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Lateral Load Analysis of Piled Raft Foundation: A Review

Mohammad Ilyas Siddiqi[1,*], Irfan Jamil[1], Muhammad Atif Hussain[1], Samiullah[1]
[1]Corresponding Author, Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan,
*Corresponding author: 16pwciv4685@uetpeshawar.edu.pk

ABSTRACT

Piled raft foundation (PRF) has become the most popular system to be used in high rise buildings and other structures where a high vertical and lateral load capacity is required. The response of PRF to horizontal and vertical load is different, and factors such as pile length, diameter, spacing, raft thickness, and the presence of vertical load can affect its lateral behaviour. This paper reviews recent researches from the past two decades that focuses on these factors. The primary objective is to provide a summary of recent research, highlight both experimental and numerical methods conducted for lateral load analysis of PRF. It was found that the vertical load greatly affects the lateral capacity of PRF, lateral deflection decreases with increasing of vertical load. by increasing the number of piles results in a decrease in soil stiffness, leading to higher loads on the front piles compared to the rear piles, and reduces the contribution of the raft to lateral loads. By neglecting the lateral resistance of the raft portion leads to an underestimation of the total resistance and overestimation of the shear force, and lateral displacements of piles. With same configuration the lateral resistance of a PRF is about 2.5 to 6 times greater than that of pile group foundation. Moreover, the piles arranged in a series configuration exhibited greater resistance to lateral loads compared to those arranged in a parallel configuration.

KEYWORDS: Piled raft, Lateral load, Sandy soil, Strain gauges

1. INTRODUCTION

PRF is the combination of two types of foundation i.e., i) piled foundation & ii) Raft foundation, creating a single integrated system. This type of foundation is more suitable for those buildings where demand of lateral load is high due to earthquake or wind, or where the soil beneath the structure is expansive. In PRF The pile is used as settlement reducers, while the raft distributes the load over a larger area to decrease the bearing pressure on the soil. PRF are favoured for their ability to minimize total and differential settlements while enhancing the load-bearing capacity of shallow foundations. In addition to high-rise structures, piles and PRF are increasingly utilized in Bridges, marine and offshore structures such as wind turbines and oil plat forms [1].

Piles must be designed to withstand not only compression and tension loads but also lateral loads. The lateral capacity of piles is influenced by soil properties. When subjected to lateral loads, piles act as transversely loaded beams, transferring the load to the surrounding soil through lateral soil resistance [2].

The main benefit of PRF over conventional foundation is that the load resistance capacity of raft which can resist 14 to 60 percent of total applied lateral load and 20 to 80 percent of total vertical load [3]. According to [4] the impact of vertical load on lateral response of PRF is not significant when both vertical and lateral loads are applied simultaneously.

The total lateral capacity of PRF is distributed between the piles and the raft through interface friction. So, the total lateral capacity of the PRF is the combined sum of the lateral capacity of the piles and the lateral capacity of the raft portion [5]. By increasing the pile spacing the influence of group interaction effects decreases [6].

There is a comparatively limited amount of research available for horizontal loads compared to vertical loading. Lateral load analysis is essential for piled raft foundations, as it enables us to find the foundation capacity to resist the lateral forces without any deformation or failure and addressing potential challenges associated with non-uniform settlement as the lateral load can impact the differential settlement. Lateral loads can induce bending moments and shear forces on piles, and without detailed lateral analysis, there is a high risk of tilting, sliding, and rotation of foundation.

This study concentrates on the key factors influencing the distribution of loads between piles and the raft in PRF systems. Its aim is to compile a comprehensive collection of previously published research findings from past investigations into one accessible resource. This compilation seeks to provide researchers and practitioners with convenient access to essential design parameters related to PRF.

2. LITERATURE REVIEW

To analyse the load distribution in pile group and PRF under lateral loading [7] conducted an experiential study. In this research they use hollow galvanized circular iron pipes having 16.7mm diameter as model piles and 25mm thick Aluminium plate with (1x1) ft as model raft, designed with holes for the purpose of connecting the piles. To establish a strong and stable connection between the raft and the piles nut and bolt system were utilize. A total 16 test has been conducted, 9 tests on PRF model and 7 tests on pile group model and the loads were measured through strain gauges installed on each pile. During the test behaviour of piles were noted against the displacement. As illustrated in figure1.

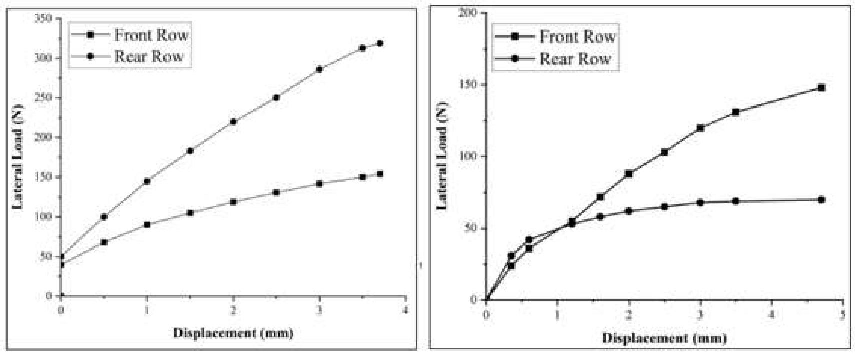

Figure 1: Load- Displacement graph for 4 Piled raft and pile group [7]

From this research they concluded that the rear piles taken more load than front piles in case of piled raft but in case of pile group front piles taken more load than Rear piles up to total pile number 9 but then it reverses with increasing the pile numbers due to decrease in raft contact pressure.

To compare PRF with Pile group foundation under combined loading an experimental study was conducted by [8]. Also, the response of both these models have been studied and comparison was conducted, which shows that the piled raft exhibits significantly higher stiffness in response to both load types when compared to the pile group. By increasing the number of piles stiffness of both the systems are decreases. The piled raft shows lower lateral deflection and vertical settlement compared to a pile group with identical pile configuration. This response to both vertical and lateral loads is due to the contribution of the raft in resisting these forces. Additionally, as the number of piles increased, the vertical and lateral resistance of raft were decreased.

An experimental and numerical analysis was carried out by [9] on PRF system under combined lateral and vertical loading in a two layered soil profile to find the lateral behaviour of PRF. strain gauges were installed on the pile shaft through epoxy resin for measuring bending moments and loads along the piles and then covered it by waterproof cover of silica gel.
Schematic diagram of this study is shown in figure 2.

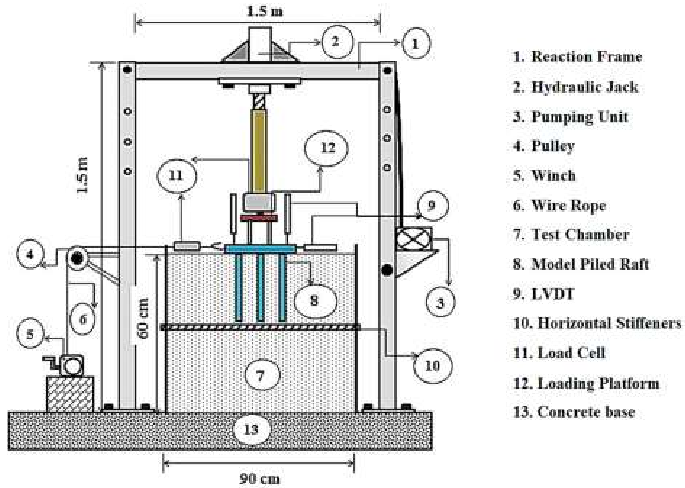

Figure 2: Schematic diagram of test

After conducting the series of experiments, they concluded that the vertical load greatly affects the lateral capacity of PRF system depend upon the soil profile i.e. Increase in vertical load enhances the lateral capacity of a PRF when the ratio of the silty clay layer to the length of the pile is between 0.5 and 1. However, as this ratio is increased, the lateral capacity reduces due to the failure of the pile-soil interface.

PRF system with fixed and rigid head connection was studied by [10]. They used finite element software for finding the load distribution among the pile and raft in PRF. To simulate sand sample, they use PLXIS-3D Standard library soil model. A square raft with 0.4m length and 0.4m width and 600mm hollow piles with 40mm diameter, were used as model raft and piles respectively. Results of this study shows that there is a little influence of rigid piled head connection on the settlement of combined PRF. but it significantly influences the load shearing mechanism between the pile and raft portion of combined PRF. By applying lateral load, it was noted that the lateral stiffness is a crucial factor that affect the settlement and lateral displacement of PRF.

Effect of pile spacing on the lateral load behaviour of PRF was studied by [11]. The pile configuration used in this study were single pile, 2 piles group, 4 piles group, 6 piles group and 9 piles group. The embedded length to dimeter ratio used were 32. Mobile pluviator has been used for sample preparation. He found that by increasing the spacing ratio (s/d) from 3-6 the ultimate load was increased with 53%. The efficiency of the piles decreased when number of piles were increased because of the stress zones formation. The value of s/d greater than 6d is enough to diminish the interaction effects in pile group foundation.

Effect of moment load and rotation on PRF was studied by [12]. They studied the effect of moment load and rotation on piled raft foundation by using centrifuge. Strain gauges were installed within the piles to measure axial strength and bending capacity along the pile length. Additionally, two

shear strain gauges were installed at outer surface of pile for measuring shear force capacity of the pile.
Based on these tests it was concluded that the vertical displacement caused by lateral load in PRF is different from displacement in piled group foundation. The lateral load carrying capacity of a pile within PRF is greater than that of a pile in a pile group configuration, and this is primarily due to the interaction between the raft and soil in PRF.

To find the influence of pile head connection on PRF under cyclic lateral load in dry sand [13] conducted experimental study. they used two connections i.e. rigid and flexible connection. A detail investigation was carried out to find the load shred between piles and raft, with emphasis on lateral stiffness and foundation rotation.
The key findings from this study are:

1. With same pile numbers PRF has greater lateral stiffness than pile group.
2. Piles within the piled raft experience lower bending moments compared to piles in pile group configuration.
3. For hinged connection the degree of rotation of the raft portion reduces compared to fixed connection.
4. In PRF the lateral load resistance is not affected by rigidity of piles head connection

[14] performed a lateral loading test at level of 1g on small scale model piled rafts to find the load distribution in PRF. A fixed head connection was established at the top of the piled raft during the experiment. The sand tests were divided, half test was conducted on loose sand and others on dense sand These tests involved subjecting the system to a lateral load of 1.2 KN, with varying constant loads. From results it is clear that, by increasing the vertical load, lateral deflection decreases. And for smaller vertical loads, front piles bear a higher lateral load, whereas for larger vertical loads, the rear piles carry a greater lateral load.

Series of tests were conducted by [15] on PRF and raft only, piles under lateral loading by using centrifuge at 50g. A uniform relative density of sand was maintained throughout all the tests by layering and compacting the sand consistently. effect of pile head connection was also studied during this test. Key findings of this study are:

1. Stiffness of isolated single pile increases from that of pile in the PRF.
2. Number of piles significantly influence lateral ultimate capacity of PRF.
3. The lateral resistance is greater in the case of rigid head connection compared to hinge connection in PRF and the total stiffness of piled raft is not increased only due to the raft portion.
4. Bending resistance of rear piles are greater than front piles.

3 CONCLUSIONS

Based on the above literature review, the distribution of lateral loads among piles and the raft in PRF is significantly influenced by vertical load and pile parameters.
By increasing the spacing-to-diameter ratio within the range of 3-5, results increased in the lateral capacity of PRF.

The raft provides a crucial role in enhancing the lateral capacity (Resist 14 to 60 percent of total applied lateral load and 20 to 80 percent of total vertical load) of PRF in comparison to a pile group foundation.
Number of piles and their configuration also affect the lateral load distribution among the piles and raft in PRF i.e. series configuration exhibited greater resistance to lateral loads compared to those arranged in a parallel configuration

4 RECOMMENDATIONS

- Further study is required to find the load sharing mechanism under varying vertical load.
- The factors outlined in this paper should be examined specifically in clayey soil conditions.
- Conducting large-scale tests to analyze the lateral load behavior of PRF is need to be studied.

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