Numerical Modelling and Analysis of Factors Influencing Bearing Capacity of Skirt Foundation

C. Goutham, S. Chezhiyan

Abstract*: Skirt foundations have been discovered to be one of the alternatives to stacking offshore structures such as wind turbines, petroleum platforms etc. Offshore wind turbines are primarily exposed to vertical and lateral loads due to wind and present conditions. Many scientists have already carried out multiple vertical loading experiments on a circular footing and have found that this category of foundation increases bearing ability, decreases settlement and changes the behavior of load settlement. In this study, a 3D finite element analysis is carried out to evaluate how the skirt foundations are influenced by the vertical loads. The soil medium and skirt foundation were designed for analyses with varying in their aspect ratios (change in dimensions of depth, d and diameter, D) of skirt foundation and area ratio of skirt foundation. The effect of compactness of soil medium is also calculated by using various types of soil parameters. Furthermore, the current results express how the load carrying capacity of skirt foundation is varied by changing in the aspect ratios and area ratios of the skirt foundation. Also conclusions were drawn that compactness of soil medium plays a vital role in carrying vertical load.

Index Terms*: Skirt foundation, soil, Abaqus, Aspect ratio, Area ratio.

I. INTRODUCTION

There are various methods to stabilize the soil that have been developed and used. It has been expensive on operation and equipment's also restricted by the site conditions. In some situations, they are hard to apply to current foundations. Skirt foundations are good alternative to improve the ability of the bearings and to reduce the settlement of footing on the ground. Skirted foundations are a type of offshore shallow foundations consisting of a plate on the sea bed and an outer skirt penetrating into the sea bed surrounding a soil plug [1] as shown in figure 1. The foundation design comprises of a steel cylinder with a diameter D, skirt length L and skirt thickness t that is closed by a usually highly stiff upper steel cover is shown in figure 2. The skirted foundation system was originally created for floating offshore oil and gas platforms. . For a significant period, skirt foundation have been used to improve the efficient depth of the foundations and other circumstances, where water scouring is a significant issue, used for petroleum and gas advances in shallow and deep water and wind turbines, often needed to withstand heavy loads or important times of overturning. [2] First explored the use of buckets as foundations for wind energy, while [3] and [4] submitted status reports on the subject. They indicated that the efficiency of bucket suction foundations for offshore wind farms under the previous combined loading (V, H, M) conditions. The analysis of vertical load carrying capacity of skirt foundations are being tested over a period of time [5], [6]. The capacity of piles in various soil densities is assessed using both experimental [7] and numerical modelling [8] with varying in aspect ratios (L/D) [9] and the failure envelops were also considered for all spacing impacts [10]. Coming to field tests outcomes with skirt bucket type foundation in sand with vertical loading are shown in [4], [11]. These experiments are used for numerical modelling validation in some cases. There are also some field tests reported in [12], [13]. In this study the bearing capacity subjected to vertical loading is determined through Finite element analysis. Finally this study investigates the factors influencing the bearing capacity of the skirt foundation, such as varying in type of soil, change in length of the foundation and varying in the thickness of the skirt foundation.

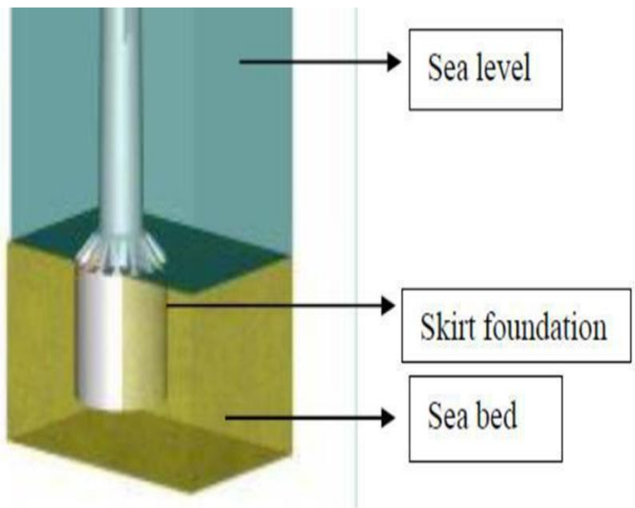

Figure 1 Prototype of the skirt foundation inserted in sea bed

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C. Goutham, Department of Civil Engineering, SRM Institute of Science & Technology, Kattankulathur, Kancheepuram District, Tamil Nadu, India.

S. Chezhiyan, Assistant Professor, Department of Civil Engineering, SRM Institute of Science & Technology, Kattankulathur, Kancheepuram District, Tamil Nadu, India.

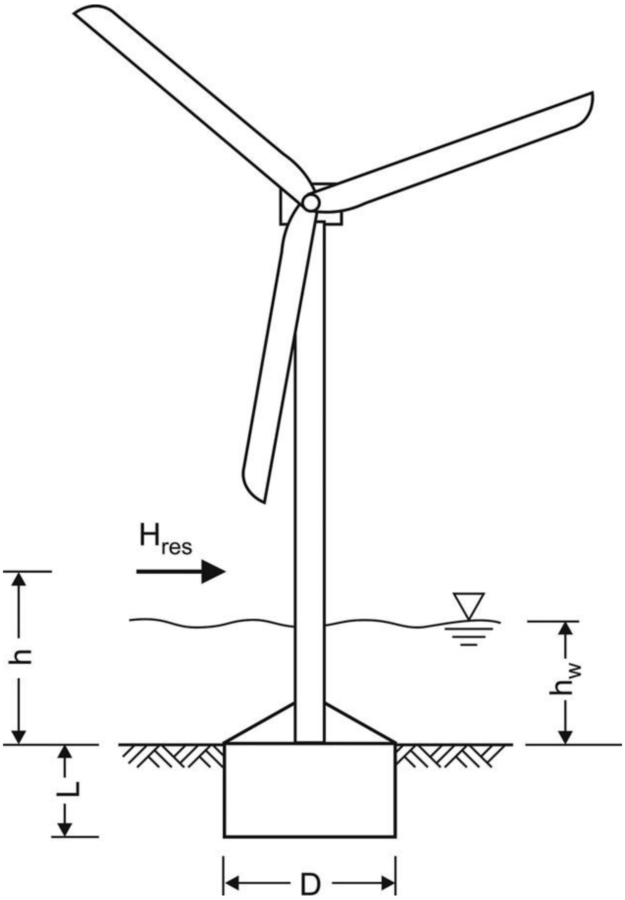

Figure 2 Offshore wind power converter schematic sketch with a monopod skirt foundation

II. FINITE ELEMENT MODELS

In this research, a model of a skirt foundation scheme was created and used in the parametric research scope. The finite element ABAQUS program software Version (6.12) [14] were used for analyses. The materials used in this model are sand and steel. From the previous studies, data was considered and used to analyze in the different field conditions such as varying the aspect ratio (depth/diameter), area ratio and other aspects such as changing in unit weight of the soil. The foundations with embedding ratios (d/D) of 0.5, 1, 1.5, 2, 2.5 and skirt wall thickness of (t/D) = 0.003 were considered, where d is the depth of the embedding skirt, D is the circular foundation diameter and t is the foundation thickness. The sand was modelled as an elastic-perfect plastic material in accordance with the Mohr-Coulomb yield criterion. The unit weight of soil is considered as $\gamma = 19.5$ KN/m3 [4] and the under watered elastic properties having a 50 MPa young's modulus and the poisons ratio Ʋ of 0.3 [9]. The undrained plastic properties like cohesion c, internal friction angle Ø and dilation angle Ψ are attributed to the sand. The figure 2 shows a typical axi-symmetric finite element mesh. Preliminary analyses were performed to determine mesh fineness and model size in order to achieve adequate results precision and prevent the impact of boundary conditions. The width of the modelled sand medium was three times the diameter from the center of the skirt and six times the length of the skirt to avoid limiting effects on the bearing

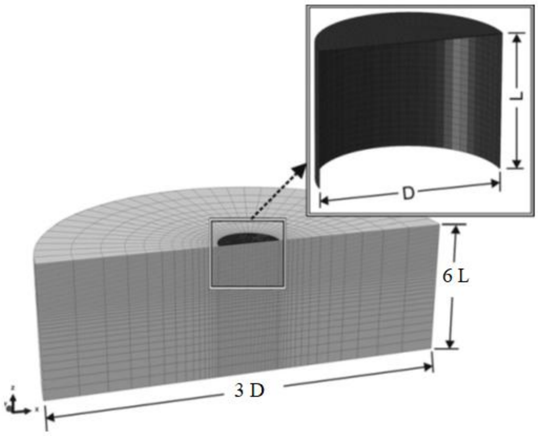

Figure 3 Typical axi-symmetric finite element mesh of skirt foundation

Capacity. Displacements were provided along the boundaries of the sand medium. Eight-node C3D8 elements were for meshing the structure of the foundation and the soil. An example mesh of the finite element model is presented with geometric properties in figure 3. Fixed supports are given to the bottom of the soil medium. Simulation of the interfaces between the skirt and the sand are given by using the penalty function in Abaqus. The contact between the outer surface of the skirt and inner surface of the sand which is in contact with the skirt foundation are assumed to be rough to make the calculation more stable. To determine the ultimate load carrying capacity under vertical loading, vertical restrictions were applied. The force versus displacement graph for each case provided the ultimate load carrying capacity of skirt foundation.

III. RESULTS AND DISCUSSIONS

A. Effect of Aspect Ratio on Vertical Loading Capacity

The analysis for different Aspect ratio of skirt foundation has been done for five models for this study with the variance of aspect ratios (L/D) as 0.5, 1, 1.5, 2 and 2.5. The aspect ratios and dimensions are presented in Table 1.

Table 1 Dimensions of skirt with different aspect ratio

S. No	Aspect ratio (L/D)	Diameter of skirt [D] in m	Length of skirt [L] in m	Thicknes s of skirt [T] in m
1	0.5	12	6	0.04
2	1	12	12	0.04
3	1.5	12	18	0.04
4	2	12	24	0.04
5	2.5	12	30	0.04

The load displacement curves for different Aspect ratios of skirt foundation are shown in Figure 3. To study the effect of Aspect ratio of the skirt foundation a series of analysis are carried out. The ultimate vertical load carrying capacities of integrated skirt foundations for Aspect ratios 1, 1.5, 2 and 2.5 are increased by approximately 22.7%, 59.24%, 123.4% and 179.05% respectively, compared with the skirt foundation of Aspect ratio 0.5.

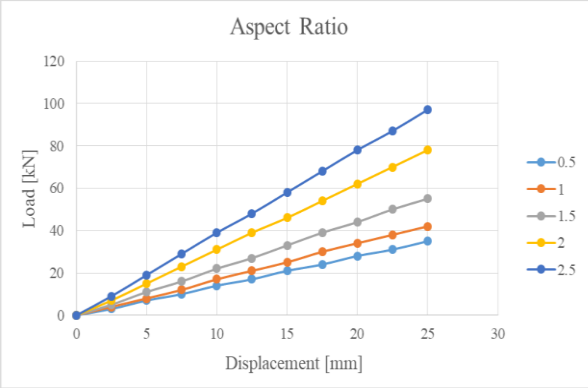

Figure 4 Force vs displacement curve of different aspect ratios

The vertical loads for each aspect ratio at 25 mm displacement are shown in Table 2

Table 2 Vertical load capacity of skirts with different aspect ratios

Aspect ratio	Displacement (mm)	Load (kN)
0.5	25	35.16
1	25	42.87
1.5	25	55.35
2	25	78.58
2.5	25	97.5

B. Effect of Area Ratio on Vertical Loading Capacity

The analysis for different Area ratios of skirt foundation for five models were done for this study with the variance of area ratios as 0.5, 1, 1.5, 2 and 2.5. The area ratios and dimensions are presented in Table 3.

$$A_r = \frac{D_o^2 - D_i^2}{D_i^2} X\,100$$

Where A_r is the area ratio, D_o is the outer diameter and D_i is inner diameter of the skirt foundation.

Table 3 Dimensions of skirt with different area ratio for vertical loading

S. No	Area Ratio	Diameter of Skirt [D] in m	Length of Skirt [L] in m	Thickness of Skirt [T] in m
1	0.5	12	12	0.015
2	1	12	12	0.030
3	1.5	12	12	0.045
4	2	12	12	0.060
5	2.5	12	12	0.075

To study the effect of Area ratio of the skirt foundation, a series of analysis are carried out. The ultimate vertical load carrying capacities of integrated skirt foundations for Area ratios 1, 1.5, 2 and 2.5 are increased by approximately 99.74%, 267.63%, 390.79%, 513.17% respectively, compared with the skirt foundation of Area ratio 0.5. The load displacement curves for different Area ratio of skirt foundations are shown in Figure 5.

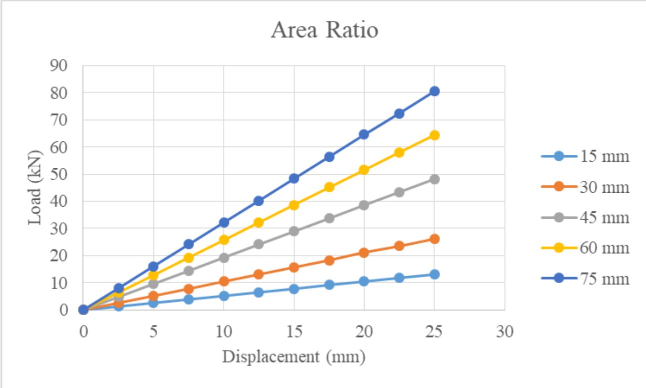

Figure 5 Force vs displacement curve for area ratio

The vertical loads for each area ratio at 25 mm displacement are shown in Table 4

Table 4 Vertical load capacity of skirts with different area ratio

Area ratio	Displacement (mm)	Load (kN)
0.5	25	13.42
1	25	26.5
1.5	25	48.63
2	25	64.17
2.5	25	80.61

C. Effect of Compactness of Soil Medium on Vertical Loading Capacity of Skirt Foundation

The analysis for finding the compactness of soil medium under skirt foundation were done for this study with aspect ratio 1 for various types of soil (very loose, loose, medium, dense and very dense). The unit weight property for different types of soil are presented in Table 5.

Table 5 Unit weights of soil medium

S. No	Type of Soil	Unit weight kN/m
1	Very loose	15.25
2	Loose	15.80
3	Medium dense	16.72
4	Dense	17.38
5	Very dense	17.93

The aspect ratios and dimensions are presented in Table 6.

S. No	Aspect ratio (L/D)	Diameter of skirt [D] in m	Length of skirt [L] in m	Thickness of skirt [T] in m
1	1	12	12	0.04

To study the effect of compactness of soil medium, a series of analysis are carried out. The ultimate vertical load carrying capacities of integrated skirt foundations for different types of soils (very loose, loose, medium dense, dense, very dense) are increased by approximately 3.51%, 9.59%, 14.19%, 17.42% respectively, compared with the loose soil medium. The load Displacement curves for different types of soil medium of skirt foundation are shown in figure 6.

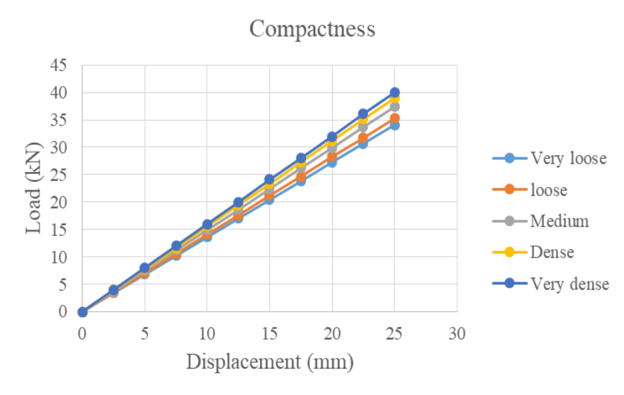

Figure 6 Force vs displacement curve of skirt foundation on different soil medium

The vertical loads for different type of soil at 25 mm displacement are shown in Table 7

Table 7 Vertical load capacity of skirts in different soil medium

Type of soil	Load (kN)
Very loose	34.8
Loose	35.7
Medium Dense	37.42
Dense	39.7
Very Dense	40.9

IV. CONCLUSION

By numerical modelling, the impact of vertical loads on the conduct of piles in sand was explored. The numerical models were carried out with the ABAQUS computer program and the models were checked. The verified numerical models were then used to carry out a parametric survey with different aspect ratios, area ratios and different soil configurations to evaluate the load carrying capacities of steel piles subjected to vertical loads. On this basis, the following are the conclusions drawn

1. A sequence of load displacement curves were obtained by numerical analysis of skirt model with different aspect ratio (d/D) to establish the vertical load capacity under ultimate conditions. Aspect ratio of skirt foundation play an important role in the vertical load carrying capacity. The increase in the aspect ratio of skirt foundation will increase the vertical load carrying capacity significantly.
2. The effect of area ratio in vertical load carrying capacity of skirt foundation is relatively insignificant, the results of numerical analysis concluded that the vertical load carrying capacity is increasing with the increase of area ratio of skirt foundation.
3. The effect of compactness for different types of soil are analysed to determine the load carrying capacity of the pile foundation based on the soil unit weights. The increase in the densities of soil medium tends to increase in the vertical load carrying capacity.

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AUTHORS PROFILE

Mr. C. Goutham completed B.E Civil Engineering at Vasireddy Venkatadri Institute of Technology in Guntur, Andhra Pradesh and pursuing masters in Geotechnical Engineering from SRMIST, Chennai, Tamil Nadu.

Mr. S. Chezhiyan (corresponding Author) working as an assistant professor of Civil Engineering in SRMIST, Chennai, Tamil Nadu. Completed B.E Civil Engineering at Senguthar Engineering College, Anna University and masters in College of Engineering Guindy Campus, Anna University.