Paper ID: CE 0201

Effect of Moisture on the Stress-Deflection Behavior of Laterally Loaded Group Piles

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Abstract

Group piles are commonly utilized in various structures, such as cross river and sea bridges, wharfs, ports, and marine platforms, to support axial and lateral loads. These pile groups exhibit high foundation bearing capacity, minimal settlement, and superior stability, while also reducing flow resistance and local scouring. Quantitative models play a crucial role in simulating larger-scale phenomena, but model uncertainty poses challenges when assessing the safety factor of structures subjected to significant lateral loads, such as earthquakes, squalls, and tsunamis. This study presents a small-scale prototype of laterally loaded group piles to evaluate their resistance to lateral loads under different moisture conditions. Specifically, a (2x2) configuration with a pile head was developed, and the piles were subjected to increasing lateral stresses until failure. The foundation soil had three distinct moisture content conditions, and the load-deflection properties were analyzed for each moisture state. The results indicate a non-linear relationship between load and deflection, with minimal bending observed under optimum moisture conditions and maximum deflection observed under saturated conditions. The deflection variations for different moisture contents, particularly at saturation, were found to be significant for lateral loads.

Keywords: *Lateral load; Sandy soil; Moisture condition; Group pile; Pile head.*

1 Introduction

Pile foundations play a crucial role in supporting axial and lateral loads for various structures, particularly in challenging environments such as marine platforms, wharfs, and cross river bridges. Among the different types of pile foundations, group piles have gained significant attention due to their enhanced bearing capacity, reduced settlement, and improved stability. However, the behavior of group piles under lateral loads, especially in the presence of moisture, remains a subject of investigation and interest for engineers and researchers.

Moisture content in the foundation soil has been recognized as a critical factor that can influence the performance and behavior of pile foundations. The presence of moisture, whether it be in the form of natural moisture content, optimum moisture content, or saturation, can have significant effects on the stress-deflection relationship of laterally loaded group piles. Understanding these effects is vital for accurate and reliable design and analysis of pile foundations in various engineering applications.

Maharaj and Gill (2018) investigated the ability of vertical and damaged piles to support lateral loads. They experimented with several arrangements of a collection of vertical, damaged heaps that were combined and unmixed. They discovered that resistance was higher in pile groups with negative damaged heaps. But the amount of soil moisture was not taken into consideration as a factor. In order to investigate the impact of the installation procedure of piles on lateral soil resistance, Huang et al. (2001) conducted a full-scale test on groups of drilled and driven precast piles. Because driven pile installation caused the earth to move laterally and become thicker, the study found that bored pile installation lowered group interaction whereas driven pile installation increased it. In homogenous sand, Meyerhof and Ranjan (1972) performed model experiments on stiff single piles and pile groups under centrally inclined loads and created a semi-empirical interaction relationship based on the assumption that the ultimate capacity varied elliptically under axial and lateral pressures. According to Meyerhof et al. (1981), the ultimate resistance of a pile per unit width is higher than the ultimate resistance of a wall in uniform sand. The pile/pile group was evaluated at full size in varied soil conditions by Ruesta and Townsend (1997). They both arrived to the same conclusion, which was that the group interaction effect, which increases with higher deflection and decreases with increased center-to-center spacing, caused the average soil resistance per pile to decrease in pile groups. The average load per pile for the group is also lower than for a single isolated pile at the same deflection.

Reviewing past and present studies on laterally loaded piles reveals a lack of systematic research on the qualitative and quantitative effects of variables like moisture content, length to diameter ratio, configuration of the group of piles, number of piles, spacing, and pile friction angle on the final lateral resistance.

In this paper, we present a study that focuses on investigating the effect of moisture on the stress-deflection behavior of laterally loaded group piles. The study aims to contribute to the existing body of knowledge by providing insights into the behavior and performance of group piles under varying moisture conditions. This knowledge will assist engineers and researchers in making informed decisions during the design and construction stages of pile foundations, ensuring their structural integrity and stability.

To accomplish the research objective, a small-scale prototype of laterally loaded group piles was developed in a laboratory setting. The experimental setup followed recommended procedures from previous studies and incorporated specific moisture conditions: field condition, optimum moisture content (OMC), and saturated condition. The load-deflection properties of the group piles were systematically investigated under each moisture state.

The subsequent sections of this paper will present a detailed description of the experimental setup, sample preparation techniques, loading arrangements, and data collection methods. Additionally, the collected data will be analyzed and interpreted to understand the moisture-dependent behavior of the group piles under lateral loads.

The findings of this study will shed light on the influence of moisture on the stress-deflection behavior of laterally loaded group piles. The conclusions drawn from this research will have implications for the design and analysis of pile foundations, providing valuable insights for engineers working on projects involving lateral loading in diverse environmental conditions.

Ultimately, by comprehending the effects of moisture on the behavior of group piles, engineers will be better equipped to design and construct pile foundations that ensure the long-term stability and performance of various structures, particularly in challenging geotechnical and marine environments

2 Experimental Setup

The static lateral load tests conducted on piles followed the procedure recommended by Reddy and Ayothiraman (2015) with guidance from the work of Sazzad et al. (2018), Sazzad et al. (2019) and Sazzad et al. (2022) for this experimental setup. The following sections provide a detailed description of the experimental setup, including sample preparation, loading arrangements, and data collection.

2.1 Sample Preparation

In this small-scale model, cohesionless granular soil was used. Standard non-cohesive sand from the northern region was retrieved to ensure consistency. The sand was filled in a concrete box with dimensions of length, width, and height equal to 72 cm. The sand was placed in layers, ensuring that each layer received the same amount of soil and the same number of blows to maintain uniform density. The moisture content of the soil was adjusted based on different conditions. For the moist condition, no additional water was added, as the field moisture content was 4.3%. To achieve the optimum moisture condition of 12.47%, 8.17% moisture was added to each layer, equivalent to 11.85 liters of water. The soil layers were compacted using the same number of blows. To prepare the samples for the saturated condition, the concrete box was flooded with water until the sand was fully saturated.

2.2 Loading Arrangements

The loading arrangements involved the use of a pulley system, as depicted in Figure 1. A pulley with a concrete block as a base and a counterweight was constructed. A small, properly frictionless bearing was used to secure the wire applying tension. A hook stand was hung on one end, and the other end of the wire was tied to the pile for single piles or to the pile cap for group action.

Lateral load was incrementally added to the hook stand, which, in turn, applied the lateral load to the pile. This loading procedure was repeated until the pile failed or a specified maximum deflection value of 10 mm was reached. Load blocks weighing 4 kg and 8 kg were used to apply the lateral load.

2.3 Data Collection

For data collection, a deflection gauge with an accuracy of 0.01 mm was employed to measure the deflection values corresponding to the incremented lateral loadings. The initial reading on the dial gauges was recorded before applying the load. Additional dead weights were incorporated into the loading setup (as shown in Figure1) to deliver the static lateral stress in increments. The horizontal deflection of the pile head and pile group head was measured at several points after each loading increment. Simultaneous loading and data collection were continued until the piles failed or exhibited significant displacement.

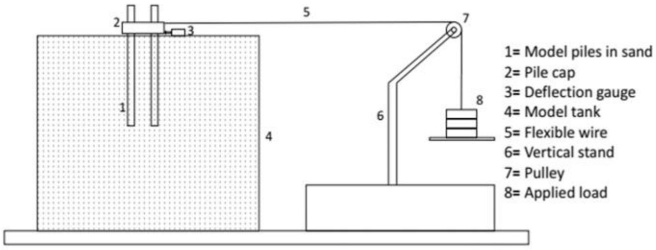

Figure 1. Side view of the experimental setup for group pile.

To ensure proper spacing between the locations of embedment, the locations where a pile was embedded were marked by embedding small-diameter pipes. This marking process helped eliminate disturbance and maintain proper spacing between the embedment locations. The dial gauge was kept stationary with the help of additional loads to obtain precise deflection values and ensure the gauge remained stationary during data collection.

Table 1. Data table for group of piles (L/D = 10)

Load (kg)	Load (N)	Deflection (0.01 mm)		
		Field condition	OMC condition	Saturated condition
0	0	0	0	0
0.718	7.0364	0	0	4
8.718	85.4364	4	3	15
16.718	163.8364	11	8	26
24.718	242.2364	22	15	45
32.718	320.6364	32	22	56
40.718	399.0364	40	30	68
48.718	477.4364	51	39	89
56.718	555.8364	76	50	111
64.718	634.2364	87	61	144
72.718	712.6364	106	79	185
80.718	791.0364	141	104	221
88.718	869.4364	169	138	250
96.718	947.8364	205	178	293

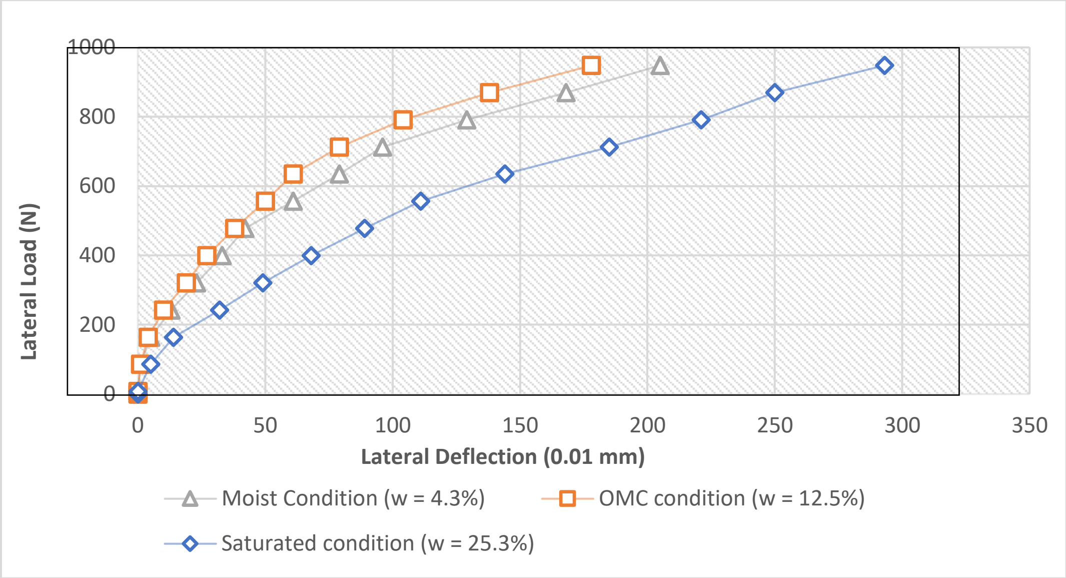

Figure 2. Graphical representation of lateral deflection for group of piles (L/D = 10)

3 Result and Discussion

We can analyze the relationship between load and deflection for different moisture conditions: field condition, OMC condition, and saturated condition. Here are the key points:

3.1 Load vs. Deflection Relationship:
From Figure 2, if we observe the curve for moist condition, it is clear that the deflection values increase with increasing load. Observing the OMC condition, we can say, the deflection values also increase with increasing load, but the relationship appears to be less linear compared to the field condition.
In the saturated condition, the deflection values tend to increase more rapidly with increasing load, indicating a higher susceptibility to deformation.

3.2 Comparisons between Moisture Conditions:
Comparing the deflection values for the same load from Figure 2, a difference can be seen between moisture conditions.
The deflection values are higher in the saturated condition, followed by the OMC condition, and the field condition shows the lowest deflection values.

3.3 Deflection Behavior:
In Figure 2 the deflection curves demonstrate exponential behavior, especially when saturated.
The slope of the deflection curves changes noticeably at different load levels, suggesting varied stiffness and deformation properties.

3.4 Optimum Moisture Condition:
The optimum moisture condition was depicted at 12.5%, which in turn gave the biggest resistance to deflection.

Overall, the results indicate that moisture content has a considerable impact on the stress-deflection behavior of the laterally loaded group piles. Higher deflections and an exponential response are observed in the saturated state, suggesting less pile stiffness and increased susceptibility to deformation. The moist condition has smaller deflections, indicating improved load-bearing capacity.

4 Conclusion and Recommendations

4.1 Conclusion:
Based on the analysis of the data for the group of piles (L/D = 10) under different moisture conditions, the following conclusions can be drawn:

- Moisture Content Effect: Moisture content significantly influences the stress-deflection behavior of laterally loaded group piles. The saturated condition exhibits higher deflections and an exponential response compared to the field condition and OMC condition.

- Optimum Moisture Condition: At OMC the deflection of pile head was minimum, suggesting better load-bearing capacity compared to the other moisture conditions.

- Load-Deflection Relationship: The deflection behavior is nonlinear, and notable changes in slope can be observed at different load levels for all three moisture contents.

4.2 Recommendations:

Based on the findings of the study, the following recommendations can be made:

- Moisture Control: Proper moisture control during pile installation and foundation construction is crucial. Maintaining moisture content within the optimum range can help minimize deflections and improve the load-bearing capacity of group piles.

- Moist Condition Consideration: The moist condition, representing the natural moisture content of the soil, tends to exhibit relatively lower deflections. Therefore, when designing pile foundations, it is advisable to consider the natural moisture conditions of the site to achieve better load-bearing performance.

- Further Research: Conducting additional research with a larger dataset and considering other parameters such as pile spacing, soil properties, and group size would provide a more comprehensive understanding of the stress-deflection behavior of laterally loaded group piles. Statistical analyses and comparative studies with different pile configurations would also be valuable.

- Field Validation: Field validation tests can be performed to verify the findings from small-scale model experiments. This would provide real-world data and further validate the conclusions drawn from laboratory experiments.

By implementing these recommendations, engineers and researchers can enhance the design and performance of laterally loaded group piles, leading to more reliable and efficient pile foundations in various construction projects**.**

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