COMPARATIVE STUDY OF PILE GROUP AND PILE RAFT FOUNDATION FOR TALL WIND TURBINE

Utkarsha Patel[1], S. N. Tande[2]

[1]PG Student, Dept. of Civil Engineering, Walchand College of Engineering, Sangli, Maharashtra, India 416415
[2]Professor, Walchand College of Engineering, Sangli, Maharashtra, India 416415

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Abstract - *Wind turbine plays a vital role in fulfilling the growing energy demand. To increase its power generation capacity taller towers should be used. To safely carry these heavy loads of taller towers, foundation should be efficient. In this study two foundations like pile group with pile cap and pile raft that is hybrid foundation for 130m tall wind turbine are designed and compared. Using the parameters total settlement, differential settlement, rotation and volume of material, how the pile raft foundation is safe and economical is shown in results.*

Key Words: Wind turbine, Differential settlement, Pile raft foundation, Hybrid foundation, Pile group etc.

1.INTRODUCTION

To satisfy the ever-increasing demand, wind turbine power output has risen dramatically during the last several decades. Wind energy has been discovered to be reliable and effective source of electricity in terms of cost and efficiency if planned and constructed at most suitable site.

Building taller wind turbine towers to reach higher wind velocities is a cost-effective approach for increasing wind energy output. However, as the height increases, so does the size of the base, and the design gets more complicated. Because foundation construction stands for a major portion of total cost, it is important to create cost-effective foundations to sustain large structures.

Controlling differential and total settlements is critical. Differential settlement specially, can have a detrimental impact on superstructure by increasing internal stress and, have consequence like lessening service life of building. As a output within acceptable range are required. Types of foundations listed above, the piled raft foundation is now globally used for reduction of an effective total and differential settlement for heavy loads. This foundation structure is composed of piles, and raft, with piles having the most important function in minimizing settlements. However, from an economical perspective, the settlement of this foundation is also in acceptable limits. However, from an economic standpoint, the settlements of P-R foundation should be regulated for an affordable design while achieving an safety.

Two foundation types (pile group and piled-raft) were studied in this study to withstand a 130 m tall wind turbine at wind farm location in Tamil Nadu. The pile raft foundation was discovered to be the cost efficient solution for the given site and loads.

LOADS AND SOIL PROPERTIES:

Design of wind turbine foundation, load considered are the vertical load due to the superstructure weight and the horizontal load because of wind load and bending moment due to the wind load acting at different levels on the superstructure. It is calculated based on the height of tower and other equipment's weight and wind speed for the selected site. To exemplify the suggested technique, a hybrid hollow cylindrical tower with bottom 93 m of concrete and top 37 m of steel was studied in this work (Grunbeg and Gohlmann 2013). Its diameter increases gradually from 12.0 m at the base to 4.0 m at the top. The total vertical load operating on the tower was estimated by adding the weights of the tower's concrete and steel components (Grunbeg and Gohlmann 2013), and additional components such as the nacelle and rotor were obtained from Malhotra (2011). The final dead load of the tower was calculated to be 53.42 MN. The survival wind speed considered for Tamil Nadu is 50m/s. The horizontal load was calculated as the sum of all the horizontal loads acting on the superstructure, obtained as 5.63 MN. The bending moment at the base of the tower was calculated by multiplying the horizontal loads with the respective moment arms from the base of the tower is 344.73 MN.

The necessary geotechnical properties were obtained from a geotechnical report produced for the wind turbine testing facility located in Tamil Nadu, India. Soil depth considered up to 30m. It consists of 6 layers with varying thickness and geological properties. For this soil block weight average of all soil layers taken for calculations of unit weight, poissions ratio, and cohesion. Calculated unit weight, poissions ratio, cohesion as, 20.91 kN/m^3, 0.48, 79.63 kN/m^2, respectively. Water table is at 6m from ground surface.

ANAYTICAL DESIGN OF FOUNDATIONS

If foundation fails in bearing capacity or excessive settlement, can result in the full collapse of a wind turbine system, choosing a cost-effective foundation and designing it using actual site data is critical in terms of safety. For onshore site, wind turbine tower foundation alternatives include rafts, pile group with pile cap, and hybrid foundations such as piled-raft. The foundation selection is influenced by not only the loads, but also by the layered soil condition for specific site. This section designs and compares pile groups with pile caps and pile raft foundations.

PILE GROUP FOUNDATION

When pile groups are subjected to axial load , lateral load, and bending loads, a complicated interaction between the piles and soil occurs. If the piles are put too near together, they might interact with each other, results in overlapping stress zones. This work presents the analytical design of a pile group foundation utilizing a well-known analytical design approach. The design method entails changing the pile's quantity, length, size, and location until all design requirements are fulfilled.

Using Rao (2011) technique, the total axial load operating on each pile was computed as the sum of dead load and vertical load contribution owing to moment. This was done to include the impression of the occasion. To assure that the vertical design load on each pile is less than single pile capacity, the resultant load operating on each pile was compared to the ultimate downward or uplift pile capacity. The vertical load capacity of the pile group was calculated as the minimum of the total of the ultimate single pile capacity of the individual piles in the group and the block's ultimate capacity, as detailed in Das (2007) and AASHTO (2012). According to design requirements in both compression and tension, it was required to increase the length of some of the piles which are located around the circumference (in the direction of moment). The final design resulted in 40 number of pre-stressed concrete piles of diameter 600mm and length varying as 25m or 30m. Out of the 40 piles, 20 piles were arranged at a radius of 5.3 m and the rest were arranged at a radius of 6.7 m. 20 number of piles having length 25m and 20 number of piles having length 30m as per design.

The pile cap minimum dimension is 0.31 m into the pile cap and that the distance from the edge of the pile to end of the pile cap should be greater than 0.22m. The final design resulted in the pile cap thickness of 1.0 m and radius of 7.5 m. The plan view of the designed pile group foundation with pile cap is shown in Fig.

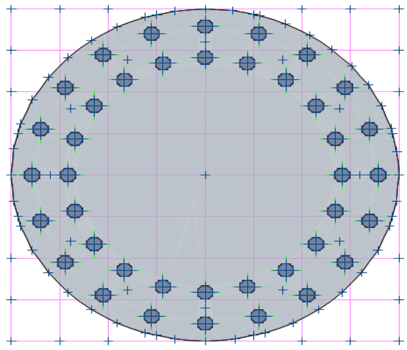

Figure 1: Plan of Pile Group Foundation

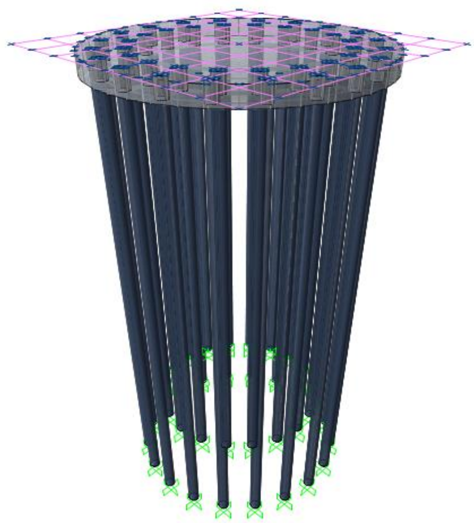

Figure1: 3D View of Pile Raft Foundation

PILE RAFT FOUNDATION

The benefits of a foundation, such as a piled raft, for sustaining a bigger load is that it uses the raft's stronger bearing resistance to overcome bearing capacity failure and piles' higher resistance to overcome total and differential settlements. Since individual design processes for rafts and piles are extensively documented, the design of piled-rafts is difficult, and there is only a limited amount of documentation accessible in the literature. The most difficult challenges in the design are estimating the mobilized strength and determining the percentage of the load borne by the raft and piles for a particular settlement. This is mostly related to knowledge of the complicated soil-raft-pile relationship. As a result, there is no valid design guideline available in the literature, especially when the piled-raft is subjected to vertical, horizontal, and bending moment stresses.

The most difficult job in the design of a piled-raft foundation is determining the percentage of applied load shared by pile and raft. The combined action of the raft and the piles can enhance bearing capacity while decreasing settlement, and smart pile placement can decrease differential settlement. Despite the advantages of piled-raft foundations, reliable design guidelines are still lacking, particularly for foundations subjected to axial, lateral, and moment stresses, due to a less research of the intricate interplay between soil, raft, and piles. Simplified techniques, approximate computer-based methods, and more rigorous computer-based methods are the major categories of processes now accessible in the literature.
In this work, a preliminary design of the P-R foundation was carried out using the technique provided by Hemsley (2000), which integrated the procedures proposed by Poulos and Davis (1980) and Randolph (1994). The elements are taken into account in the preliminary design are ultimate vertical, moment, and lateral capacity, average and differential settlement, tower rotation due to high winds load, and foundation lateral movement. The preliminary design step established the size of the raft, as well as the size and number of piles necessary to meet the design criteria. The P-R foundation capability was tested for vertical load, lateral load, bending moment, total and differential settlements. A minimum factor of safety of 2 was considered to fulfil safety and serviceability criteria (Hemsley, 2000).

The final design considers 40 number of concrete piles of width 0.6 m and length 15m. Out of the 40 piles, 20 piles were arranged at a radius of 5.3 m and the rest were arranged at a radius of 6.7 m.

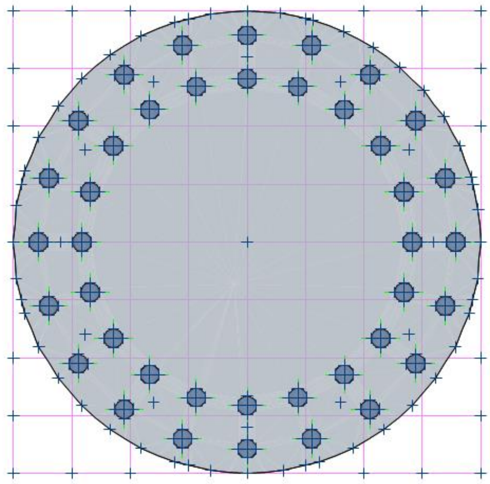

Figure3: Plan of Pile Raft Foundation

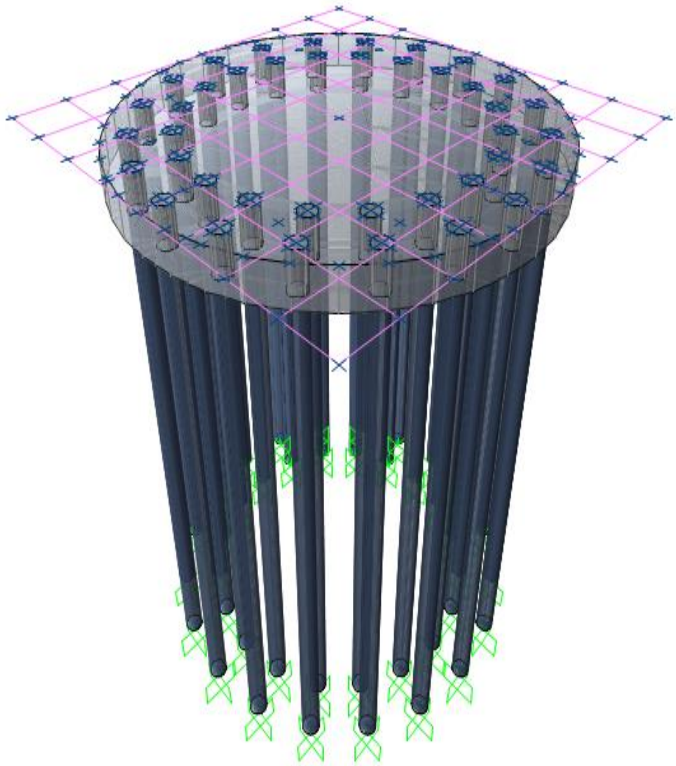

Figure 4: 3D View of Pile Raft Foundation

STABILITY CHECK

Capacity is calculated as the minimum of the sum of the ultimate capacities of the raft and all of the piles individually and the ultimate capacity of the block containing the raft, pile and soil in between piles. For pile group factor of safety checked for axial a, lateral are 2.07 and 2.86 respectively. For both vertical and bending moment capacity, both cases was observed. The capacity of the P-R foundation was then compared with the considered load to the factor of safety obtained. The factors of safety for the vertical were calculated to be 5.07 and factor of safety for bending moment were calculated to be 2.41, which is acceptable. The horizontal capacity of a single pile was initially estimated and then the horizontal capacity of the piled-raft foundation was estimated by multiplying the total number of piles by the single pile capacity. The horizontal capacity was then compared with the applied horizontal load to the factor of safety obtained. For the loads and dimensions of foundation, the factor of safety for horizontal load was found to be 8.69, which is acceptable.

SERVICEABILITY CHECK

The vertical load-settlement performance of the piled-raft foundation was calculated using Paulo's (2001) and Randolph's (2001) technique (1994). The stiffness of the individual components, namely piles and raft, as well as piled-raft as a block, is employed in this technique to estimate the load sharing between the raft and piles. It was decided to construct a vertical load-settlement relationship.

For $P \leq PA$: $S = \frac{P}{Kpr}$

For $P > PA$: $S = \frac{P}{Kpr} + \frac{P - Pa}{Kr}$

Where, K_p, K_r, and K_{pr} are the stiffness of piles, stiffness of raft, and stiffness of piled-raft, respectively, P and P_A are design load and load calculated at which the pile capacity is fully used. At the loads higher than P_A, only raft takes load. For corresponding load settlement is calculated.

RESULTS AND DISCUSSION

Objective of this study is to compare pile group foundation with pile raft foundation for specific loading and specific site condition. And to find best selection which is most economical, as well as safe for multi layered soil condition. Thus the results of both foundations after analytical design are stated below in table.

Foundation	Pile Group	Pile Raft
Volume (m3)	487.73	346.36
Total Settlement (mm)	70.50	44.07
Differential Settlement(mm)	16.30	15.56
Lateral Deflection (mm)	24.90	30.16
Rotation (rad)	1.086982×10^{-3}	0.8643×10^{-3}

From above table we can observe that, after use of pile raft instead of pile group foundation volume is reduced by 28.98%, total settlement is reduced by 37.49% and differential settlement reduced by 4.54%. Therefore it is most economical as well as safe foundation, as volume is directly depends on cost, if volume reduces cost will also reduce significantly. Differential settlement is important factor to analyse and here differential settlement is also reduced, therefore it is more safer than pile group foundation. Rotation is calculated on the basis of differential settlement for pile group foundation and pile raft foundation, it is reduced from 1.08×10^{-3} rad to 0.8643×10^{-3} rad shows tilting of foundation corresponds to tilting of tower. Both designs were checked for two criteria as safety and economic using parameters as differential and total settlement, rotational angle and volume of material required for construction and also compared in above table.

CONCLUSION

Based on comparative study conducted for safe and economic foundation for heavy wind turbine load. Pile raft foundation that is hybrid foundation is most economical and safe foundation. Differential settlement is reduced by use of combination of both shallow and deep foundation, and this leads to make more safe foundation. Volume and construction cost reduction directly affects its economic state, by use of pile raft foundation reduces its volume of materials used for construction and leads to make it economically most efficient foundation. Therefore pile raft foundation is best selection of foundation for heavy loading.

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