Performance of Inclined Skirt Footing: Numerical Analysis

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Abstract: The skirt footings are considered as alternate to enhance the bearing capacity of shallow foundation on sandy soil as an alternate of deep foundation. The experimental data of paper titled “Performance of skirt strip footing subjected to eccentric inclined load” was considered as base for validation and other parameters of material for numerical investigation for different conditions. Numerical analysis was conducted to determine the behavior of two-sided skirt footing on eccentric loading with different angle and projections provided to skirt. The study reveals good impact of skirt angle and skirt projection lengths on load capacity of footing system.
Keywords: Skirt footing Eccentric Loading Skirt Angle

1. Introduction

Retaining wall footings, abutments, industrial machinery, and portal framed buildings are all subjected to moments in addition to vertical or inclined loads. Horizontal forces acting on the structure, such as earth pressure, wind pressure, seismic force, and water hydrostatic pressure, cause moments on the foundation base. Soil pressures below shallow foundations and earth retaining structures subjected to moments due to oblique or eccentric loads generally are not uniform. The non-uniformity of the soil pressure [1] tends to tilt the footing. When the load eccentricity grows, the tilt increases, and the bearing capacity decreases. Eccentric inclined load on the footing can replace these pressures and moments. Therefore, the design of foundation needs to be done appropriately otherwise some designers can enlarges the footing size and that raises the cost of foundation work. There are many approaches to stabilize the soil but some are time consuming, complex and complicated due to site condition. In that case skirt footing is used which is a best option for enhance the bearing capacity of soil and lowering the settlement skirt is used to footing to increase the effective depth of footing in onshore structure and other places [2,3].

According to this procedure to enhance the bearing capacity, there is no restriction by appearance of higher level of ground water table. Skirt footing is connected with footing formed an enclosure which is used to strictly confined the soil. Skirt footing is beneficial for offshore structure such as wind turbine because there is no need of deep foundation, so skirt footing and stiffener are provided to enhance the stiffness of footing. It was seen that skirt increase the bearing capacity of footing by tapping soil beneath raft or between the skirt according to that load apply to soil at skirt tip.

Many scholars have recently looked into the use of a ring beam or a skirt as a soil improvement approach. The ring beam under circular foundation. The ring beam resistance to lateral displacement of soil beneath the footing has resulted in a considerable improvement in the footing reaction.

Investigation on isolated strip footing square footing and rectangular footing to eccentric loading. The study concluded that when the pressure ratio was less, then all layers there was fail in tension and when the pressure ratio was more than all the layers of reinforcement failed in pull out.

[4,5] carried out experimental and analytical study on eccentrically loading skirted footing and ultimate bearing capacity was taken for investigation. They concluded that due to use of skirt in the footing ultimate bearing capacity increases by many folds.

[6] Experiments on the load-deformation behavior of a model square footing on reinforced soil in a two-layered system with clay as the sub-grade and mine waste as the backfill material were conducted. The addition of a reinforcing element in the soil system increases the performance of an eccentrically loaded model square footing, according to the research.

[7] An eccentrically loaded model ring footing sitting on a compacted replaced layer of sand that overlies an extended layer of loose sand with geogrid reinforcement was studied experimentally. According to test results, as the depth and relative density of the sand increases, the behaviour of an eccentrically loaded ring footing improves dramatically.

[8-9] studied effect of stiff footing under inclined and eccentric stress was investigated in an experiment. It was found that a centrally loaded square footing has a larger ultimate bearing capacity than a rectangular footing in the vertical plane, and that the eccentric load carrying capacity of a footing diminishes as the angle of inclination of loading increases.
The experimental study for ultimate load intensities of T-shaped footing. In the study, vertical loading and eccentric loading was taken in to consideration to check the tilt by taking variable \( e_x/B \) and \( e_y/B \) where \( B \) was the width of footing. It was observed that the load intensity width ratio was permissible up to 0.15.

The effect of eccentric loaded model rings supported on a layered sand deposit. They concluded that ultimate bearing capacity of the ring footing increased by increasing the geogrid layers and stiffness.

2. Numerical Investigation

Skirted foundations are a well-known bearing capacity enhancement technique in which a vertical or inclined wall surrounds one or more sides of the soil mass beneath the footing. Construction of a vertical skirt at the footing's base confines the underlying soil and creates soil resistance on the skirt side, which aids in the footing’s resistance to sliding. The performance of two-sided skirted strip footing (as illustrated in Figure 1) is investigated using [10–13] numerical analysis for variations in load eccentricity, load inclination angle, skirt length, and skirt inclination angle, see table 1 and 2.

![Figure 1: Model for Study](image)

| S No. | Various Condition                  | Parameters                   |
|-------|-----------------------------------|------------------------------|
| 1     | Eccentricity width ratio \( e/b \) | 0.0, 0.15, 0.25, 0.35        |
| 2     | Depth width ratio \( d/b \)       | 0.0, 0.25, 0.50, 1           |
| 3     | Inclined skirt angle \( \alpha \) | 0°, 20°, 30°, 45°             |

| S No. | Properties                                | Value                      |
|-------|------------------------------------------|----------------------------|
| 1     | Relative density                          | 2.63                       |
| 2     | Maximum unit weight (kN/m³)               | 18.53                      |
| 3     | Minimum unit weight (kN/m³)               | 15.59                      |
| 4     | Angle of internal friction                | 40°                        |
| 5     | Cohesion (kN/m²)                          | 0                          |
| 6     | Failure ratio \( \left( R_f \right) \)   | 0.9                        |
| 7     | Degree of dilatancy angle                 | 8.0                        |
| 8     | Stiffness                                 | 0.60                       |
| 9     | Drained tri-axial test (E₅₀ ref) (kN/m²)  | 19613.3                    |
| 10    | Poisson ratio                             | 0.30                       |

Table 1: Basic properties of soil

Table 2: Model-Testing Parameters
1.1 Validation

The primary objective of this study is to conduct a numerical inquiry into the behaviour of two-sided skirted footings under eccentric inclined loads. The experimental data from the publication "Performance of skirt strip footing under eccentric inclined load" is used to determine the attributes of various constituents. The finite element software PLAXIS-3D is used for numerical analysis. By comparing the load-settlement responses from the model footing test data with the finite element results, the validity of the numerical analysis was confirmed.

Since, it is very difficult to simulate for exactly same conditions in the Plaxis-3D software as of experimental work. Finite Element Method is also approximate method and not easy to establish the accurate working of the skirt footing because of its complex nature. There are many significant effects due to boundary condition and geometry of mesh. The results obtained by FEM are always on the higher side as compare to experimental work, see figure 2 and 3.

Methodology for the numerical analysis illustrated in Figure-4 for various models.
3. Result and Discussion
The finite element method (FEM) could be used to determine deformation and stress distribution patterns in soil. Because monitoring behavior of soil under applied loads for an extended period of time is prohibitively expensive, numerical analysis can be used to forecast soil behaviour throughout its lifetime. As the FEM's results are confirmed by experimental results, it becomes increasingly powerful. The PLAXIS-3D was used to do an elasto-plastic finite element analysis in this study. The mesh creation procedure was used for all of the finite element calculations. For different skirt lengths, skirt angles, and eccentrically loading, numerous models were investigated. see figure 5.

Figure 5: Footing model without skirt
The results of various models gave different results; some of those are depicted below. Generally, the safe load is reduced for assumed settlement by increasing load eccentricity, e/B. The lateral movement of the skirted footing subjected to eccentricity load determines the failure load. The movement of the footing affects the horizontal soil reaction on the skirt’s outer edge. On the skirt side, the horizontal soil reaction creates more barrier to footing sliding. Furthermore, when a skirted footing is subjected to eccentric stress, the footing tends to rotate in the same direction as the load, implying that the skirted footing moves laterally closer to the soil at the top of the skirt than at the bottom. Furthermore, the data show that as the skirt length grows, the horizontal soil reaction increases. This is because; it increases the volume of the displaced soil, which accordingly increases the soil pressure, see figure 6 and 7.
Figure 8: Load Vs Settlement Graph d/b=0 and e/b=0 to 0.35

Figure 9: Load Settlement curve at d/b=0.25 and skirt angle of 20°

The effect of d/b, e/b and skirt angle on footing behavior is produced in graphical form. Safe load value increases with increase in skirt length for footing (as shown in figure 8 and 9). According to the findings, as the eccentricity of the loading increases, the load reduces. The skirt angle has a stronger positive impact on the load carrying capacity of a footing because the horizontal soil reaction created on the skirt side creates more resistance to footing sliding, hence increasing the skirt's influence zone, see figure 10,11 and 12.
4. Conclusion
According to the numerical work of the study of the performance of skirt footing, the following conclusions are determined:

- **Figure 10: Effect of d/b vs Load (kN)**
- **Figure 11: Effect of e/b vs Load (kN)**
- **Figure 12: Effect of skirt angle vs Load (kN)**
• Projection length of skirt greatly influences the load settlement performance, enhancement in the projection length upgrades the load capacity.
• Enhancement in skirt angle increases the safe load and reduces the settlement.
• Higher eccentricity in loading leads to decrement in safe load.
• Most critical factor of sliding of footing was reduced by applying the skirt to footing.

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