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# Behaviour of Skirted Footing Resting on Sea Sand

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***Abstract*** **– To understand the vertical load carrying capacity of soil and in order to solve the combined load carrying problems it is very much necessary to study the relationship between vertical load and its corresponding vertical displacement in soil. Structural skirts hold good as an alternative method of improving the vertical load carrying capacity and reducing the settlement of footing resting on soil. Structural skirts are being used underneath shallow foundations of offshore structures for many decades due to their stability advantages and due to its ease of installation. These foundations are economical, as they lead to cost saving through reduction in materials and in time required for installation. These type of foundations have been used for a considerable period to increase the effective depth of the footing in marine areas and other situations where water scouring is a major issue. In this project work, a series of vertical load test was conducted for different relative density and different skirt length to diameter ratio .Tests were conducted on circular footing placed centrally on sea sand filled tank with and without skirts in different combinations of height and diameters. From the various set of data's obtained, comparison was made between the results of unconfined case and confined case.**

***Keywords***: **Structural Skirts, Offshore Structures, Settlement.**

## I. INTRODUCTION

There are many offshore structures, which have been used in India. As far as an offshore structure is concerned water scouring and the soils bearing capacity are the main problem. Geotechnical engineers have always been in search of finding a solution for the problem which is less expensive and less restricted by site conditions. In this case, the structural skirts hold good as an alternative method for the arised problem and also for improving the bearing capacity and reducing the settlement of footing resting on soil. A variety of methods of soil stabilization are known & well-developed, but they can be expensive and can be restricted by the site conditions. The skirted foundation consist of a slab which may have any shape (circular, rectangular or square) but mostly the shape of the skirt is kept same as that of the footing. The proposed footing can be used for industrial chimneys, storage tank, industrial floors, grain silos or even for small buildings. Sometimes for architectural requirements, some portion of the structure may be on weak soil, in such cases also skirted foundations are used to gain stability for the structure and thus soils are prevented from the lateral movement. And ultimately the bearing capacity is increased and settlement is reduced. For some situations the methods are difficult to apply to existing foundations, in such conditions also skirted footing is a favorable option. In this method of bearing capacity improvement , requirement of any excavation of the soil is not needed and is also not restricted by the presence of a high level ground water table. The vertical skirts improve the capacity of the foundation by 'trapping' the soil beneath the raft and between the skirts so that the applied soil is transferred to the soil at the skirt tips. Vertical loading due to the self -weight of installation of structure (eg. Jacket structure, wind turbine) is also improved as soft surface soils are confined within the skirt and these foundation loads are transferred down to harder underlying layers of soil. The horizontal load carrying capacity is improved by the skirt and resist lateral sliding.

## II. METHODOLOGY

This chapter deals with the details of material used, sample preparation and testing procedure that have been adopted.

### 1 Materials used

The materials used for the study are sea sand, and unplasticized polyvinyl chloride pipes.

### 1.1Soil

Table1. Properties of soil

| Properties of sand | Value |
|---|---|
| Specific Gravity | 2.654 |
| Coefficient of curvature, $C_C$ | 1.445 |
| Coefficient of uniformity, $C_u$ | 2.0 |
| Soil classification | Poorly graded soil(SP) |
| C and Ø | C=0, Ø=31° |

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Experiments were carried out on sea sand taken from Perumathura Beach, in Trivandrum district. The figure 3.1 shows the particle size distribution of sea sand used for the study. Table below shows the properties of soil that was found out by carrying out different laboratory experiments. The maximum and minimum dry density of the sand was found out by carrying out the test in relative density apparatus. In order to find out the minimum dry density of sand, the sand was poured into the cylindrical mould as loosely as possible using a funnel in spirally motion. Again for determining the maximum dry density, the mould was refilled and was compacted by placing the setup on a vibrating table. The values of maximum dry density and minimum dry density was 1.618gm/cc and 1.490gm/cc respectively.

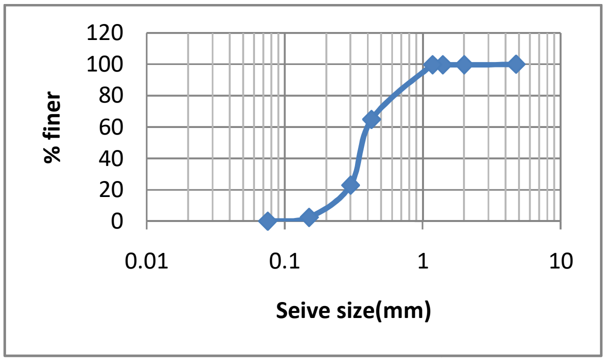


Fig.1 Particle size distribution of sand

From the paticle size distribution graph obtained by dry sieve analysis test (Fig.3.1)the Effective size of particle ($D_{10}$) is 0.2. The particle size distribution had a steep slope graph and as $C_u$ value is less than 4, thus the testing soil was classified under poorly graded sand.

**1.2 Skirt**

The skirt used in the experiment was poly vinyl chloride(i.e.PVC Pipe). Skirts were used to laterally confine the sand. PVC pipe compound consist mainly of poly vinyl thermoplastic resin. About 70 to 90% of PVC pipe compound is comprised of resin and the rest by chemical additives that chemically react with resin to optimise the processing and generate desirable finished product. The rigid PVC pipes as per IS 4985:2000 specifications of different diameters 6cm,7.3cm, 8.8cm and 9.2cm were used as skirts. These PVC pipes were cut in lengths for a L/D ratios of 1, 1.5, and 2 respectively. The interior and exterior of the skirt were smooth. The thickness of the cylinder wall, of the PVC pipe varies from 1.5mm to 1.8mm as mentioned in the IS code.

Where, D = Diameter of the footing
d=Diameter of skirt
h=Height of skirt

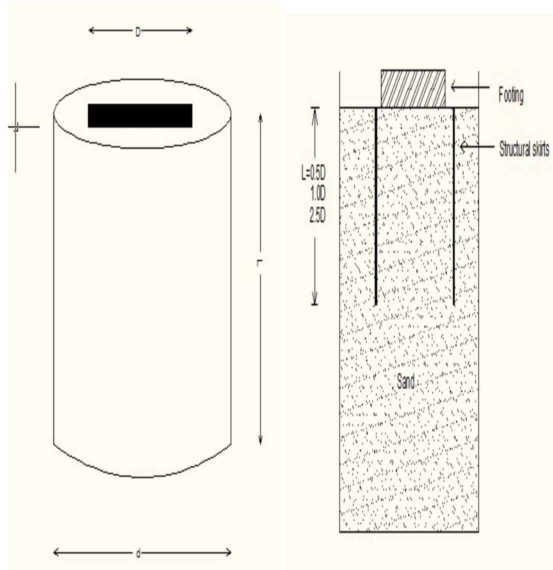


Fig. 2. Geometrical parameters of skirt foundation model.

**2 Experimental Procedure**

To study the behavior of a skirted footing on sea sand, laboratory tests were conducted on a model of circular footing having diameter (D) equal to 600mm.The model testing tank was of diameter 208cm. Dimension of the model test tank was fixed by keeping in view the ratios adopted by various researchers and the adopted tank dimensions as 3 times the diameter of footing. The footing model was made from high yield tension (HYSD) steel metal. Beach sand was used as the foundation soil in the physical model testing . The sand is filled in the model tank for relative densities of 30%, 45% and 60% by compacting using a rammer of 200 mm diameter. After filling the sand at required densities, the top surface of the sand was leveled using a straight steel plate and the skirts were pushed vertically into the sand and a circular fooring of 600mm is placed centrally above the soil. The setup was placed on a strain controlled loading platform without disturbing. Now the load was applied on the setup ad its corresponding deflection was measured . Dial gauge was placed on the footings in order to measure the vertical settlement of the footing while at the time of application of load. The load settlement graph was plotted with the readings obtained.3 series of tests were carried out with varying L/D ratio as 1, 1.5, and 2. Reference test was carried out in the similar manner on the footing with L/D ratio of zero to know the effect of skirt on the bearing capacity of the footing. The failure load for the smooth skirted footing is obtained from the load settlement curve that was plotted from the values obtained from the different laboratory tests.

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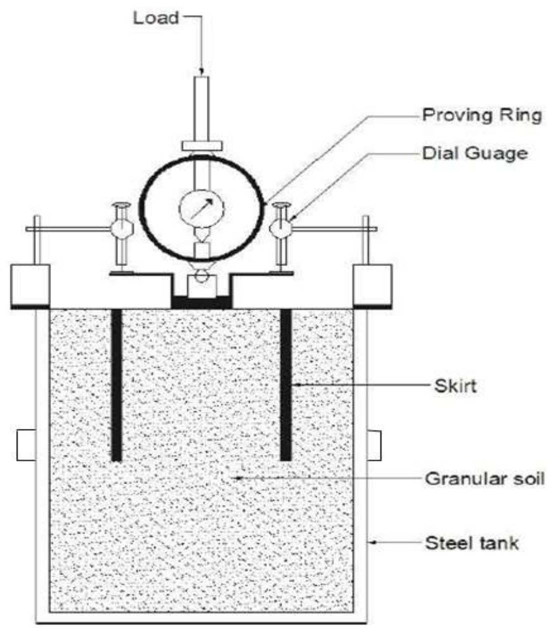


Fig. 3 Schematic diagram for the setup of vertical load test.

Table 2. The summary of the experiments

| Test Series | Constant parameters | Variable parameters | | |
|---|---|---|---|---|
| | | d/D | R.D | No. Of tests |
| A | Unconfined sand | | 30% | 1 |
| B | Diameter of skirt=6cm | 1.0, 1.5, 2.0 | | 3 x 1=3 |
| C | Diameter of skirt=7.3cm | 1.0, 1.5 ,2.0 | | 3 x 1=3 |
| D | Diameter of skirt=8.8cm | 1.0 ,1.5 ,2.0 | | 3 x 1=3 |
| E | Diameter of skirt=9.8cm | 1.0 ,1.5 ,2.0 | | 3 x 1=3 |
| A | Unconfined sand | | 45% | 1 |
| B | Diameter of skirt=6cm | 1.0, 1.5, 2.0 | | 3 x 1=3 |
| C | Diameter of skirt=7.3cm | 1.0, 1.5 ,2.0 | | 3 x 1=3 |
| D | Diameter of skirt=8.8cm | 1.0 ,1.5 ,2.0 | | 3 x 1=3 |
| E | Diameter of skirt=9.8cm | 1.0 ,1.5 ,2.0 | | 3 x 1=3 |
| A | Unconfined sand | | 60% | 1 |
| B | Diameter of skirt=6cm | 1.0, 1.5, 2.0 | | 3 x 1=3 |
| C | Diameter of skirt=7.3cm | 1.0, 1.5 ,2.0 | | 3 x 1=3 |
| D | Diameter of skirt=8.8cm | 1.0 ,1.5 ,2.0 | | 3 x 1=3 |
| E | Diameter of skirt=9.8cm | 1.0 ,1.5 ,2.0 | | 3 x 1=3 |

The summary of different test carried out are tabulated in the table above.(Table.3.2) 3 set of experiments were carried out for each of relative densities of 30%,45% and 60%.Confined and unconfined conditions are considered with different L/D ratios of 1,1.5 and 2.

## III. RESULTS

### 1 Comparison of Graph With Varying L/D Ratio

The graph is plotted between load and settlement with different L/D ratio for corresponding diameters and for their respective relative densities (30%,45% and 60%)

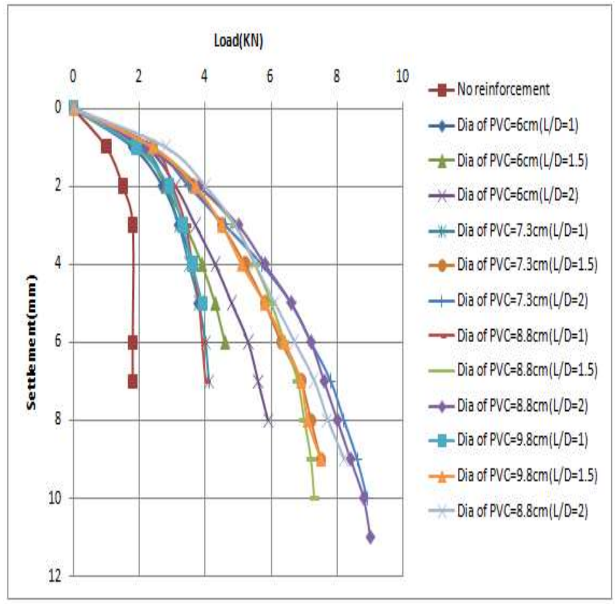


Fig. 4 Comparison of graph for relative density of 30%

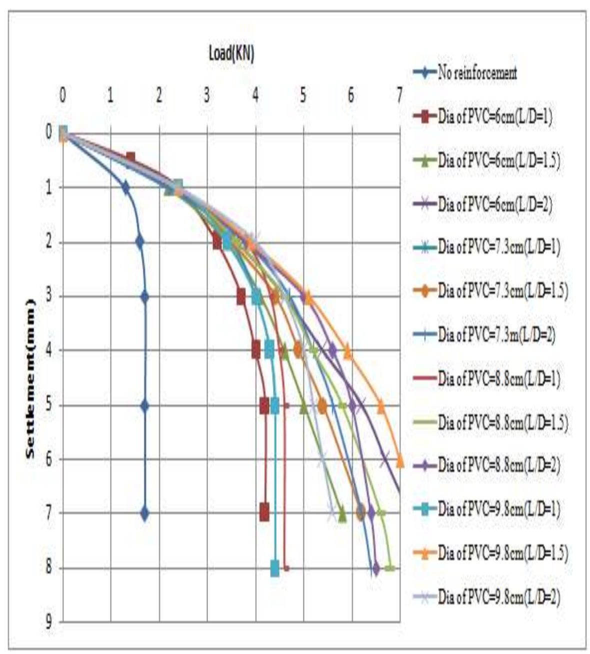


Fig. 5. Comparison of graph for relative density of 45%

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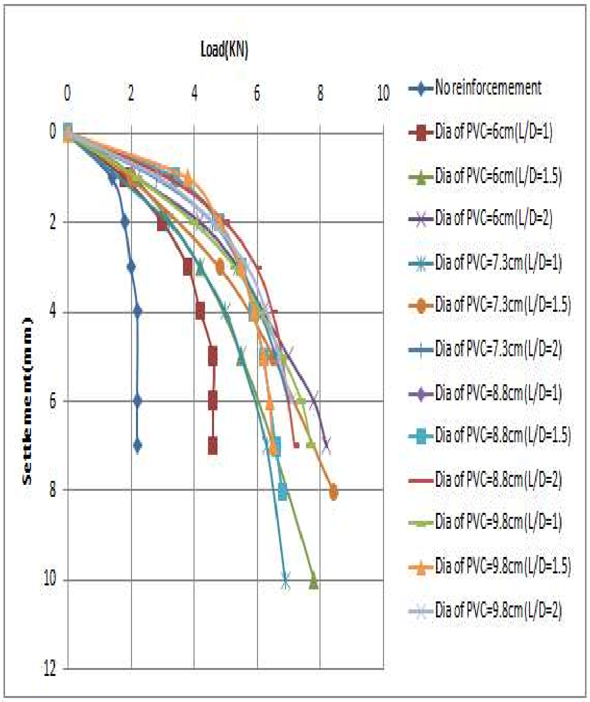


Fig. 6. Comparison of graph for relative density of 60%

Test result indicated that for sand of different relative density the load varies between 2KN to 8KN for a settlement of 6mm for unconfined and confined case respectively.

### 3.2 Effect of Skirt on the Bearing Capacity Ratio in Sea Sand

Bearing capacity ratio is defined as the ratio of failure load after skirt application (confined case) to the failure load without its application(unconfined case).Results show the values of BCR for all the L/D ratio at different relative densities (30%,45% and 60%) both in tabular form (Table.3) as well as in graphical form(Fig7, Fig8 and Fig 9)

From the table shown above it was found that as the length of the skirt increases, the bearing capacity is also increased. That is the increase in length transfers the load to a safer area and are distributed to different layers. Now for the length,as the length of the skirt was increased, the footing was deeply seated and the depth of foundation increased. Due to this, the bearing capacity of the skirted footing increases as there is increase in relative density and increase in length of skirts.

Now when considering the ratio between diameter of skirt and diameter of footing, the bearing capacity increases as the ratio of diameter of skirt to diameter of footing increases(d/D). Generally, the displacement of sand are mainly due to displacement of sand grains and due to compressibility of sand. And the effect of these two factors on displacement are also influenced by applied load, relative density of the sand and the L/D rtaio.

Table 3: BCR for all L/D ratio at RD of 30%, 45% and 60%

| Diameter of skirt / Diameter of footing | BCR | | | |
|---|---|---|---|---|
| | L=1D | L=1.5D | L=2D | |
| 1 | 1.64 | 1.71 | 1.85 | Relative Density=30% |
| 1.21 | 2.01 | 2.24 | 2.37 | |
| 1.46 | 2.21 | 2.76 | 2.96 | |
| 1.63 | 1.7 | 2.3 | 2.7 | |
| 1 | 1.93 | 2.06 | 2.13 | Relative Density=45% |
| 1.21 | 2.26 | 2.46 | 2.75 | |
| 1.46 | 2.53 | 3 | 3.4 | |
| 1.63 | 2.35 | 2.8 | 3.12 | |
| 1 | 1.98 | 2.23 | 2.35 | Relative Density=60% |
| 1.21 | 2.38 | 2.72 | 2.98 | |
| 1.46 | 2.59 | 3.12 | 3.73 | |
| 1.63 | 2.4 | 2.9 | 3.2 | |

A graph is plotted with bearing capacity ratio (BCR) and Skirt diameter to Diameter of footing. The graph below shows that as the ratio of diameter of skirt to diameter of footing increases the bearing capacity also increase linearly and then decreases steeply. The graph below shows the variation in bearing capacity ratio to the ratio of the skirt diameter to diameter of footing for a relative density of 30%. After reaching a d/D ratio of 1.46 the graph starts to fall.

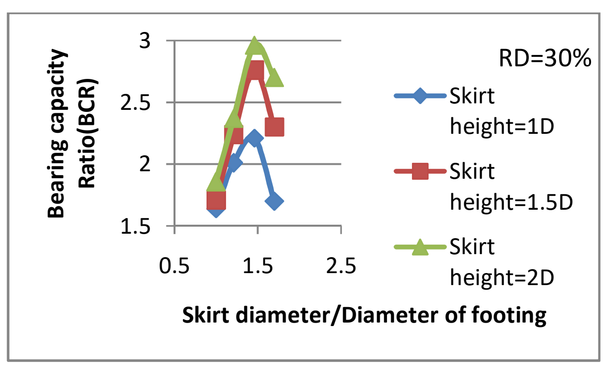


Fig.7: (Skirt diameter/Diameter of footing) & BCR relationship for R.D of 30%

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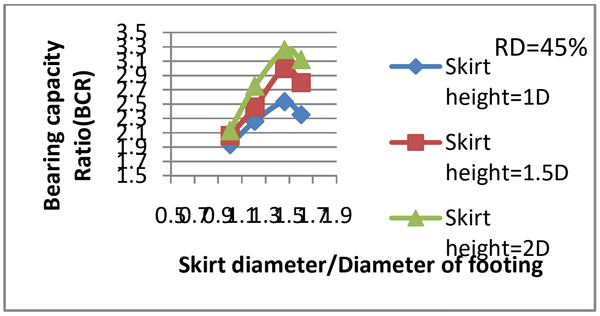


Fig. 8. (Skirt diameter/Diameter of footing) & BCR relationship for R.D of 45%

Above fig shows the variation of bearing capacity ratio and Diameter of skirt to diameter of footing for a relative density of 45%. The maximum bearing capacity for the graphs was attained for a L/D=2 and and d/D=1.46.

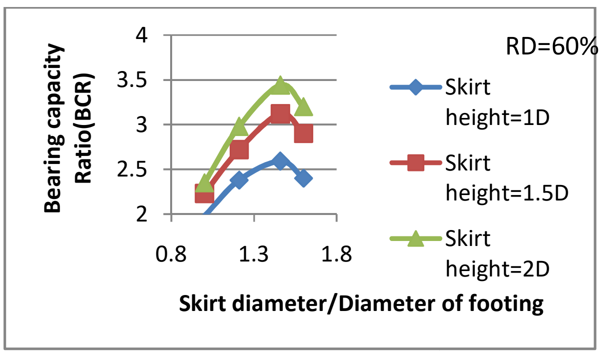


Fig.9: (Skirt diameter/Diameter of footing) & BCR relationship for R.D of 60%

The above figure shows the variation of BCR ratio to that of ratio of Diameter of skirt to Diameter of footing.The BCR value has an increase to a maximum of 3.73 for a skirt length of 2 times the diameter of footing for a relative density of 60%.

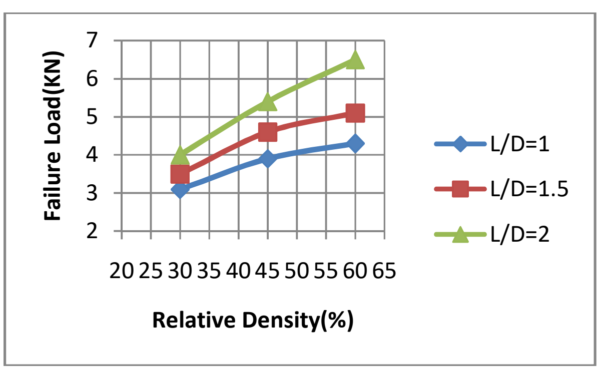


Fig.10. Failure load vs Relative density for d/D=1.46

Fig 10.presents the relationship between the failure load of skirted footing and the relative densities of sand. The figure shows that the failure load increases almost linearly till a relative density of 45%, and as the relative density is increased to 60%, gradually the curve shows non linear variations, as the result of this, the usage of skirt is a good option for sand of RD less than 60% and are most beneficial for footing in sand with a relative density less than 45%.

## IV. CONCLUSION

The purpose of the study was to assess the variation in vertical load carrying capacity of the skirted foundations at different skirt length to diameter ratio having different relative densities (30%,45%,60%). A series of experimental tests were carried out on a model test tank to evaluate the performance of structural skirts in terms of bearing capacity ratio. From the test datas and results the following conclusions are drawn:

- A structural skirt increases the bearing capacity, reduces the settlement in sand and modifies the load-settlement behaviour of the footing.
- The displacement of the skirted footings depend upon, the load applied, the length of skirt to footing diameter ratio and the relative densties of sand.
- The ultimate bearing capacity of skirted foundation increases as the length of skirt increased and skirts are beneficial for sand of relative density less than 60%.
- For a small diameter (or equal diameter) of skirts with respect to footing size, the skirt-sand-footing system settle together. Whereas for large diameter of skirts, skirt-sand-footing system behaves as a unit initially but as the failure approaches, footing settles alone while the skirt seem to be unaffected.
- Maximum Bearing Capacity Ratio(BCR) was reported when the skirt diameter was kept at 1.46 times the diameter of the footing in all the cases.

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