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THE BEHAVIOR OF A PILE FOUNDATION IN UNSATURATED SOILS: A REVIEW

Ankita Panariya[1], Dr Anil Kumar Saxena[2]
Research Scholar, Department of Civil Engineering, LNCT Bhopal
Professor, Department of Civil Engineering, LNCT Bhopal

ABSTRACT

For both saturated and unsaturated soils, pile foundations are commonly employed. Such foundations are exposed to combined vertical and lateral stress in some instances. In unsaturated soils, saturated soil mechanics concepts are commonly applied in the construction of pile foundations. Unsaturated soils are a three-phase substance with three interfaces: solids, liquids, and gaseous. As a result of disregarding the impact of matric suction, such techniques lead to incorrect estimations of pile behaviour. On unstable soil, pile foundations are often employed for a variety of constructions. The importance of seismic design in ensuring the effective operation of a structure under severe seismic loading conditions cannot be overstated. For the study of seismic forces on a structure, IS: 1893 is employed. The influence of pile stiffness on the structure's seismic response will be investigated. The rigidity of the piling foundation might have an impact on the structure. With the rise in seismic activity, there may be a need for more efficient pile foundation design to withstand earthquake load and damage. In this overview, the basis of piles and the functions of piles are discussed. The research also covers and displays the reinforcing information for each pile and pile group.

Keywords— Pile Foundation, Structure, Stiffness, zone, Load Estimation, Pattern of Pile, Earthquake, Seismic activities

INTRODUCTION

In soft soils, deep foundations are essential for structure design. By transmitting the construction weight to a firmer deeper soil layer, they allow structures to be erected on weak or unpredictable soils. Drilled shafts, driven piles and caissons are all examples of deep foundations. The kind of foundation chosen is influenced by factors such as soil, groundwater table level, and estimated loads. The strength and stiffness of soils are governed by the effective stress levels. The effective stresses in the soil layer might alter depending on the degree of water saturation, resulting in varied soil behaviour. The variation in the degree of saturation of the site must be carefully investigated and monitored since it has the potential to alter the deep foundation response to loads and the pile-soil interaction. [1][2]

Numerous earthquakes across the world have caused extensive damage to pile-supported bridges as well as other infrastructure in zones of liquefaction and lateral spreading. In recent years, research studies, physical model testing, and mathematical studies have yielded many valuable lessons & insights, but several concerns remain about the underlying principles of soil-pile interaction in liquefied soil and their consequences on superstructure performance. Understanding such mechanisms and comparing the capabilities of new analysis tools to physical facts (case histories and model studies) are critical first stages in establishing safe and cost-effective design procedures.

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Figure 1 depicts different methods of damage to pile foundations in scenarios with and without lateral spreading. Both inertial and kinematic loading must be taken into account, with the best load combination changing as liquefaction progresses during shaking. Throughout a loading cycle, kinematic loading will change depending on the extent of ground deformations as well as the strength/stiffness of the soil. Depending on the degree of transitory ground movements (lurching) during the lateral spreading phase, peak groundq deformations might occur at or towards the conclusion of shaking. [3] Estimating the proper mix of kinematic and inertial stresses requires considerable judgement, and the controlling case for the substructure and superstructure may differ. [4]

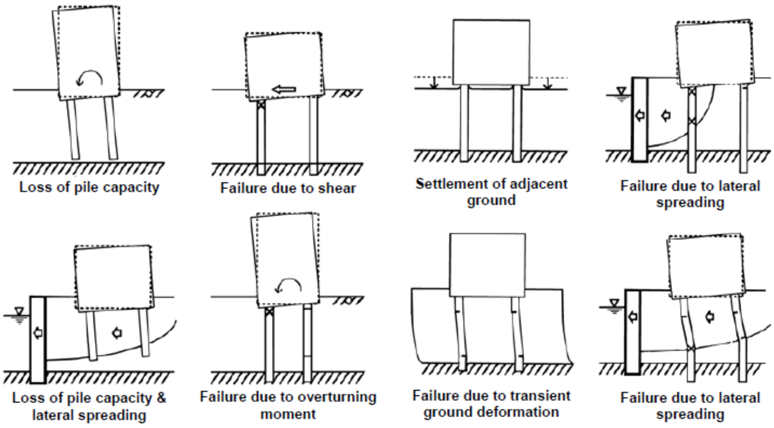

Figure 1: Schematics of pile damage mechanisms

Pile Foundations

Pile foundations seem to be the parts of a structure that transport and transfer the structure's weight to the bearing ground, which is located below ground level. The pile cap & piles are the foundation's most important components. Piles are high, thin elements that carry the weight to deeper, higher-bearing soil or rock, minimizing shallow, low-bearing soil. Wood, steel, and concrete are the most common materials used for piling. These materials are used to construct piles that are pushed, drilled, or jacked into the earth and then attached to pile caps. The pile material as well as load-transmitting characteristics of piles are categorised based on the kind of soil. [5]

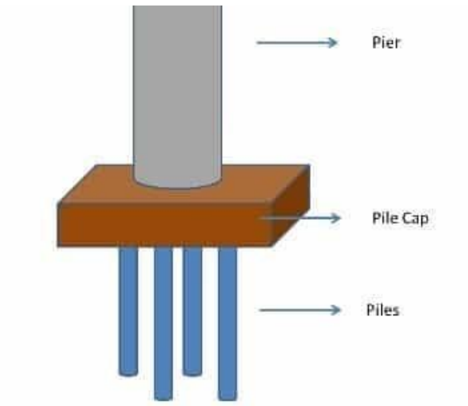

Figure 2: Pile Foundation

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Functions of Piles

The goal of a pile foundation, like those of other types of foundations, is to:

- convey a foundation load to solid ground
- resist vertical, lateral, and uplift load

If the soil directly beneath a structure's base lacks sufficient bearing capability, it can be built on piles. A pile foundation may be considered if the findings of the site research reveal that the shallow soil is unstable and weak, or if the size of the predicted settlement is unacceptable. Furthermore, a cost assessment may show that a pile foundation is less expensive than any other ground improvement option. In the event of massive structures, the shallow soil's carrying capacity is unlikely to be sufficient, and the structure should be placed on piling foundations. Piles can also be utilised to withstand horizontal loads under typical ground conditions. For works over water, like jetties or bridge piers, piles are a suitable kind of foundation. [6]

Piles in Unsaturated Soils

Unsaturated soil mechanics extends this focus to three-phase sands, silts, and clays. Solid, liquid, and gas are the bulk phases in unsaturated soils (Figure). These three bulk phases also have three interfaces: solid-liquid, solid-gas, and liquid-gas. The bulk phases, interfaces, and interactions among the distinct bulk phases and interfaces determine the mechanical behaviour of unsaturated soil. The liquid-gas interface, also known as the contractile skin, is the most important of the three interfaces in the mechanical and flow characteristics of unsaturated soil. The contractile skin maintains the dynamic balance between the water and air phases. The quantity of water in the soil, as well as numerous other factors such as particle size distribution, grain shape, and surface roughness, influences the contractile skin's features.

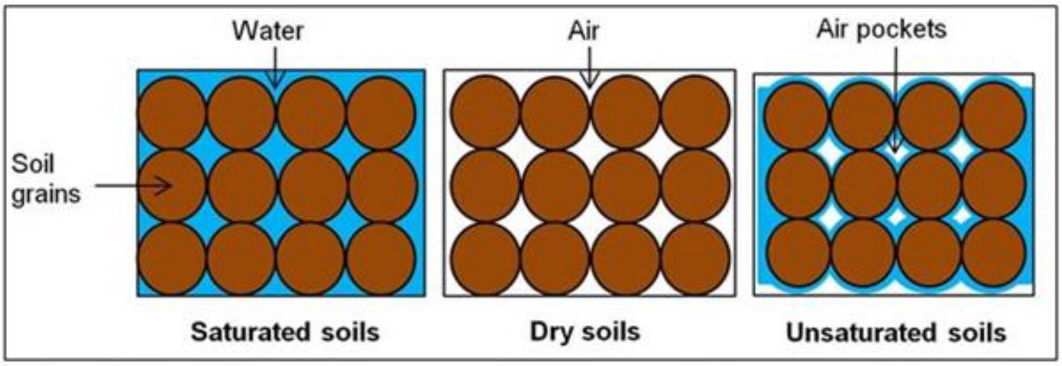

Figure 3: Illustration of microstructure for fully saturated, dry and unsaturated soils.

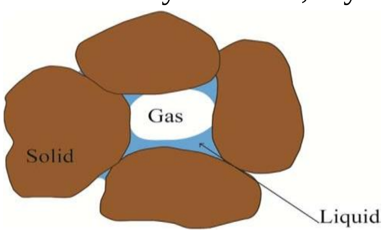

Figure 4: The Bulk Phases of Unsaturated Soils

For piles in unsaturated soils, there is currently no unique design technique. When modelling soil structure interaction issues, geotechnical engineers commonly believe that using wet soil is conservative. When lateral piles are designed using saturated soil values, the displacements at a given weight are higher than when using unsaturated soil properties. This is not conservative if the actual lateral foundation reaction is substantially stiffer than calculations predict, resulting in piling and structural performance issues.

Failure to account for unsaturated soils can result in a variety of issues, including slope and foundation collapses. Extreme swelling or expansion can occur in some soils as the liquid-to-gas ratios alter as a result of wetness or drying. When other soils are moist, their shear strength decreases, and when they dry, their shear strength increases. If unsaturated soil mechanics to be included in engineering design, the climate is a key component to consider.

LITERATURE REVIEW

(Cheng & Vanapalli, 2021) [1] In both saturated and unsaturated soils, pile foundations are commonly employed. Such foundations are exposed to combined vertical and lateral stress in some instances. In unsaturated soils, saturated soil mechanics concepts are commonly applied in the construction of pile foundations. As a result of disregarding the impact of matric suction, such techniques lead to incorrect estimations of pile behaviour. This is accomplished using a function created specifically for the ABAQUS programme. The suggested numerical technique predicted the vertical load-displacement behaviour of a published model pile tested in saturated and unsaturated sands with high accuracy. In addition, 3D finite element analysis was used to evaluate the impact of changes in the "ground water table (GWT)" on vertical bearing capacity as well as the impact of vertical loads on pile lateral reaction. The suggested numerical approach is a potential tool for incorporating current knowledge of unsaturated soil mechanics into traditional engineering practise.

(Naeini & Mortezaee, 2021) [2] The final bearing capacity of a pile installed in the soil is affected by a number of elements, including the technique of installation, pile type, pile material, and pile form; among these, the method of installation is particularly important. Physical modelling is one of the most effective methods for studying pile behaviour in the laboratory. As a result, the current research first introduces and evaluates the "frustum confining vessel (FCV)" as a useful tool for deep foundation physical modelling. The influence of end conditions and installation technique on the ultimate bearing capacity of the pile is next explored by explaining the loading tests of two open-ended and closed-end steel piles, each of which was done in two methods, "with displacement" and "without displacement". The soil employed in this study is Firuzkuh silty sand from Iran. The findings of the trials demonstrate that the without displacement installation technique has a greater bearing capacity in both piles in general, while the closed ended pile has a marginally greater bearing capacity in a specific manner of installation.

(Xing et al., 2021) [3] A series of indoor 1 g model experiments were carried out with self-made loading equipment to investigate the pile-soil interaction response in saturated sand under long-term horizontal cyclic loading. The self-made loading mechanism and test software are initially introduced in this publication. The rotation angle, the mono-pile horizontal cyclic stiffness, the cyclic p-y curve, the pore water pressure, the soil settlement, and fractures around mono-pile are then thoroughly investigated. Furthermore, the cyclic p-y curve obtained by the test is often less than the p-y curve predicted from the API standard, and during cyclic loading, the soil near the mono-pile will settle with annular fractures.

(Kwon & Yoo, 2020) [4] Due to the creation of extra pore pressure produced by cyclic loading, the dynamic behaviour of structures in liquefiable sand is more difficult than that of dry sand. To avoid damage to the buildings, it is critical to precisely forecast the behaviour of the soil–pile structure during liquefaction. The dynamic soil–pile behaviour during liquefaction was predicted using three-dimensional numerical modelling in this work. The Finn liquefaction model was used in conjunction with the Mohr-Coulomb elasto-plastic model to directly predict pore pressure development owing to soil shear deformation. Hysteretic damping was used to account for soil nonlinearity, as well as the interface model was used to mimic various dynamic events between the soil and the pile. To avoid reflection wave production and improve analysis efficiency, simplified continuum modelling was adopted. The experimental data were used to validate the applicability of the suggested numerical model. Then, to have a better understanding of the dynamic behaviour of pile foundations during liquefaction, a parametric analysis was carried out. Several critical parameters that might impact the dynamic pile reactions in liquefiable sand were found through a series of parametric investigations. In addition, the qualitative and quantitative aspects of the dynamic soil–pile structure interacting behaviour, which differ considerably in liquid and dry sand, were investigated.

(Kale & Student, 2020) [5] On unstable soil, pile foundations are often employed for a variety of constructions. The importance of seismic design in ensuring the effective operation of a structure under severe seismic loading conditions cannot be overstated. Selection of a specific form of building construction is part of the research. A comparison of buildings with and without pile foundations will be provided. Because of the differences in their properties, the seismic behaviour of the various structures differs. The influence of pile stiffness on the structure's seismic response will be investigated. The rigidity of the piling foundation might have an impact on the structure. With the rise in seismic activity, there may be a need for more efficient pile foundation design to withstand earthquake load and damage. The major goal of this study is to compare pile stiffness with changes in diameter and zone.

(Bandehzadeh et al., 2018) [6] Almost all structural piles are built above groundwater level, and these piles are in unsaturated soils. The mechanical behaviour of unsaturated soils is greatly influenced by the negative orifice water pressure induced by capillarity in this situation. As a result, structural suction is critical to a load's load-bearing capability. The Mohr-Coulomb, modified Cam-Clay, and Barcelona behavioural models were compared using the finite-difference approach in this study, and the results of investigations done to determine load-bearing capacity in the static state were presented. The behavioural model guidelines were identical to those used in the lab. The water-soil curve (showing suction patterns in proportion to moisture) was used to measure soil vividness on the suction level of concern. The numerical examination's overall settling tendencies are consistent with pile insert test findings. The Barcelona personality model (BBM), which considers the influence of unsaturated soil suction, appears to produce more realistic load capacity predictions.

(Bao, 2017) [7] Based on non-liner pseudo static analysis, the author analysed the lateral dynamic reaction of pile foundation in liquefiable soil in this study. The reliability of a modified model of dynamic p-y curves of pile foundation in liquefiable soil layer is also verified. Through a study of

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the influencing elements, modification technique, and mode of the new model construction of the p-y curve in liquefiable soil strata, the fundamental form of the main trunk circuit of the pile p-y curve is obtained, as well as the difference and connection with the p-y curve in API Code. Create a new computational model using the modified double-parameters technique. The new formula eliminates the problem of a quick rise in soil-pile interaction force within a modest deformation. This study uses a shaking table test to verify the new formula's dependability.

Necessity of Pile Foundation

The pile foundation is required to withstand uplift forces caused by rising water tables or other factors. In the building of transmission towers and off-shore platforms, uplift forces are more prevalent. Pile foundations will be required for these structures: [8][9][10]

- When the stratum directly under the ground surface is very compressible and incapable of bearing the load
- When a structure's layout is irregular in terms of its contour and load distribution. It would result in a non-homogeneous settlement.
- When horizontal forces must be resisted in addition to vertical loads
- When the soil layer directly under the structure is subjected to uplift and overturning moments, the structure is susceptible to scour.
- Where expansive soils, such as black cotton soil, occur and inflate or contract as the water content changes.
- A pile foundation is a preferable alternative in regions where settlement concerns are widespread owing to soil liquefaction or water table issues.
- Pile foundations are required in situations where there is a risk of soil erosion around the structure. The shallow foundations may not be able to withstand this.
- Near deep drainage and canal lines, a piling foundation is required. [11] [12]

CONCLUSION

The goal of this study was to learn more about pile foundation behaviour in unsaturated soils subjected to lateral stress. Although there is still a lot of work to be done to create deterministic equations, p-y curves, and mathematical modelling for laterally loaded piles in unsaturated soils, the findings from the centrifuge model as well as the FEM provided some conclusions and many suggestions for future research. This study is driven by issues such as novel uses of current technology, such as offshore wind projects, climate change, and environmental concerns. The relevance of this ongoing effort is evidenced by the excellent collaboration between business and academics in numerous JiP initiatives. However, many problems remain. As reliability engineering becomes increasingly prominent in geotechnical engineering practise, a thorough understanding of three phase soils might lead to useful design equations and models.

It is advised that the pile–soil interaction in a single pile be investigated and compared to that of piles bent under axial and lateral stresses. It will be critical to investigate the impact of a wide variety of critical design factors. This comparison will show design engineers the difference between a single pile and a group of piles in terms of pile–soil interaction.

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