comparing computed load versus pile movement curves with the pile's behaviour in the field. He conducts tests relating skin friction to pile movement for model steel pipe piles embedded in poorly graded Arkansas River sand of medium density. The apparatus used to conduct the tests and correlations with the behaviour of full-scale piles loaded in compression were reported. The full-scale steel pipe pile data were obtained from a report by Fruco and Associates. Correlations achieved for piles subjected to uplift loads by comparing computed load versus pile movement curves with the actual behaviour of the field piles.

Broms and Fredriksson (1976) - A different analytical solution is investigated which could be useful if a varied subgrade reaction is to be used in an analytical model. Even a moderate subsidence can increase the maximum bending moment in the piles just below the pile cap so that the yield strength of the reinforcement is exceeded. Subsidence has also caused pile failures due to the lateral displacement of the soil and Batter or raked piles are resisting lateral loads.

O'Neill, Hawkins and Mahar (1982) - They describe the phenomenological and analytical study of axial load transfer in a full-sized group of nine 273 mm diameter steel-pipe piles fixed thirteen metre in a layered over-maximum consolidated clay. Uplift tests were conducted on six piles at the conclusion of the group and sub-group testing under compression.

Poorooshasb and Parameswaran (1982) - They analysed vertical uplift behaviour of a single rigid pile or pier embedded in a frozen sandy soil. Using a simple displacement field, the vertical uplift behaviour of a single rigid pile (or pier) embedded in a frozen sandy soil is analysed. Results of the analysis are represented by curves from the magnitude but movement can be estimated for given uplift forces. The procedure is directly applicable to piles embedded in moderately to heavily over consolidated clay deposits.

Chaudhuri and Symons (1983) - They reported test results on piles of various diameters, depths, and pile surfaces embedded in medium and dense sand. The difference of skin friction lengthwise the shaft was found to be of like parabolic shape with the maximum value attained nearly at 70%- 80% of the depth. They indicated that the critical depth is nearly 30 times the diameter, d, of a pile in dense sand or medium dense sand. For rough piles in medium dense sand it is 15d.

Das and Azim (1985) - Model tests are carried out by them on group of piles embedded in clay under axial uplift load. Piles were having the L/d ratio of 12 and 15. The group efficiency varied with embedment ratio, number of piles in the group and spacing of piles.

Subba Rao and Venkatesh (1985) - The laboratory studies on the uplift behaviour of short piles in uniform sands given by them. The uplift capacity was found to be increase with pile roughness, soil density, particle size and L/d ratio (dry and submerged conditions of soil).

Ismael and AI-Sanand (1986) - The uplift capacity of bored piles in dense calcareous soils by field tests at three sites in Kuwait and test results were corelated with skin friction to the standard penetration test results only. They concluded that bored piles developed substantial skin friction in dense weakly cemented calcareous sand soils.

Chattopadhyay and Pise (1986) - They proposed the theoretical analysis and also carried out laboratory experimental investigation on piles under different pulling load conditions. The present analysis takes into consideration of various pile and soil parameters such as length (L), diameter (d) of the pile, angle of internal friction of soil (ϕ), soil pile friction angle (δ) and unit weight of soil (γ). A modified value of coefficient of lateral earth pressure in uplift has been developed considering the arching effect of soil. A comparative assessment of the uplift capacity of piles predicted by using proposed theory and the existing available theories is made with the existing field and model test results. It has been observed that the present model considering the arching effect predicts the results closer.

Madhav (1987) - He has studied theoretically the interaction between two identical piles in tension by modelling the soil as a homogeneous, linearly elastic medium and by using the boundary integral technique.

Sharma and Soneja (1987) - They carried out investigation wherein the pile is subjected to uplift load at the top (at pile head), as well as, at the pile toe. They found that the skin friction is higher for piles pulled from toe than piles pulled from top.

Turner and Kulhawy (1990) **-** They carried out experimental study of the effects of repeated loading on drained uplift capacity of drilled shafts in granular soil.

Nagararjun and Pise (1995) **-** They have reported model test results on the behaviour of single piles embedded in layered sand under inclined pulling loads. The qualitative and quantitative effects of the various parameters have been studied.

Pise (1996) - He has reviewed some of the existing approaches used to predict the uplift capacity of piles in sand with applicability of the theoretical results. A modified value of coefficient of lateral earth pressure in uplift has been developed considering the arching effect of soil. An analytical method has been proposed to predict the ultimate uplift capacity of single vertical piles embedded in sand considering arching effect.

Mukherjee (1996) **-** Mukherjee carried out experimental and theoretical investigations to study the pull-out behaviour of pile groups in sand. An attempt has been made to find out the failure surface profile around the group through experimentally and using finite clement method.

Kastranta et al, 1998 - During Kobe (1995) earthquake, the only one quay in Maya Wharf that suffered limited displacement was that built with inclined piles, while the two other types, without inclined piles were severely damaged.

McVay Et Al. (1996) - He has studied the effect of battered piles in fixed-head 3x3 pile group and compared the pile cap displacement of these pile group with a vertical pile group. In medium dense sands, the battered groups were in an A frame arrangement, i.e., each pile in a given row battered the same. results of the tests showed that fixed-head plumb groups have a 30 to 55% higher lateral resistance than free-headed piles depending on soil density and pile spacing. For the battered 3D-spaced group, the lateral resistance was greater by 20 to 50% than the fixed-head plumb response in the medium dense sand; however, in the medium loose sand, the battered and plumb fixed-head group response was very similar. The latter is attributed to the limited axial tension capacity of the piles in the medium loose sand. Increasing the dead load on a battered group to 45% of its axial capacity resulted in a 30% increase in the group's lateral resistance. The lateral resistance of the 5D-spaced battered groups were in all cases greater than their 3D counterparts.

Zhang et al. (1999) – His study was based on centrifuge tests, the effect of the pile inclination and soil density by submitting a single inflight battered pile to horizontal static loading. the lateral capacity increases over plumb piles were 4, 14, 24, and up to 50 % in very loose, loose, medium-dense, and dense sands, respectively, at negative angle batter (-14°). In contrast, the lateral capacity decreases over plumb piles were 4, 5, 15, and up to 35 %, respectively, at positive angle batter (14°).

Lam et al. cited by Gazetas (2003) - He showed that both, the pile-cap displacement and the bending moment profile, may be drastically reduced in liquefied soil due to the stiffening effect of the battered piles until today.

Guo and Ghee (2004) - It can be seen in these tests that a maximum pressure against the pile is reached at a relative displacement of the soil depending on different factors such as the prole of the moving soil.

Poulos (2006) - He mentioned the effect of the possible soil densification that follows an earthquake which induces bending stress and reduction of bending capacity in the inclined piles and the development of large tensile force during an earthquake by shear box tests, where a vertical pile stands in a movable soil medium, to test pure lateral displacement of soil.

F. Zhang, K. Okawa, and M. Kimura, (July 2008) - They carried out the experimental study by Centrifuge model test on dynamic behaviour of group-pile foundation with inclined piles and its numerical simulation. They concluded that the effects of pile batter were significant in medium dense and dense sands, but minor in very loose and loose sands. Larger contrasts exist between the results obtained throughout these experimental studies of lateral response of battered piles under lateral loads.

H. Mroueh and I. Shahrour, (2009) – They analysed the uplift capacity of battered piles by Numerical analysis of the response of battered piles to inclined pull-out loads. Analyses show that the load's inclination with regard to the pile's axis affects both the lateral and axial response of the battered piles. Analyses also show that the pull-out capacity of battered piles is affected by the pile's inclination regarding the vertical axis as well as the load's inclination regarding the pile's axis. The investigation of the influence of the contact condition at the soil–pile interface shows that the possibility of sliding at the soil–pile interface affects the response of battered piles subjected to loads with low inclination regarding the pile's axis.

Qin and Guo (2010) and Lin et al. (2014) - There studies covering the lateral displacement of tension piles between a pile and soil. The profiles of bending moment, shear force and pile deflection along the pile, the development of maximum bending moment, maximum shear force, and pile deflection at the ground surface with soil movement. The tests reveal the effects of axial load P (at pile head), the distance between the tested pile and source of free-soil movement Sb, sliding depths, and angle of soil movement (via loading angle) on the pile response. It can be reached at a relative displacement of the soil by pressure against the pile due to prole of soil.

Nasr, A. M. A. (2014), They carried out experimental and theoretical studies of laterally loaded finned piles in sand. The results indicated that the uplift resistance was drastically reduced by oil contamination. The maximum reduction in uplift resistance and skin friction factor occurred at low contamination (oil content = 1%). The initial sand density and method of pile installation are significant factors affecting uplift capacity of piles embedded in oil-contaminated sand

Sharma B, Zaheer S, Hussain Z (2014), They carried out the experimental model for studying the performance of vertical and batter micro piles. The unit skin friction during pull-out tests are significantly less than during push-in tests, especially in case of rough.

K. M. Reddy and R. Ayothiraman (2015), Experimental studies on behaviour of single pile under combined uplift and lateral loading. The maximum value of skin friction increases with depth of embedment and it reaches by a constant value at a critical depth of embedment.

Ganesh R. and Sahoo J. P. (2015), Influence of groundwater on the ultimate uplift resistance of circular plate anchors". The presence of ground water decreases the ultimate uplift resistance continuously with an increase in the level of water table towards the ground surface. The maximum reduction in uplift capacity occurs when the level of water table is at the ground surface irrespective of embedment depth of anchor.

R. Nazir, H. Moayedi, A. Pratikso, and M. Mosallanezhad (2015), They carried out experimental based study. In their study, the uplift load capacity is direct proportional to size of embedded base of tension pile in dry sand.

Pelecanos, L, Soga, K, Hardy, S, Blair, A & Carter, K (2016), It can be seen in these tests that Distributed fibre optic monitoring of tension piles and increase the uplift capacity of tension pile. These piles exhibited a more nonlinear load-movement behaviour in uplift than in compression, probably due to the release of residual load.

Azzam, W. and Elwakil, A. (2016), They have carried out the Study on the performance of single-finned pile in sand by using of tension loads. Investigations were done by changing the fin-width ratio (b/D), fin inclination angle (β), pile length-to-diameter ratio (L/D), and soil density. Results indicate that there is a considerable increase in uplift capacity of the piles when using fins at the end of the piles. When fins were installed with effective width equal to the pile diameter and at an inclination angle (β) of 90° for sand, with relative density (Dr) of 50%, the improvement in uplift capacity reached 1.82, 3, and 6 times that of the normal pile with L/D stiffnesses of 15, 20, and 30, respectively. It was also found that fins should be installed with an optimum fin inclination angle (β) equal to or greater than 45° to achieve the beneficial effect. The existence of such fins at the lower part of the tested piles provided an ideal anchorage system because of the significant locking-up effect of the soils within the fins, resulting in increased uplift capacity.

W. Wang D, J. Wu B, and J. Wang X (2016), Their study based by load tests for bearing capacity and deformation behaviour of uplift piles and piles group with enlarged base. A comparison of two-pile interaction factors determined using their Finite Element analysis may go some way to explaining the source of the incongruity, for a loaded (free-headed) 49-pile group, the discussers observed 15% difference in the centre pile settlement when the distance to the lateral boundary was increased from 13 m to 30 m.

Kranthikumar, A., Sawant, V. A., and Shukla, S. K. (2016), Numerical modelling of granular anchor pile system in loose sandy soil subjected to uplift loading. It is observed that the increase in depth of dense layer or loose layer at the top increases or decreases the axial uplift capacity significantly.

Azzam, W. R. and Basha, A. (2017), They worked out on shear strength and settlement in cohesive soil. Shear strength is inversely proportional to settlement of cohesive soil. The skin friction increased with depth for shallow depth range. The higher value was associated with relatively deeper piles.

Pelecanos, L., Soga, K. (2018), They analysed of fibreoptic strain data using finite element analysis and optimisation by development of axial load. provides detailed information about the axial pile strains along the entire length of a pile. The load-transfer analysis method is a practical approach for analysing the deformation behaviour of foundation piles where the soil is modelled with a series of springs following a nonlinear response according to load-transfer curves. Distributed fibre optic sensing following the Brillouin Optical Time-Domain. The Analysis and methodology of direct integration and differentiation provide the corresponding values for vertical displacements and shaft friction which can therefore be used to develop relevant load-transfer curves.

W. R. Azzam and A. M. Basha (2018), They carried out experimental and numerical study of Utilization of micro-piles by improving the sub-grade. the effect of the groundwater level rising on the soil pile interaction under uplift load. A series of model test for piles embedded in partially submerged sand along pile depth under pull out loads were carried out. A rigid steel cylindrical cell measuring 315 mm inside diameter with 850 mm high was used as a sand container. Investigations were done by varying parameters as the ratio between groundwater height to embedded pile length (hw/L), pile stiffness (L/D), installation method and sand density. Results showed that there is a considerable decrease in the uplift capacity of the piles due to increase in the groundwater level. It has been found that the variation of the submerged pile length ratio from 0 % to 100 % leads to decrease in the uplift capacity as much as 60% of its initial value in dry condition. Peak side resistance in uplift was also approximately equal to that in compression, although the distribution was different.

IV. SUMMARY

Pile Foundations - A shallow foundation is usually provided when the soil at a shallow depth is up to the significant depth has adequate capacity to support the load of the superstructure. However, where the top soil is either soft or of swelling type or loose, the depth of foundation has to be increased till a suitable stratum is met in order to transmit the load safely. In such situations pile foundations are by choice. Piles are usually used in groups to provide foundations for structures.

Tension pile - Also known as anchor piles or uplift piles, are a type of pile foundation that is used to resist uplift forces that might otherwise cause it to be take out from the ground by the hydrostatic pressure. Hydrostatic pressure takes placed due to uplift force which caused overturning moments or seismic activity.

Pile Groups - Pile group response to uplift load depends on the configuration of the pile groups, spacing of piles, and number of piles in the group. The pile group efficiency increases with their spacing. It decreases with increase in the size and number of piles in the group. It's may be subjected to uplift loads or vertical compressive, horizontal loads or combination of vertical, horizontal and laterals loads.

Pile-Soil Interaction Phenomenon - Pile-soil interaction problem is very complicated. It depends upon the pile material, end conditions, soil characteristics like consistency, its surface characteristics, length, diameter, soil-pile friction angle, compactness, consolidation, sensitivity, drainage conditions, dissipation of excess pore pressures, shear parameters, water table and type of loading. Extensive theoretical and experimental investigations are available on the behaviour of piles and pile groups. It subjected to axial loading, inclined loading or lateral and compressive loadings. They directly relate to load-displacement response, load carrying capacity of the piles/pile groups, and buckling etc. Consequently, the design and analysis of piles under these loading conditions can be done with greater assurance and economy under nom1al operating conditions.

Pile Foundations Under Loads (Vertical, Lateral and Uplift) - Foundations of some structures like mooring systems for ocean surface or submerged platforms, tall chimneys, transmission towers, jetty structures are subjected to uplift loads. Grillage footings, rock anchors, concrete steel cased piles, and concrete cylindrical piles arc extensively used in such cases depending on in-situ conditions. Cased or uncased cylindrical piles arc generally used where caving. high water table or other causes make it difficult and costly for constructing other types of foundations. Large inclined uplift loads act on the foundations of retaining walls, anchors for bulkheads. Abutments of bridge. piers, anchorage for guyed structures and Offshore structures, which are generally supported on piles. However, when the foundation is required to carry large inclined loads, inclined or batter piles along with vertical piles are used.

The design of pile foundation under compressive load is, in general based on the requirements that complete collapse of the pile group or of the supporting structure should not occur under the most adverse conditions and that the displacements at working loads should not be so excessive so as to impair the proper functioning of the foundation or damage the superstructure. The allowable displacements depend on the importance of the structure and the practice followed in the particular country or their Professional Societies or Institutions. Thus, for structures in which displacements may not be critical, the design is governed by the ultimate resistance of the pile or pile groups and the allowable load is often determined by applying a suitable factor of safety to the computed load.

The limiting frictional approach is the universal approach followed to evaluate the uplift resistance of piles, which is practically similar to the analysis of piles to compressive loads. The analysis is based on the formation of the failure surface under the action of uplift load or empirical correlations based on the experimental investigations. The uplift capacity theories of piles have been mostly extended from the analysis of horizontal plate anchors under uplift load and development of failure surfaces starting from the edges of the anchor. Pile is considered as a cylindrical shaft and the failure surfaces may be similar to those developed for the anchors. Different failure surfaces assumed/considered for the horizontal plate anchors and the equations developed to predict the uplift capacity of the plate anchors by many scientists are reviewed and presented by (Dickit1 and Leung, 1990; Ramesh Babu, 1998). The analysis and theories pertaining to horizontal plate anchors have not been described/discussed here to restrict the scope of the present review to piles only.

Determination of safe load by the following types of loadings:

a) Vertical load test (compression),
b) Lateral load test, and
c) Pull-out test.

Earth Pressure Coefficient - Ireland (1957) suggests that average skin friction along the pile shaft as same for downward and uplift loading. Sowa (1957) and Downs and Chiurzzi (1966) indicate variation in skin friction indicating reduction for uplift load. Reduction of 2/3 for uplift load compared to compressive load. Begemann (1965) suggests reduction for average skin friction. Meyerhof and Adams (1968) recommends uplift coefficient between 0.7 to 1.0. Yesic (1970) finds skin friction same in tension and compression. Awad and Ayoub (1976) gives 0.33 for cast in situ piles and 0.25 for other pile. Ismail and Klym (1979) recommends same value of uplift coefficient in tension and compression Kulhawy, Kozera and Withiam (1979) Finds K, = Ka and K, = (Kp) = 112. Ismael and Al-Sanand (1986) finds K = 1.05.

Unit Skin Friction - Unit skin friction along the depth of the pile varies approximately linearly up to a critical embedment depth and beyond it the skin friction remains roughly constant. The critical embedment depth is a function of relative density of sand and it lies between 10- 30 times the diameter of pile (Das and Seeley, 1975; Chaudhuri and Symons, 1983; Das, 1983).

Chattopadhyay and Pise (1986) have also noted the presence of critical depth from their study. They found that it depends on length/diameter ratio, L/ d, ¢ and ᵟ. It is more rational as it considers the shear and soil-pile friction angles and slenderness ratio.

Length and Diameter - The depth of embedment has significant influence as it is directly related to the surface area of the pile. Longer piles are more resistant than shorter piles. As expected, the larger diameter increases the surface area and so the resistance offered by them. Enlarged base piles have larger uplift capacity and it depends on the enlarged base diameter/shaft diameter ratio. Open-ended and closed-ended piles behave differently. The axial displacement associated with failure is also a function of the above parameters.

Pile Surface Characteristics - The surface characteristics are reflected by the soil-pile friction angle. Therefore, the soil-pile friction angle has significant influence on the behaviour of piles under uplift load. With increase in value, the resistance increases i.e. rough piles gives higher resistance. However, the analysis and investigation by Meyerhof and Adams (1968) conclude that for any value of ¢ and 0 = 2/3¢, the uplift coefficient Ku is relatively constant. Almost all the investigators found that soil-pile friction angle is a very important parameter. Similarly, the adhesion coefficient between pile surface and cohesive soil has significant influence.

Shear Strength Parameters - Shear strength parameters have significant influence on the pull-out resistance of piles. The adhesion factor a on which the uplift capacity of pile depends is influenced by the type of clay, its consistency, moisture content etc. along with the method of installation and type of loading. In general, it is the function of untrained cohesion and it decreases with increase in strength and stabilises at higher values of cohesion from about 1.0 to 0.45 (Sowa, 1970). There are very limited studies available in cohesive soils.

The angle of shearing resistance ¢ has significant influence. In general, higher the value of¢; more is the uplift resistance. Also 6 is inter-related to ¢ for piles.

Relative Density or the unit weight of soil and angle of shearing resistance of soil are functions of relative density. Higher the relative density of the soil, ultimate resistance is more.

Additional Factors - Method of installation of piles is a very important factor. The driven piles, their modes of driving influence the capacity (Vcsic, 1970: McClelland, I 'J74; A wad and Ayoub, 1976; Levac her and Sicffcrt, 1984; Alawneh, Malkawi and AI-Dccky, I999) These piles offer more resistance. The loading history, method of application of load from the top or bottom (Turner and Kulhawy, 1990; Joshi and Achari, 1992; Sharma and Soneja, 1987; Das and Pise, 2003) influence the chaviour.

The enlargement of the base of the pile significantly increases the resistance.

Pile head movement of roughly 5 to 15% of pile diameter is generally required to develop the ultimate resistance for straight shafted piles.

V. SCOPE OF FURTHER RESEARCH

- Piles and pile groups under different conditions of loading.
- A study on tension pile for different angle.
- Studies on instrumented piles for load transfer mechanism.
- Mechanism of failures including failure surfaces and modes of failure
- Parametric study on the coefficient of earth pressure and adhesion factor.
- Effect of grain size distribution of soils and size effects of piles and pile groups.
- Studies on Micro-piles for improving the sub-grade.

VI. CONCLUDING REMARKS

- The ultimate uplift capacity and also the efficiency of a pile group depends on the embedment length to diameter ratio, pile group configuration, soil-pile friction angle, spacing of piles in a group, and angle of shearing resistance of soil.
- The enhancement of the tension bearing capacity gets more obvious for higher cohesion strength of the soil.
- Inclined piles should not be used due to the large induced bending moments when the soil is expected to settle.
- The pile-soil interfacial behaviour is a key issue for efficiently evaluating the bearing capacity of tension piles installed in various sediments in the field.
- The enhancement of the tension bearing capacity gets more obvious when the cohesion strength of sediment gets higher.
- Interfacial shear degradation effects are investigated to reveal the mechanism of the "critical embedded length" phenomenon, which was previously noticed in the engineering applications.
- The distributions of interfacial sliding displacement and the shear stress along the pile depth indicate that, the degradation of shear stress occurs firstly at the pile-top and then spreads to the pile-bottom due to the breakage of the bonding mechanism; meanwhile, the interfacial shear stress is always mobilized only within certain part along the whole pile, especially for a long tension pile.

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