Experimental and Numerical Investigation of Combined Batter Pile-Raft Foundation Embedded in Sand

Mahalakshmi M ✉, Soundara B and Hashini C D

Department of Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, India
mahalakshmice@gmail.com

Abstract. A geotechnical composite foundation system named Combined Pile-Raft Foundation (CPRF) is widely used in buildings experiencing colossal loads. Even though raft foundation reduces differential settlement, it tends to cause excessive settlement which can be subsided by using piles. Batter piles are deliberately known for their lateral resistance compared to plumb. The response of CPRF with batter pile under horizontal loading needs enhanced studies. This research focusses on the parametric configuration of combined batter pile-raft foundation embedded in sand. The effect of direction of batter and the angle of batter is studied experimentally under constant relative density. For experimental investigation, model test tank was used and 2 x 1 solid steel piled raft model was fabricated and used. The basic parametric configuration chosen for the combined batter pile-raft foundation is L/D – 20, S/D – 3 and diameter of pile & thickness of the raft was taken as 10 mm. The model is numerically simulated in a comprehensive three-dimensional finite element software ANSYS. The results of the experimental investigation and the numerical simulation are compared. The efficient direction of batter was found to be negative and was carried over for the further studies. The angle of batter taken for the study were 10˚, 15˚, 20˚, 25˚ and 30˚ in-battered. The optimum batter angle was found to be in the range of 15˚ to 20˚ in-battered. The results from the numerical investigation were found to be in accordance with the experimental results.

Keywords: Combined Pile-Raft Foundation, Batter Pile, Model Test Tank, Sand, ANSYS.

1 Introduction

The emerging need to accommodate high rise buildings on the problematic ground conditions has drawn a major attention on deep foundation and the one which proves to be significant in such situation is combined pile – raft foundation. CPRF consist of two elements namely a raft and pile, where the raft acts as a load sharing element and the pile as the settlement reducer. Batter piles are often used in places where they are subjected to lateral and inclined forces such as earthquake, wave currents, off shore structures etc., In this study, an attempt has been made to study the effect of lateral load on the Combined pile - raft foundation containing batter pile. Reese [1] developed p – y curves for analysis of vertical piles in sand under lateral loads and suggested that the same can be employed for the behavior prediction of batter pile also. The guidelines for lateral response prediction of fixed head and free head piles was provided by Pise [2 & 3]. Chae et al. [4] provided validation for the experimental data using 3D Finite Element Method (FEM) for the lateral resistance of short piles and pile groups located near slopes. The response of piles and pile group by displacement method was analysed by Martin and Chen [5] using FLAC 3D and proposed that the same method can be employed to pile foundation design which undergoes lateral soil movement and Chen [6] conducted model analysis on the response of batter piles to lateral soil movement using FLAC 3D and inferred that the batter piles experience lesser displacement compared to vertical piles. The resistance mechanism of pile foundations having batter piles has been studied by Vu et al. [7] by conducting model experiment in sand and stated that the resistance increase was much observed in piled raft having batter piles. Escoffier [8] conducted centrifuge tests on raked piles and noted that the batter pile in pile group induces an increase in the bending moment at the pile cap and axial load at the rear pile compared to the front. Hazzard [9] carried out 3D finite difference parametric analyses on the lateral performance of battered piles in sand and clay and stated that the lateral response is influenced by the batter angle and direction of pile inclination. The lateral resistance of the battered pile groups in the presence of vertical dead load was discussed by Zhang [10] and account that it depends on the pile arrangement, inclination and soil density. The optimum batter angle of 20° was found by Mohammed A.Al-Neami [11] when the effect of different batter angle on different relative densities of sand has been studied. Bharathi and Dubey [12] presented the insignificant lateral behaviour of under reamed batter piles. In this paper, the effect of horizontal loading on 2 x 1 Combined Batter Pile – Raft is studied experimentally and the same has been numerically analysed using ANSYS software to simulate the response of the system under lateral loading.

2 Experimental Setup and Test Program

The experiment was carried out in a model steel test tank placed under a loading frame supported by four hot rolled steel columns. An automized lateral loading jack was harnessed on the side columns. The model tank was made as deep as two times the length of the piles in order to avoid stress concentration at the rigid base as stated by Randolph [13] and on the side surface as well. This is done to avoid the influence of boundary on the behavior and response of the CPRF. The combined piled raft of 2 x 1 containing batter pile was modelled as solid steel pile having an angle of 10°,15°,20°,25° and 30° and length as 200 mm. The pile diameter was taken as 10 mm and series of piled raft models were fabricated with a constant thickness of raft as 10 mm. Since the thickness of raft doesn't make any consequential effect on the response of pile raft as stated by Oh et al. [14], a constant thickness of 10 mm has been adopted throughout the study. Short or rigid piles behave partially plastic and partially elastic whereas long or slender piles behave completely as plastic, hence an optimum L/D of 20 was taken for this study.

The sand bed was prepared by filling the tank with sand using rainfall technique by maintaining height of fall as 400 mm in order to achieve a constant relative density of 60%. The sand used for the experimental purpose was collected from the Kodivei River Bank flowing through Sathyamangalam at 11.4731˚ N and 77.2966˚ E. Test were done to determine the properties like particle size distribution, specific gravity, density etc., and the values has been listed in the Table 1. The values listed in the table include parameters for the finite element modelling using ANSYS.

Table 1. Properties of Sand

Property	Unit	Value
Specific Gravity (G_s)	-	2.77
Young's Modulus (E)	kN/m^2	40,000
Poisson's ratio (ν)	(no unit)	0.15
Mass Density (γ)	kN/m^3	16.3
Angle of internal friction (ϕ)	-	20º
Dilatancy Angle (ψ)	-	0º
Cohesion (c)	kN/m^2	10.79

Experiments were conducted by varying the batter angle while the direction of batter was kept fixed i.e., negative batter throughout the test since the experimental results of Bushra and Anmar [15] and Maharaj et al. [16] proved that the negative batter has higher lateral load carrying capacity. Numerical simulation was carried out to prove the negative batter resistance to lateral load. The lateral load was applied gradually in incremental manner on the pile raft using hydraulic jack. The deflection was measured at the raft top using Linear Variable Differential Transformer.

3 Results and Discussion

3.1 Direction of Batter

The effect of direction of batter was numerically simulated. The direction of batter was taken as negative i.e., in-battered since the in-battered piles proved to be more significant in the lateral load carrying capacity. The improved resistance to lateral loads is because the loads transferred are tensile in nature compared to the positive batter which transfer loads compressively. The load displacement curve for the numerically simulated in-battered, vertical and out-battered piles are shown in Fig. 1.

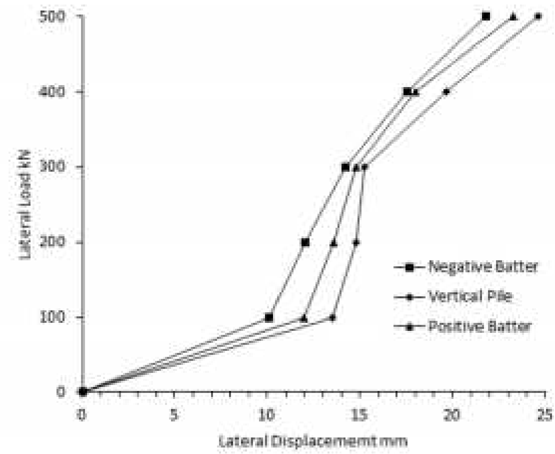

Fig. 1. Effect of Direction of Batter

3.2 Batter Angle

The combined Batter pile raft with batter angle of 10°,15°,20°,25° and 30° were investigated both experimentally and numerically. It was observed that at a particular angle the lateral stability of combined batter pile – raft system is found to be maximum because a large peripheral surface of the pile encounters the lateral load compared to other batter angle. The system with batter angle of 15° to 20° was seen to perform well under lateral loading and was considered to be the optimum batter angle. The load displacement curve for the different batter angle which was experimentally investigated is shown in Fig.2. To verify the experimental values numerical simulation was done using ANSYS for varying batter angle and it was found to be in accordance with the experimental value and the load displacement curve is shown in Fig.3.

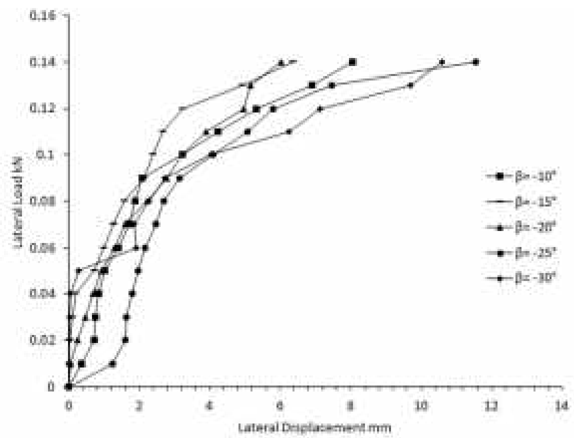

Fig. 2. Experimental Result of Batter Angle

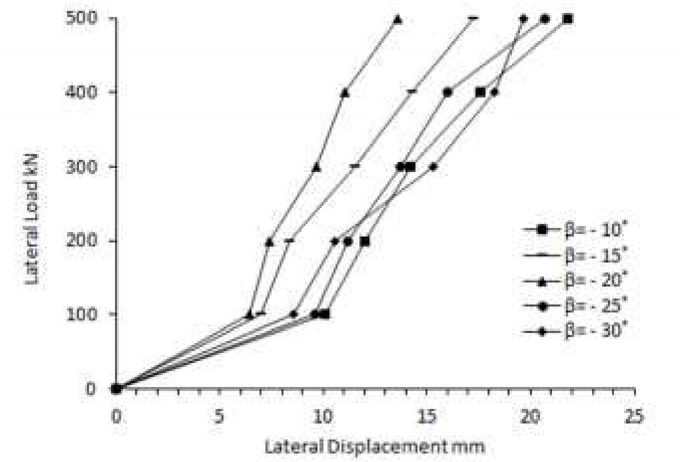

Fig.3. Numerical Simulation Result of Batter Angle

3.3 Comparison Between Experimental Result and Numerical Result

The lateral load and displacement curve for the experimental and numerical results have been shown in Fig.4. and Fig.5. for an optimum batter angle of 20°.

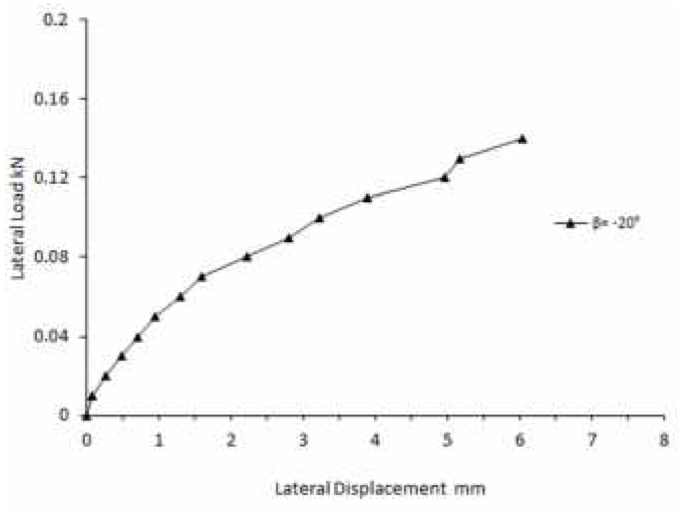

Fig. 4. Experimental Displacement Curve for 20° Batter Angle

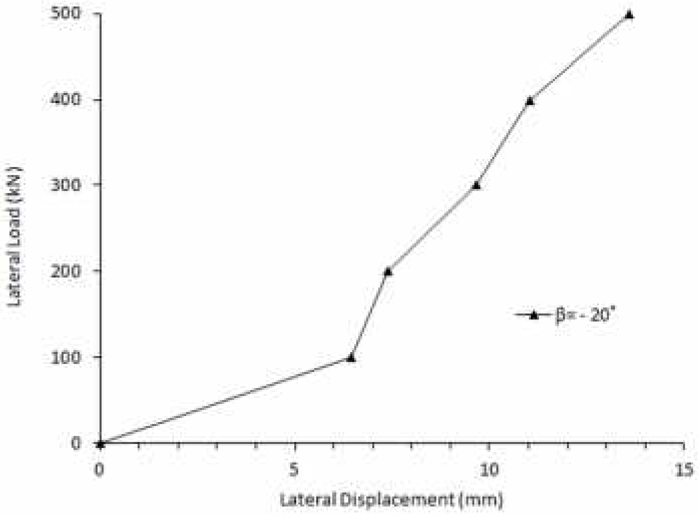

Fig. 5. Numerical Simulation Displacement Curve for 20° Batter Angle

By comparing the above graph, we can infer that the experimental inadequacy in lateral load application along with measurement of parameters and theoretical assumptions existing in the numerical analysis of ANSYS software might have caused a constant shift in graphical relation of lateral displacement & lateral loads.

4 Conclusions

The effect of lateral loading on combined batter pile – raft foundation has been studied in this paper. The following are the conclusions drawn from the experiment and numerical analysis.

1. The efficient direction of batter to resist lateral loading is negative battered piles compared to vertical and positive battered piles.
2. The optimum batter angle was found out to be 20° in battered based on the lateral load carrying capacity compared to the other batter angle.
3. The numerical analysis of combined batter pile raft shows a similar effect on the lateral loading from the experimental test.

References

1. Lymon C. Reese, William R. Cox, Francis D. Koop, Lawrence – Allison & Associates: Analysis of Laterally Loaded Piles in Sand. In: Sixth Annual Offshore Technology Conference 1984, pp. 473 – 483.
2. Prabhakar J.Pise: Lateral Response of Fixed-Head Pile. Journal of Geotechnical Engineering ASCE 109 (8), 1126-1131 (1983).

3. Prabhakar J. Pise: Lateral Response of Free- Head Pile. Journal of Geotechnical Engineering ASCE 110 (12), 1805-1809 (1984).
4. K.S.Chae, K.Ugai, A.Wakai: Lateral Resistance of Short Single Piles and Pile Groups located near Slopes. International Journal of Geomechanics ASCE 4(2), 93-103 (2004).
5. G.R. Martin, C.-Y. Chen: Response of Piles due to lateral slope movement. Computers and Structures 83, 588-598 (2005).
6. C Y Chen and H Q Hsu: Modeling of Batter Pile Behavior under Lateral Soil Movement. In: 2nd International Conference on Civil Engineering and Materials Science 2017, Materials Science and Engineering 216, 012039, doi:10.1088/1757-899X/216/1/012039, IOP Publishing (2017).
7. Anh-Tuan Vu, Tastunori Matsumoto: Experimental Study on Pile Foundations having Batter Piles Subjected to Combination of Vertical and Horizontal at 1-g. Geotechnical Engineering Journal of SEAGS & AGSSEA 48(3), (2017), ISSN 0046-5828.
8. Sandra Escoffier, Jean-Louis Chazelas and Jacques Garnier: Centrifuge modelling of raked piles. Bull Earthquake Eng, 689–704 (2008), DOI 10.1007/s10518-008-9094-1.
9. Lassaad Hazzar, Mahmoud N. Hussien & Mourad Karray: Numerical Investigation of the lateral response of battered pile foundations. International Journal of Geotechnical Engineering (2016), DOI 10.1080/19386362.2016.1224030.
10. L.M. Zhang, M.C. McVay, S.J. Han, P.W. Lai, and R. Gardner: Effect of Dead loads on the lateral response of battered pile groups. Canadian Geotechnical Journal, 561-575, DOI: 10.1139/T02-008
11. Mohammed A. Al-Neami, Falah H. Rahil & Khaldoon S. Al-Bayati: Bearing capacity of batter piles embedded in sandy soil. International Journal of geotechnical Engineering (2016), DOI: 10.1080/19386362.2016.1203094.
12. M. Bharathi, R.N. Dubey: Dynamic lateral response of under-reamed vertical and batter piles. Construction and Building Materials 158, 910 – 920 (2018).
13. Randolph MF: Design methods for pile groups and piled rafts. In: Proc. 13th International Conference on Soil Mechanics and Foundation Engineering, pp. 61–82 (1994).
14. Oh E Y N, Huang M, Surrak C, Adame R and Balasubramaniam A S: Finite element modelling for piled raft foundation in sand. In: Eleventh East Asia-Pacific Conference on Structural Engineering & Construction (EASEC-11), Building Sustainable Environment, pp. 1-8. Taiwan, (2008).
15. Bushra S. Albusoda and Anmar F. Alsaddi: Experimental study on performance of laterally loaded plumb and battered piles in layered sand. Journal of Engineering 9(23), 24-37 (2017).
16. Dr D.K. Maharaj, Deepak Kumar and Dr Sanjeev Gill: Comparison of Vertical and Battered Piles Subjected to Lateral Loads. In: Conference on Recent Innovations in

Emerging Technology & Science 2018, ISSN: 2320-2882.