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LATERAL CAPACITY OF SKIRT FOUNDATION ON LOOSE SUBMERGED SAND

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ABSTRACT

Skirted foundation consist of a plate resting on the bed level and a peripheral skirt attached to the plate which is hollow inside so that the hollow space was accumulated with soil plug inside it. Skirt foundations was found to be one of the alternative solution to pile foundations for offshore structures such as wind turbines, oil platforms etc. Offshore wind turbines are largely subjected to lateral loads mainly due to wind and current. This study had been made to find out the lateral load carrying capacity of the circular skirted footings with different L/D ratios on loose submerged sand. The load carrying capacity of skirt foundation was studied on the model bucket foundation, which was scaled down from actual prototype. The tests have been conducted for poorly graded sand. The load vs displacement behaviour of foundation was observed from the tests.

Key words: Offshore, Lateral load, Dynamic friction, Threshold, Rotation, Prototype.

INTRODUCTION

There are many onshore wind turbines, which have been used in India. However, there is a lot of controversy associated with this option for renewable energy generation. The main reason for this is the aesthetic effect of the onshore wind farm on the landscape. Moving wind turbines offshore could be a solution for this problem. Moreover, by using offshore wind turbines, larger wind turbines can be constructed which therefore supply much more power and can be more economically efficient. In the development of offshore wind turbines, the foundations usually are a significant. Skirt foundation is one such type. Skirt foundation controls the movement of soil below the footing due to which confining pressure develops inside the skirt thereby increasing the strength of the skirt foundation. Bransby and Randolph (1998) studied the behaviour of skirted strip footings and circular footings subject to combined vertical, horizontal and moment loading using finite element and plasticity analysis of equivalent surface foundations and observed that the shape of the yield locus for

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two foundation geometries was similar but the purevertical, moment and horizontal capacities varied with the footing shape and soil strength. In the case of shallow offshore foundations the stability is achieved through the foundation bearing on the sea bed and it can idealize as large circular footings subjected to Vertical, horizontal and moment loading. Byrne (2002) used the shallow inverted buckets as foundations, installed by suction, in place of the piles and the important mechanisms to consider in the design of these shallow foundations for dense sand. These foundations lead to cost savings through reduction in materials and in time required for installation.

Wakil (2010) proved that the horizontal displacement-load relationship for skirted and unskirted circular footings is linear up to horizontal displacement and equals to 2% of the footing diameter. The horizontal displacement of skirted and unskirted footings at failure threshold is some value between 6% and 8% of the footing diameter. Singh (2013) evaluated the performance of a circular footing with a structural skirt resting on sand subjected to a horizontal load. They investigated through an experimental study and concluded that the increase of horizontal load carrying capacity is substantial when the relative density of soil is more than 60% and this may be attributed to the increase of confinement provided by the surrounding soil. The average deformation undergone by the Shallow Skirted Footings before failure is typically in the range 20 to 40% of the diameter of the circular footing. Many researchers had carried out research work for skirted foundations in dry state. This study is focusing on the behaviour of skirt foundation on loose submerged sand subjected to lateral eccentric load.

Testing arrangement

Soil bin

Laboratory tests on skirted foundations were carried out in a steel square tank with internal dimensions of 420 mm x 420 mm and the wall thickness was 4 mm. The depth of the tank was 600 mm. The dimensions of the tank was chosen on manner to avoid the confinement effect due to tank wall.

Submergence arrangement

Piping arrangement was provided at the bottom of the tank above 30 mm sand bed to submerge the soil. Piping arrangement consists of longitudinal pipe and 6 number of lateral pipes. The diameter of the pipe was 24 mm. 8 number of 4 mm diameter holes were provided on longitudinal pipe and 4 number of 4 mm diameter holes were provided on each lateral pipe. Geotextile was placed over the piping arrangement to avoid clogging of sand inside the holes on piping arrangement.

Skirt foundation model

Model skirted foundation was made using mild steel. The diameter of skirt and plate was 90 mm with thickness of about 2 mm. Dimensions of the skirt foundation model were reduced from geometrical similarity from the actual prototype in Frederikshavn (Ibsen, 2005). Four number of skirt foundation model were made by varying L/D ratio i.e. length of the skirt (L) to the footing diameter (D) were 1.0, 1.5, 2.0 and 2.5 shown in Fig. 1.

Fig. 1: Model skirt foundation

Loading arrangement

Two dial gauges were used to measure the horizontal displacement and one dial gauge was used to measure rotation. All the dial gauges had an accuracy of 0.01 mm. The lateral load was applied using a pulley arrangement. Rope was used to pull the footing. One end of the rope was clamped with footing and other end with loading plate as shown in Fig. 2. All the dial gauges were placed on the opposite side of loading arrangement.

Fig. 2: Horizontal loading arrangement

Soil properties

Beach sand which was collected from Kovalam, Chennai were used for testing. The properties of collected sand was given in Table 1.

Table 1: Index properties of submerged sand

S. No.	Description	Values
1	Percentage of medium sand	10%
2	Percentage of fine sand	90%
3	Uniformity coefficient	1.18
4	Coefficient of curvature	1.00
5	Soil classification as per IS 1498-1970	SP Poorly graded sand
6	Specific gravity	2.66
7	Minimum dry density γ_{min}	14.28 KN/m^3
8	Maximum dry density γ_{max}	16.68 KN/m^3

Methodology

In the tank sand was filled in layers. Each layer of filling is 100 mm thick. Sand filling funnel was used to fill the soil inside the tank. Loose state of soil was achieved by filling the sand with the height of fall of about 25 mm. The sand was formed up to a height of 58 cm from bottom including the piping arrangement. Then water was applied using piping arrangement and sand inside the tank was submerged. The water level was maintained at 10 mm above the top level of formed sand medium. Finally the skirt foundation model was pushed inside the submerged sand.

The load was applied incrementally on the foundation model. Each load increment was kept constant until the foundation displacement reaches the value of 0.01 mm for 5 min for three consecutive such readings. Then next load increment was applied.

RESULTS AND DISCUSSION

Effect of l/d ratio on horizontal displacement

To find out the effect of L/D ratio of skirt foundation model, four different L/D ratios were used. The L/D ratios used are 1.0, 1.5, 2.0 and 2.5. Then skirt foundation model is subjected to lateral loading without any control in strain. From the Fig. 3, it is evident that there is increase in lateral capacity with increase in L/D ratio. The lateral capacity of skirt foundation with L/D = 2.5 was 94.598, which is 6.6 times higher than L/D = 1.0.

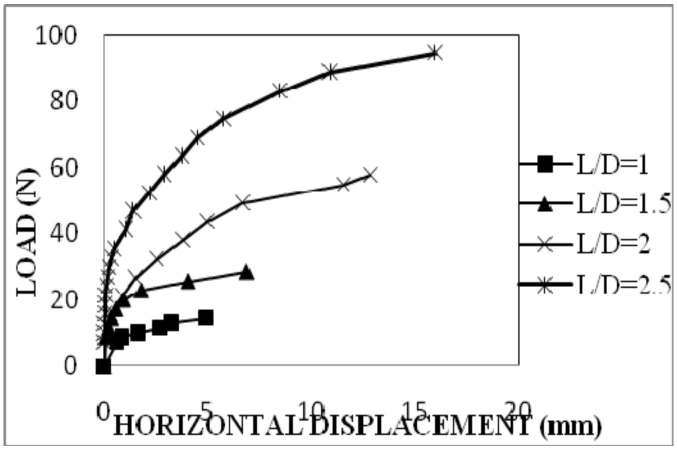

Fig. 3: Load vs horizontal displacement for model skirt foundation with L/D = 1, 1.5, 2.0 and 2.5

Load vs rotation for different L/D ratios

From the Fig. 4 it is seen that the rotation of skirt foundation model is linear up to the threshold value thereafter the foundation is running to failure with excessive rotation i.e., when the rotation is less than or equal to 1 degree the behavior is proportional. When the rotation exceeds 1 degree dynamic friction behavior of foundation is noticed.

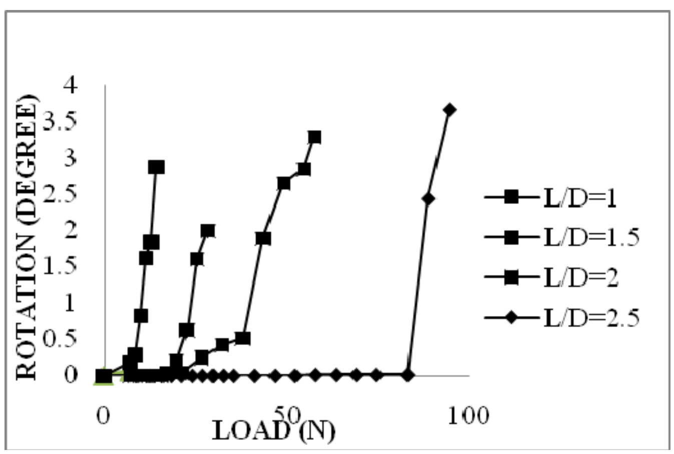

Fig. 4: Load vs rotation for model skirt foundation with L/D = 1, 1.5, 2.0 and 2.5

Effect of horizontal displacement on rotation

From the Fig. 5, it is evident that the rotation of foundation model is linear up to 5 mm. When the horizontal displacement of foundation exceeds 5 mm the variation in rotation found to be more even though when the magnitude of applied load is small. However the foundation model L/D shows insignificant rotation above 8 mm. This is due to the soil plug inside it was more when compared to other foundation model. The failure of the foundation is mainly due to excessive rotation which causes the excessive horizontal displacement.

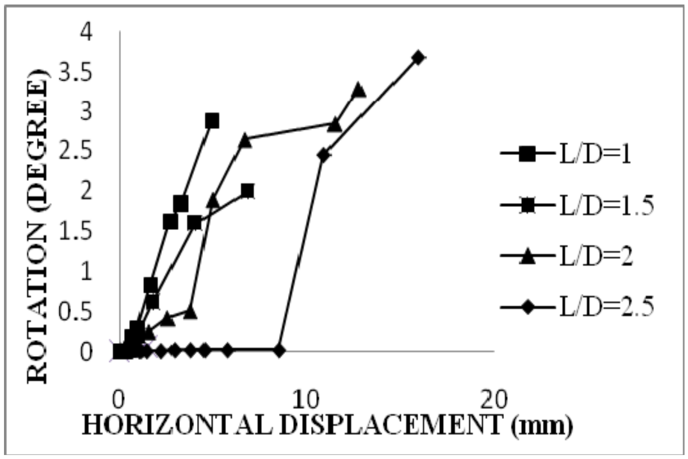

Fig. 5: Horizontal displacement Vs rotation for model skirt foundation with L/D = 1, 1.5, 2.0 and 2.5

CONCLUSION

(i) Lateral load carrying capacity of the skirt foundation increases with increase in L/D ratio (6.6 times more for L/D = 2.5 when compared to L/D = 1.0).

(ii) When the footing displacement increases beyond the threshold value the foundation fails suddenly with excessive rotation and excessive horizontal displacement.

(iii) The mode of failure changes from sliding to rotation after the threshold value.

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