Experimental Study of Comparison of Settlement Behavior of Pile Raft Foundation with Batter and Vertical Piles

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Abstract

Lateral forces on the high-rise buildings and infrastructures causes them to topple down. A simple deep foundation of vertical piles is not enough to full fill the design requirement for lateral forces on these structures. Pile raft foundation is found to be efficient in high rise buildings by reducing the settlement produce in the foundation and increasing its load carrying capacity but in some cases the pile raft foundation with vertical piles is unable to sustain the structure for the lateral load. Therefore, batter piles are used in pile raft foundation which has greater load carrying capacity in both vertical and horizontal direction. Batter piles with different angle with vertical are used to resist lateral load accordingly. This paper presents the experimental study of the comparison of the settlement and load carrying capacity of the pile raft foundation with vertical and batter piles, this study is divided into two parts, first part is experimental study of pile group foundation model having vertical and batter pile in which raft is not active to take load and in second part the pile raft foundation model having vertical and batter piles is studied in which the raft is active to take load. Vertical load is applied on all these foundation type separately and load settlement curves are plotted. It is concluded that pile raft foundation having batter piles has greater load carrying capacity and less settlement than that of pile raft foundation with vertical piles.

Keywords: Pile Raft foundation, Pile group foundation, settlement, batter piles.

1. BACKGROUND AND HISTORY:

Foundation is fundamental part of structure which carry and transfer load from super structure to bearing ground and is located at certain depth from ground surface. Structures ranges from simple residential building to sky scraper have foundation of its required type. On the bases of type (vertical, lateral, Earthquake, wind) and direction of loads on super structure and bearing ground properties foundation type for the structure changes. Shallow foundation is preferred for vertical load and stiff soil while deep foundation is preferred for lateral load and soft soil. Land availability issue in the world causes the shifting of construction industry to areas where soil is not suitable for shallow foundation, deep foundation is preferred in such soil type. Pile foundation is given to structure in soft soil which transfer load both by bearing and shearing. In some situation pile foundation alone does not fulfill the requirement of foundation for a structure, in this case pile and raft are used together to get the required sub structure. In Piled raft foundation load is transferred to soil both by raft and pile and interaction occurs among piles and between pile and raft. In case of earthquake, wind or any lateral load when it exceeds its limit raked piles are used in place of vertical piles or combination of both vertical and raked piles is used.

Piles and raft are used in two different arrangements to carry load, pile group and piled raft foundation. In pile group foundation raft act as pile cap and is not connected to bearing ground. All the load is carried by the piles only, this type of arrangement has small load carrying capacity while in case of piled raft foundation raft lie on the bearing ground. Load is carried by both raft and piles and has greater load carrying capacity than pile group foundation. Different analytical, numerical and experimental studies have been performed on the behavior of pile group and piled raft foundation under vertical and lateral loads and concluded various results which explain the behavior of pile group and piled raft under different loads and external conditions.

Anh-Tuan VU et al (2017) studied experimentally 3-pile and 6-pile batter pile foundation model both for pile group and piled raft arrangement under vertical and lateral load and concluded that introducing batter piles to the pile raft foundation have positive impact on its behavior by increasing its stiffness in both horizontal and vertical direction and reduced settlement caused by both vertical and horizontal loads. Pastsakorn Kitiyodom and Tatsunori Matsumoto (2002) developed numerical analysis method to study the deformation and load distribution in pile raft foundation having batter pile, also parametric studies were performed and concluded that batter pile helps in improving the deformation behavior of pile raft foundation. M. Hajialilue-Bonabb et al. studied the effect of inclination angle of batter piles and concluded that with increase in the inclination angle reduce rigid length of piles and hence causes more settlement during lateral forces. Mahmoud Ghazav et al. (2014) has also studied the performance of batter piles in offshore structures and concluded that the lateral loads efficiency of pile groups increases by introducing batter piles. Nan DENG et al. (2007) has studied attraction of seismic forces in terms of axial force by batter piles in pile group and found that during seismic waves, more axial forces are generated in batter piles rather than vertical piles and that's due to kinematic interaction between pile group and soil. Bharathi et al. (2019) stated that batter piles have less displacement as compared to vertical piles and their

reduction percentage remains up to 25%-50% probably. Z. Li et al. (2016) studied that, in past, Poor analytical, numerical approach and lack of knowledge about batter piles made them poor resistant to earthquakes. Poulos (2006) studied the effects of ground motion on raked piles by considering six-pile group and concluded that with the raking a pile in the absence of ground motion can reduce settlement, lateral deflection and cap rotation but in the presence of ground motion the result is affected adversely as compared to the group having only vertical piles. The ground motion will result in increase in pile load on raked piles such situation may face in case of bridge abutments.

This manuscript presents the experimental study of the settlement behavior and load carrying capacity of pile group and piled raft foundation having vertical and raked (batter) piles subjected to vertical load. Increasing vertical load is applied on the pile raft model placed in sandy soil which is instrumented with transducer and load cell to measure the settlement of the raft and applied load respectively. The load settlement curve of both pile group and piled raft foundation are compared to know their behavior.

2. METHODOLOGY:

2.1 Model preparation and Experimental Setup:

Aluminum plate of dimension 1’ x 1’ x 0.0196’ is used as raft because of its rigidity, high stiffness and transferring equal load to the piles when load is applied at the center of the raft. Four holes at offset of 2 inches from sides of raft are driven and copper piles of diameter 0.75” are attached to the raft through two pins. Piles angle with vertical can be changed from 0º to 40 º with 10 º degree increment. The raked piles used for this paper are inclined at 10º with vertical. The connection of piles and raft is rigid allowing zero moment when load is applied. Piles can be detached from the raft in case of experimental settlement study of only raft foundation. The model is placed in a clay sandy soil of known properties which is enclosed in a cubic box of size 3’ x 3’ x 3.5’ which gives fixed boundary condition to the sandy soil. In case of pile group model, the raft is about the soil surface while in case of piled raft model the raft lies on the surface of the soil. Figure 1 shows the small-scale model of pile group foundation placed in soil.

Figure 1: Small scale Pile Group Model

2.2 Instrumentation:

To find settlement of raft and piles, two Settlement Transducer are used each having settlement calculation capacity more than 50 mm. The transducers are installed at two opposite sides of the raft which gives different settlement values. Average of these two settlement values are taken for plotting load settlement curve. load cell is used to find the applied load on the model having capacity to measure up to 200kN of load. Data from transducers and load cell are recorded using UCAM 70 data logger. This data logger has 30 channels by which it can be connected to 30 different instruments at the same time and their data can be recorded. Figure 2 shows the instrumentation of transducer and load cell to the pile raft model.

Figure 2: Instrumentation of Pile Group Model

2.3 Load Assembly:

Loading strain frame having applying load capacity of 200kN is used to apply vertical load on the raft. Strain frame consists of a frame which support a hydraulic jack for load application. The position of frame and hydraulic jack can be changed horizontally and vertically respectively. Load cell sandwiched between loading jack and raft measure the load transferred to the raft. A dial gauge is set in the loading strain frame machine which shows the total load applied by the hydraulic jack. Figure 3 shows the loading strain frame set above the model for load application.

Figure 3: Loading strain frame

3. RESULTS AND DISCUSSION:

After experimental setup and instrumentation, continues vertical load is applied on 4 different type of models, two pile group models having vertical and batter piles and two pile raft model having vertical and batter pile inclined at 10^{o} with vertical. The settlements and load are recorded using UCAM 70 a 30 channel Data logger and transferred to a computer programmed for plotting the load settlement curve.

3.1 Pile Group foundation Model with Batter Piles:

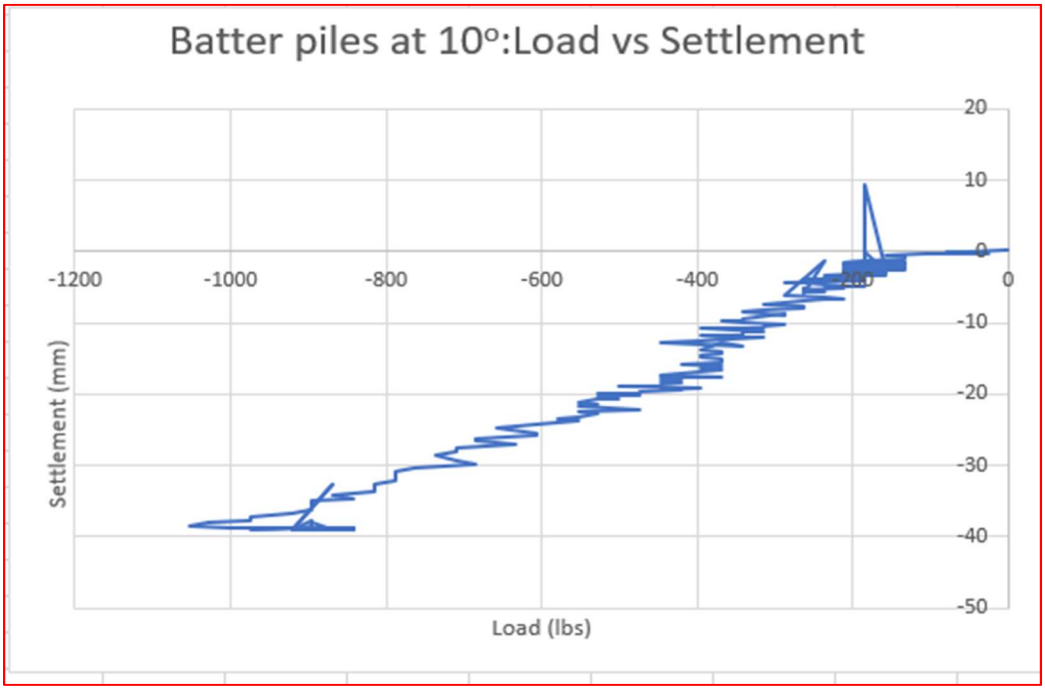

Figure 4: load settlement curve of batter pile group foundation model

Figure 4 shows the settlement behavior of pile group foundation model with batter piles at 10^0. It can be seen from the graph that by increasing the load on the model the settlement of the pile group increases. Also, at small value of load settlement produced in the pile group is greater. The irregularity and zigzag shape of the graph is due to the arrangement of the soil particles when load is applied to the model. Moreover, the negative sign of load shows that the load is applied in the downward direction on the model while the negative sign of the settlement is due to the arrangement of the Transducers. The transducers were fixed on the upper surface of the raft and its gauge is fixed at 60mm settlement. When load is applied on the raft, settlement gauge of transducer starts reducing from 60mm that's why the data recorded has negative sign.

3.2 Pile Raft Foundation Model with Batter Piles:

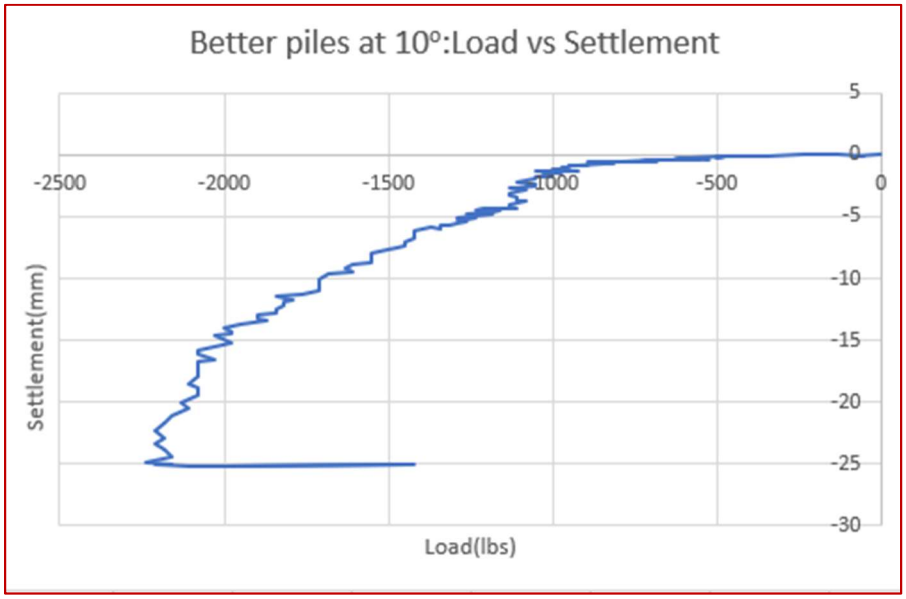

Figure 5: load settlement curve of pile raft foundation model having batter pile

Figure 5 shows the settlement behavior of piled raft model having better pile at 10^0 inclination with vertical under continuously increasing vertical load. settlement values increase with increasing load and at higher load values the values of settlement are smaller as compared to the pile group model. Also, the load carried by the piled raft model is greater than 2000lb with 25mm settlement. The graph shows that at high values of load the capacity of piles to take load is fully mobilized and only Raft is active for taking the load.

3.3 Pile Group Foundation Model with Vertical Pile:

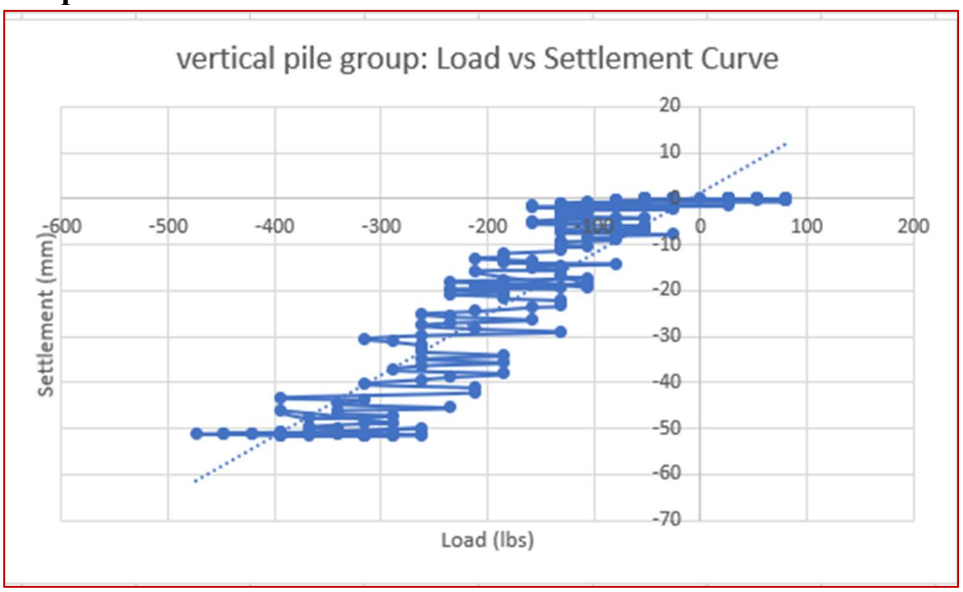

Figure 6: Load Settlement Curve of Vertical Pile group Foundation Model

Figure 6 shows the load verses settlement curve of the pile group foundation model having vertical piles. The trend line of the graph is having constantly increasing slope which shows increase in settlement with vertical load. The total load carried by the model is less than 500 lbs. which is less than that of load carried by pile group foundation with vertical piles. Also, there is more settlement in foundation model than that of the settlement in batter pile group foundation model.

3.4 Pile Raft Foundation Model with Vertical Pile:

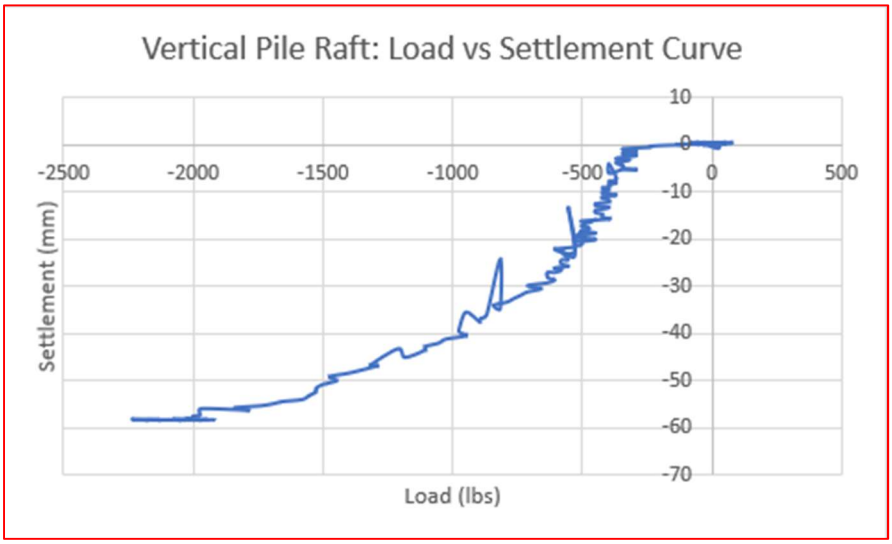

Figure 7: Load Settlement Curve of Vertical Pile Raft Foundation Model

Figure 7 shows the load vs settlement curve of the pile raft foundation having vertical piles and raft lies on the soil surface. The overall graph shows increase in settlement with load with some fluctuation due to the arrangement of the disturbed soil and load cell property i.e. load cell only give load value if the model show reaction to the applied load and in case of the soil particle arrangement the foundation settles without giving reaction to applied load, so the graph obtained is not smooth. The graph shows that the load carried by the model is less than that of the load carried by pile raft with batter piles and also the settlement is more in this case.

4. RESULT COMPARISON:

Table 1: Result Comparison of Pile Raft and pile group Foundation model

Foundation Type	Pile Group Foundation Model		Pile Raft foundation Model	
	Batter piles with 10^0 inclination	Vertical Piles	Batter piles with 10^0 inclination	Vertical Piles
Load carrying Capacity (lbs.)	921	473	2237	2237

Settlement (mm)	38.9	51.3	25	58.2

Table No 1 compares the load carrying capacity and settlement of the pile group and pile raft foundation having batter and vertical piles. In case of pile group foundation model, the load carried by the pile group having batter piles is greater than that of vertical piles group. Also, the settlement produced in batter pile group is less than that of vertical pile group. On the other hand, the pile raft foundation in both vertical and batter pile type carries the same load, but the settlement produce in the batter pile raft foundation is less than that of vertical pile raft foundation.

5. CONCLUSION AND RECOMMENDATION:

Comparison of pile group and piled raft foundation model having vertical and batter pile at 10^0 inclination shows that pile raft model has greater load carrying capacity than pile group model because in pile group foundation load is carried by only piles while in case of pile raft model both raft and pile are taking the load.

It is also concluded that pile raft foundation can be used in soft soil because off its more contact area with soil and small settlement.

Different values of settlement transducers show that settlement produce in pile raft and pile group is different at different location of the raft which conclude that settlement depends on the condition of soil under the foundation.

It is also concluded that using batter pile instead of vertical pile cause the settlement reduction and increase in load carrying capacity.

It is recommended to study the settlement and load carrying capacity of pile raft foundation when horizontal load is acting on the foundation, Also, the stresses produced in both vertical and batter piles can be studied experimentally by using strain gauges.

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