Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 46 No. 6
June 2025

Experimental And Analytical Investigation Of Piled Raft Foundations On Silty Sand Soils

Mr. Surya Teja Veeranki[1*], Dr. Padmavathi. V[2]

[1]Resaerch Scholar, Civil Engineering Department, Jawaharlal Nehru Technological University Hyderabad, Kukatpally, Hyderabad - 500085, Telangana, India,

[2]Professor, Civil Engineering Department, Jawaharlal Nehru Technological University Hyderabad, Kukatpally, Hyderabad - 500085, Telangana, India,

Abstract

The effects of raft foundations on sandy, silty soil were investigated. On difficult soil profiles, engineers utilise piled-raft foundations to combine pile and raft strengths. The study indicated that silty sand lowers and deforms, causing foundation problems. plaxis-3d is the tool to investigate the effects of pile length, raft thickness, and pile spacing on foundation load-carrying, settlement, and stability. To understand piled raft foundations at various stress levels by studying piles, rafts, and silty sand interactions. To comprehend the system, we investigated settlement patterns, load-displacement curves, and failure processes. Researchers are experimenting with soil modification and strengthening techniques for silty sands on raft foundations. Discover how ground improvement and geosynthetic reinforcements may be used to strengthen foundations and reduce settlement. This experiment demonstrates about piled raft foundations on silty sandy soil beds, which improves load carrying capacity and reduces settlements. The findings might assist engineers and practitioners in enhancing foundation designs, construction, and the stability and dependability of silty sandy soil structures. The piled raft foundations were evaluated using plaxis-3d. This research particularly focuses on analysis and settlement of pile raft foundation with variation of pile spacings of 3, 4, and 5d and lengths of 10, 20, and 40d (pile diameter) by consideration of constant load application and same number of piles. According to above study settlement of piled raft group reduces with length of piles and spacing between piles are less effect in settlement.

Keywords: Piled Raft Foundation, Silty Sand, Plaxis-3d.

1. Introduction

Your foundation system is more crucial than ever when constructing on unstable terrain. Traditional foundation processes are rendered ineffective due to the shifting and distorting of silty sand. Piled raft foundations, which combine the finest properties of piles and rafts, might be the answer to these issues. This study will assess the load-carrying capacity, settlement, and stability of stacked raft foundations on silty sand soils. Piled raft foundations have a combined pile load-bearing and raft spreading characteristic. This combination is critical since traditional foundation systems struggle to manage settlements and distribute weight on silty sand soils. Due to the delicate geotechnical interaction between the piles, raft, and silty sand, a detailed analysis is required to appreciate this foundation structure.

Scaled physical model experiments were carried out in a controlled laboratory setting to replicate stacked raft foundations on silty sand. This study methodically modifies pile spacing, raft thickness, and pile length to determine how these elements affect foundation performance under different stress circumstances. Based on the experimental findings, the failure, settlement, and load-displacement processes of stacked raft foundations in silty sand will be better understood. The findings will provide insight on how different soil augmentation and strengthening procedures impact the performance of stacked raft foundations in silty sand situations. Geosynthetic reinforcements and ground enhancement approaches are being evaluated to reduce settlement and assure foundation stability. The findings of this study should increase our understanding of geotechnical engineering and provide guidance on how to build stacked raft foundations on silty sand. When planning foundations and performing construction methods for structures built on silty sand soils, engineers and practitioners may benefit from a deeper knowledge of the interaction processes. This knowledge will help these structures be more stable and long-lasting in the long run.A pile-raft foundation supports the whole substructure of a building, including walls and columns. When a raft foundation is insufficient to meet the design standards, piles may be used. A lower pile count may increase the raft's load-bearing capability and settling performance. The philosophical purpose of piles is to reduce settling. In places with poor soils and high water tables, the use of pile-supported rafts is becoming increasingly frequent for multi-story structures with basements. Because of the huge number of factors that impact system behaviour, the research of stacked rafts is more difficult than that of soil-supported rafts. There is very little information available on the behaviour of stacked raft foundations. A thorough examination of the problem's origins and consequences must include the interaction of the problem's superstructure, substructure, raft, piles, and soil medium. These properties have an effect on shears, moments, load-sharing between raft and piles, and settlements between raft and piles. Certain designers use brakes on elastic foundations. This technology is improved by using rafts as spring-supported plates [1]. Using a floor raft design in reverse is dangerous. When pressures are parallel to the mat's center, as was the case in 1988 with the introduction of rafts or mats [2] as rigid structures, Q=V/A determines the soil pressure. IS 2950 (1981) [3] addressed the design and construction of raft foundations, while IS 2911 (1980) [4] covered pile design and testing. Many studies have been conducted on a plate-on-springs system with rafts and piles [5, 6, 7]. In the literature, the behaviour of piles in sand exposed to oblique pullout loads has been characterised [8]. Numerical approaches are used to evaluate stacked-raft foundations [9]. Poulos' study on piled-raft foundations [10] did not contain any experimental data.[11] provides further information about the 51-story, 208-metre-tall Frankfurt Westend 1 Tower. The tower's base is made up of forty piles, each 30 metres long and 1.3 metres in diameter. The raft is 3 metres thick on each side and 4.5 metres thick in the center. The foundation is made of deep and long-lasting Frankfurt clay.

According to Abdel-Fattah and Hemada [12], the level of stress that the raft contact pressure transfers to the earth might range from 30 to 60%. The state of the soil determines this amount. As the distance between the piles increases and the length of the piles decreases, this ratio improves. Their findings show that the stacked raft method is efficient for constructing tall buildings made of soft clay, guaranteeing both load-bearing capability and functionality. Algulin and Pedersen created a plane strain model [13] to enhance comprehension of the piled raft foundation of a construction. The model's rational functioning suggests that PLAXIS 2D's planar strain model is a very efficient and pragmatic tool. Filled with rafts, stacks, and clusters exhibiting a collective mindset. The linear connection between load and settlement is attributed to the initial elastic range of soils and piles [14]. Several design elements have an impact on how well a stacked raft with raft footing performs. In order to achieve the aim of economic development with adequate performance, it is crucial to take into account these variables [15].

2. Piled Raft Foundation

Geotechnical engineers have increasingly adopted piled raft foundations as a reliable and efficient solution for supporting structures on challenging soil conditions. This foundation system represents a hybrid approach that strategically combines the beneficial attributes of both raft and pile foundations. By doing so, it effectively mitigates the limitations associated with each system when used in isolation. Piled raft foundations are particularly advantageous in geotechnical settings characterized by heterogeneous soil profiles, low bearing capacities, or differential settlement risks. In such scenarios, a conventional raft foundation alone may be insufficient to provide adequate support, while a fully piled foundation may prove to be economically inefficient. The integration of piles with the raft offers a balance between cost-effectiveness, load-bearing performance, and settlement control. In a piled raft system, vertical structural elements (piles) are embedded into the ground beneath a reinforced concrete raft slab. These piles primarily serve to transfer a portion of the structural loads to deeper, more competent soil strata or bedrock. Concurrently, the raft is designed to distribute the remaining loads uniformly across the foundation footprint, thereby reducing stress concentrations and minimizing differential settlement. This dual mechanism enhances the foundation's ability to maintain structural integrity, particularly under complex loading conditions. The principal advantage of the piled raft system lies in its ability to control total and differential settlements, while simultaneously offering sufficient load-bearing capacity. This is particularly critical for structures such as high-rise buildings, bridges, industrial facilities, and other heavy-load infrastructure, where traditional shallow or deep foundation systems may fall short in performance or feasibility. Effective implementation of piled raft foundations requires a comprehensive geotechnical investigation, encompassing the characterization of subsoil properties, anticipated structural loads, pile-soil interaction behavior, and site-specific conditions. Design optimization must consider these factors to ensure long-term stability, serviceability, and cost-efficiency. As a result, the piled raft foundation system has become an essential element in modern geotechnical design, especially in urban and infrastructure projects encountering problematic ground conditions.

Recent advancements in numerical modeling and soil-structure interaction analysis have further refined the understanding of piled raft behavior under varying geotechnical conditions. The adaptability of piled raft systems to both uniform and variable loading makes them ideal for regions prone to seismic activity or differential settlement. As the demand for sustainable and resilient infrastructure grows, piled raft foundations offer a robust and economical foundation solution for the future.

3. Result and Discussion

3.1. Piled Raft

The force-displacement graphs for the raft with pile lengths of 40, 20, and 10 are shown in Figures 1–13. The experiment used distances in three, four, and five dimensions. As the community grows, the data indicates that the raft becomes operational and its power intensifies. The distance the raft settled from its first point of contact with the silt was 0.1 B. The graphs depict the magnitude of the load exerted on the raft.

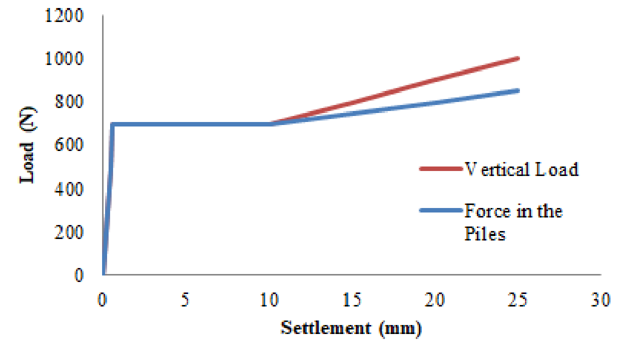

Figure 1. L/d = 40, e/d = 3 diagram of piled raft "force-displacement"

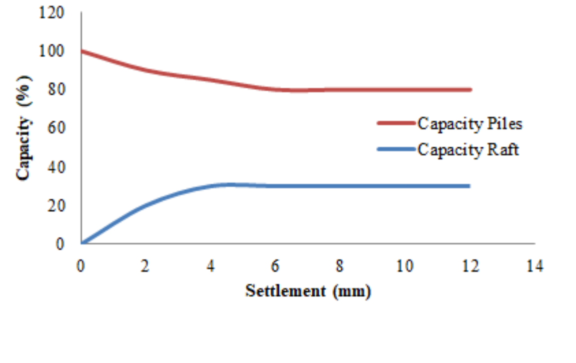

Figure 2. Load distribution diagram for a group of four piles with lengths of 40d separated by e = 3d.

Figures 1 and 2 show "force-displacement" or "load bearing capacity-settlement" graphs for piles 40 d long and spaced 3 d apart. As long as the limit settling is set at 0.1B, the piles hold 76% of the load when the raft contacts the ground (approximately 7 mm).

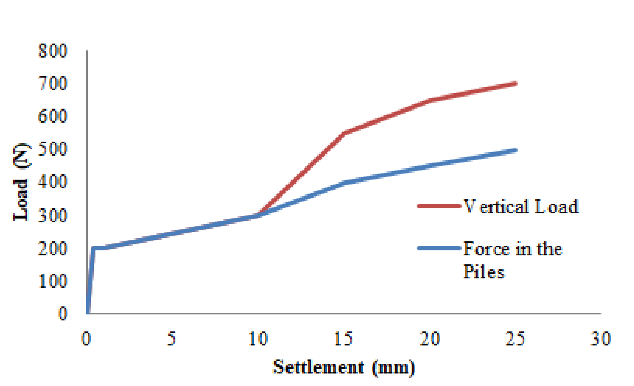

Figure 3. L/d = 20, e/d = 3 diagram of piled raft "force-displacement"

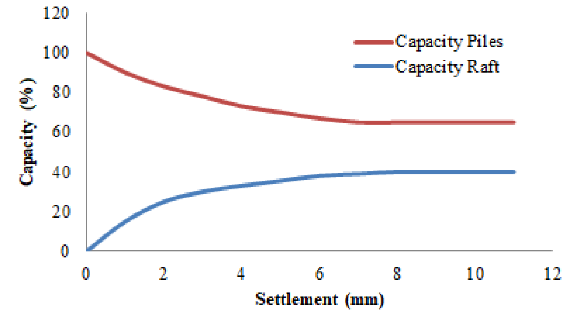

Figure 4. Load distribution diagram for a group of four piles with lengths of 20d at a distance of e = 3d.

Figures 3 and 4 show the "force displacement" and "load bearing capacity settlement" plots for piles 20 d long and 3 d apart. The piles sustain 72% of the total load by providing a limit settling of 0.1B from the time the raft meets the ground (approximately 7 mm).

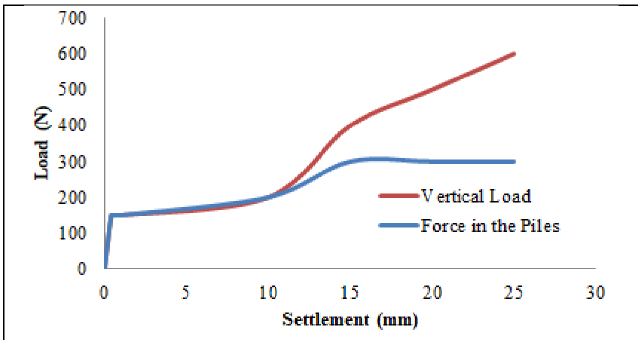

Figure 5. L/d = 10, e/d = 3 diagram of piled raft "force-displacement"

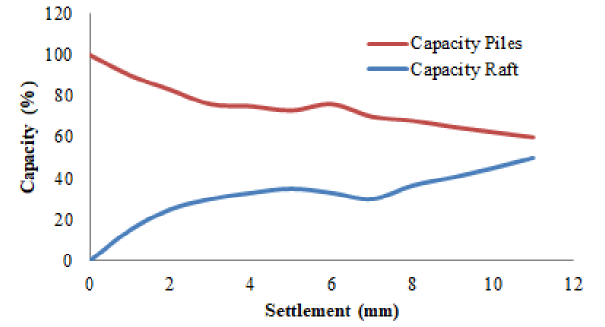

Figure 6. Load distribution diagram for a group of four piles with lengths of 10d at a distance of e = 3d.

Figures 5 and 6 illustrate "force displacement" or "load bearing capacity settlement" graphs using piles 10 d long and 3 d apart. When the limit of settling is set at 0.1B from the instant the raft meets the earth, which is around 7 mm, the piles hold 74% of the load.

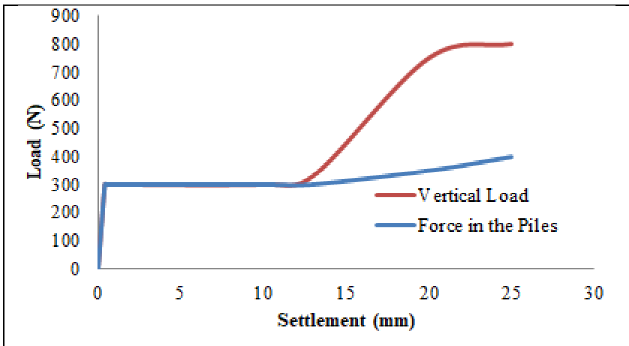

Figure 7. L/d = 40, e/d = 4 diagram of piled raft "force-displacement"

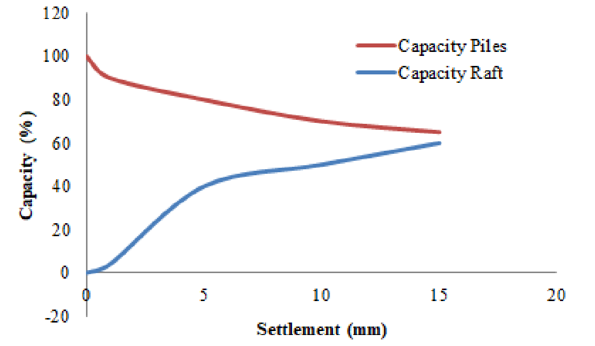

Figure 8. Load distribution diagram for a group of four piles with lengths of 40d at a distance of e = 4d.

Figures 7 and 8 show the "force-displacement" or "load bearing capacity-settlement" graphs for piles 40 d long at 4 d. The piles hold 60% of the weight once the raft contacts the ground (approximately 7 mm), with a maximum settling of 0.1B.

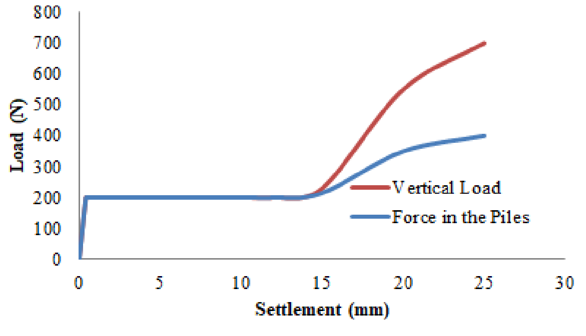

Figure 9. L/d = 20, e/d = 4 diagram of piled raft "force-displacement"

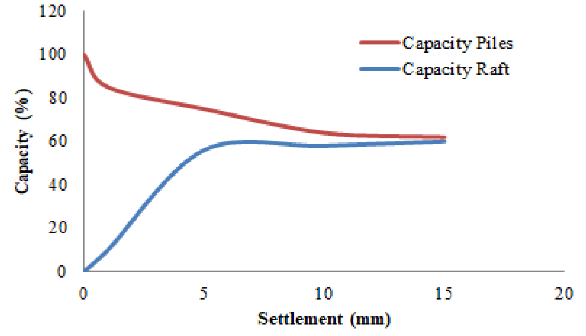

Figure 10. Load distribution diagram for a group of four piles with lengths of 20d at a distance of e = 4d.

The "force displacement" or "load bearing capacity settlement" graphs for 20-d piles at 4-d are shown in Figures 9 and 10. With a maximum settling of 8 mm, the piles hold 55% of the overall weight.

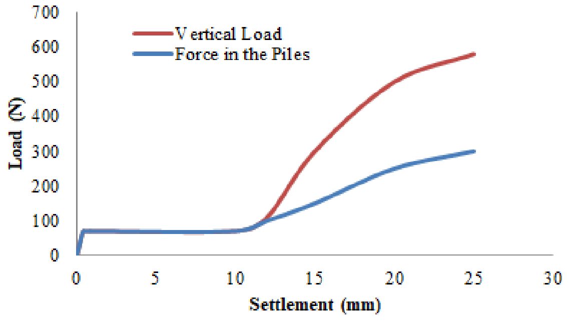

Figure 11. L/d = 10, e/d = 4 diagram of piled raft "force-displacement"

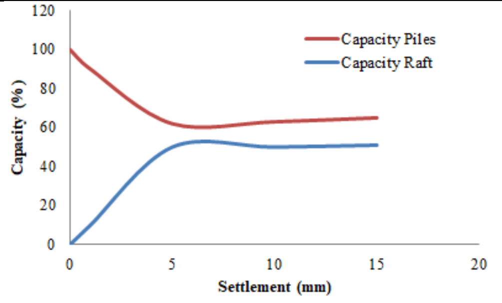

Figure 12. Load distribution diagram for a group of four piles with lengths of 10d at a distance of e = 4d.

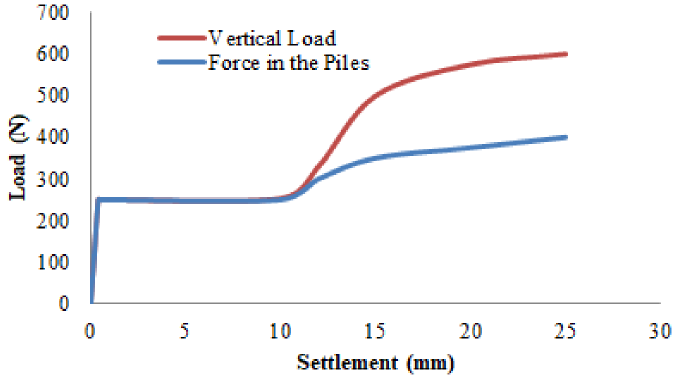

Figure 13. L/d = 40, e/d = 5 diagram of piled raft "force-displacement"

Figures 11 and 121 show "force displacement" or "load bearing capacity settlement" graphs of piles 10 d long and 4 d apart. The piles sustain 58% of the weight with a limit settling of 8 mm. Figure 13 shows the "force-displacement" graphs for piles 40d long at 5d. The piles take 53% of the load at a maximum settling of 9 mm. Based on prior research, it is advised that when building piled raft foundations, the number of piles necessary to restrict settling to approved limits be calculated rather than the load capacity. The experimental findings are consistent. The raft has a weight-bearing capacity of 30%.

4. Conclusions

Numerical model was developed by the FE software package PLAXIS 3D to analyse piled-raft foundations. The numerical model results were compared with PDR (Poulos-Davis-Randolph)-method. The results of the developed numerical model were found in well agreement with the results of measured data for case study of Torhaus building [Germany, Reul and Randolph (2003)].

The effect of parameters namely, pile spacing (Sp) and pile length (Lp) on the performance of piled-raft foundations was studied. The results of the analysis showed that some parameters have influence on the load-settlement response at small settlements and totally different from their effect at high settlements. The necessary observations relating to the impact of the investigated parameters on the load-settlement relationship of CPRF may be summarized as follows:

Aspect ratio (Lp/dp) significantly affects the settlement response and the load sharing response. Settlements are decreases with increasing aspect ratio. Instead of using larger number of shorter piles, small number of longer piles is effective in reducing settlements.

Spacing-diameter ratio (Sp/dp) influences the settlement responses. CPRF settlements decrease with increase in spacing of piles. It can be deduced that spacing of 4-6 times the diameter of piles might be optimum spacing to keep settlements within permissible limits. The percentage of load taken by raft decreases with spacing. Optimum spacing is with respect to load sharing at which raft should take at least 30 percentage of applied load. The outer piles are subjected to higher loads compared to the inner piles in the pile groups.

References

1. Poulos, H. G and Davis, Eh. (1980), Pile Foundation Analysis and Design, John Wiley and Sons Inc.
2. Bowles, J. E. (1997), Foundation Analysis and Design, Mc Grow-Hill, Singapore.
3. IS 2950 (1981), Code of Practice for Design and Construction of Raft Foundation, BIS, New Delhi.
4. IS 2911-part II (1980), Code for Practice for Design and Construction of Pile Foundation, BIS, New Delhi.
5. Clancy, P. and Randolph, M. F. (1993), Analysis and Design of Pilled Raft Foundation, Int. J. NAM Geomech.
6. Hooper, J. A. (1993), Observation on the Behaviour of a Piled-raft Foundation on London Clay, Proc. Civil Engineers, 55, No. pp 855-877.
7. Randolph. M F. (1994), Design Method for Pile Groups and Piled Rafts : State - of - the Art Report, Proc. 13th Int. Conf., Soil Mech. and Foundation Engineering, New Delhi, , pp 61-82.
8. Mandal, A. K., Patra, N. K. and Pise, P. J. (2002), Behavior of Enlarged Base Piles in Sand under Oblique Pullout Loads, Indian Geotechnical Journal, 32, No. 4.
9. Poulos, H. G. (1994 a), An Approximate Numerical Analysis of Pile-Raft Interaction, Int. J. NAM Geomech. 18, pp – 73 - 92.
10. Poulos, H. G. (2001), Pile Raft Foundations Design and Applications, Geotechnique, 51, No.- 2, pp 95 - 113.
11. Franke, E., Lutz, B. and EL Mossallany, Y. (1994), Measurement and Numerical Modeling of High-rise Building Foundation on Frunkfurt Clay, Geotechnical special publication, 40 New York American society of civil engineer, pp 1326 – 1336.
12. T.T. Abdel-Fattah, A.A. Hemada, Use of creep piles to control settlement of raft foundation on soft clay-case study, in: Eighth Alexandria Conference on Structural and Geotechnical Engineering, 14–16 (April 2014), 2014, pp. 13–14.
13. J. Algulin, B. Pedersen, Modeling of Piled Raft Foundation as a Plane Strain Model in Plaxis 2D, Master of Science, Department of Civil and Environment Eng, Division of Geo-Engineering, Chalmers University, Sweden, 2014.
14. Hussein H Karim H and Shlash K 2020 Analysis of piled raft foundation in sandy soil using full scale models (IOP Conference Series: Materials Science and Engineering, Vol. 737, 4th International Conf. on Buildings, Construction and Environmental

Engineering 7th-9th October 2019, Istanbul, Turkey).

15. Hussein H 2020 Behavior of grouting pile in sandy soil IOP (Conference Series: Materials Science and Engineering, Volume 737, 4th International Conference on Buildings, Construction and Environmental Engineering 7-9 October 2019, Istanbul, Turkey).

16. Poulos, H.G. Analysis of the settlement of pile groups. *Geotechnique* 1968, *18*, 449–471. [Google Scholar] [CrossRef]

17. Butterfield, R.; Banerjee, P.K. The problem of pile group–pile cap interaction. *Geotechnique* 1971, *21*, 135–142. [Google Scholar] [CrossRef]

18. Davis, E.H.; Poulos, H.G. The analysis of piled raft systems. *Aust. Geotech. J.* 1972, *2*, 21–27. [Google Scholar]

19. Zeevaert, L. Compensated Friction-Pile Foundation to Reduce the Settlement of Buildings on the Highly Compressible Volcanic Clay of Mexico City. In Proceedings of the 4th International Conference on Soil Mechanics and Foundation Engineering, London, UK, 12–24 August 1957. [Google Scholar]

20. Zeevaert, L. *Foundation Engineering for Difficult Subsoil Conditions*; Van Nostrand Reinhold Company: New York, NY, USA, 1973. [Google Scholar]

21. McVay, M.; Casper, R.; Shang, T.I. Lateral response of three-row groups in loose to dense sands at 3D and 5D pile spacing. *J. Geotech. Eng.* 1995, *121*, 436–441. [Google Scholar] [CrossRef]

22. Cox, W.R.; Dixon, D.A.; Murphy, B.S. Lateral-load tests on 25.4-mm (1-in.) diameter piles in very soft clay in side-by-side and in-line groups. In *Laterally Loaded Deep Foundations: Analysis and Performance*; ASTM International: West Conshohocken, PA, USA, 1984. [Google Scholar] [CrossRef]

23. Khari, M.; Kassim, K.A.B.; Adnan, A.B.; Moayedi, H. Kinematic bending moment of piles under seismic motions. *Asian J. Earth Sci.* 2014, *7*, 1. [Google Scholar] [CrossRef]