Numerical analysis of bearing capacity of rectangular footing

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Abstract. This study investigates the effects of the soil bearing pressure values of the rectangular shape footing located on the horizontal ground surface using PLAXIS software. It is Finite element method based software, used to analysis deformation and stability in engineering projects. It has a wider application in constitutive soil model (stress-strain-time relationship). PLAXIS software is a good tool which can be used for explaining the soil behaviour and settlement under different loading conditions. The two dimensional (2D) and three dimensions (3D) model of rectangular footing were analysed and compared. The results showed that the 3D analysis provides more accurate results as compared to the 2D analysis and also observed the failure mechanism of the soil model.

Keywords: Rectangular footing, soil bearing capacity, failure mechanism, PLAXIS 2D, PLAXIS 3D.

1. Introduction
A foundation is that part of a structure which transmits the load of the structure to the ground. While designing a foundation, it is necessary to know the type of soil, its behaviour and bearing capacity. The foundations have to be so designed that the stresses induced in the soil are within its capacity. If the soil is overstressed, a shear failure may occur causing the soil to slide from underneath the structure and cause its failure. Thus the estimation of load carrying capacity of footing is the most important step in design of foundation. Various researchers have correctly predicted the ultimate bearing capacity of shallow footing resting on horizontal grounds surface [Terzaghi (1943) Meyerhof (1963) Hansen (1970) Vesic (1975)]. They are either based on laboratory or in-situ test results.

The estimation of the ultimate bearing capacity method may be classified into the following categories: (1) the limit equilibrium method; (2) the method of characteristics; (3) the upper-bound plastic limit analysis and (4) the numerical method based on either the finite element method or finite difference method. The bearing capacity problem can be solved by two different approaches:
experimentally, by conducting model and full scale test; or, by using numerical method such as finite element analysis. Agrawal (1986) Saran and Agrawal (1991) used the upper bound technique of plastic limit analysis and limit equilibrium method for predicting the bearing capacity of eccentric and inclined loaded of footing on c-\(\phi\) soil. Purba (2001) studied the behavior of a strip footing resting on the surface of uniform clay in an undrained state using elasto-plastic finite element analysis (FEA). It was found that the ultimate bearing capacity of strip footings decreases with reduction in the consistency of clay from hard to very soft and with increase in inclined load. Keskin and Laman (2012) carried out numerical analysis by using PLAXIS 3D for calculate the bearing capacity of strip footing on sand slope. Sharma and Kumar (2017) carried out the behaviour of ring footing on reinforced sand subjected to subjected to eccentric-inclined loading using PLAXIS 3D software

In this study, an attempt has been made to calculate the bearing capacity of rectangular footing located on the top of the model ground using PLAXIS software. PLAXIS 2D and 3D analyses give the numeric value of ultimate bearing capacity and self-explanatory graphical pictures of the failure mechanism of model foundation.

2. Methodology

PLAXIS software was used to analyse bearing capacity and failure analysis of shallow rectangular footing. The rectangular footing was located at two positions: left corner and centre of the model soil. The Mohr-Coulomb model was adopted for cohesionless soil and the linear-elastic model was implemented for the rectangular shape foundation. It consists of three programs like Input program, Output program, and Curves. Firstly, prototype rectangular footing was created and prescribed the load in increments accompanied by iterative analysis of failure. The Output program was adopted for calculation process and erecting the results. Furthermore, curves were used for graphical features of the failure mechanism.

2.1 Plain strain analysis

PLAXIS 2D is a finite element method (FEM) based software, used to accomplish the deformation and flow analysis of geotechnical engineering projects. 2D analysis may be modeled by plain stain or axisymmetric model.

(a) Geometry of soil model: - First, a geometric model was created with dimensions 1.24m (length) x 0.91m (width) x 0.93m (height). A rectangular shape footing of size 124cm (length) x 18cm (width) x 12mm (thickness) was located on the top surface of the soil model. The geometry of the 2D model as shown in Figures 1(a) and 1(b). It was shows that the rectangular shape footing was located at the left corner and center of the soil model.
(b) Material: - The Mohr-Coulomb model was adopted for dry sandy soil and the linear-elastic model was implemented for the rectangular shape foundation which contains five parameters, i.e. two elastic and three strength parameter. The values of elastic and strength parameter is \((G=500\text{kN/m}^3, \nu= 0.33)\) and \((C=0\text{kN/m}^3, \phi= 30^0, C=0\text{kN/m}^3, \psi=0\text{kN/m}^3)\).

(c) Meshing: - In the 2D analysis, the Medium-mesh was created with a local element size factor of 0.3 as shown in figures 2(a) and 2(b).

(d) Calculations: - The calculation process of this analysis are shown in Figure 3.
**Fig. 3.** calculating phases of the soil model

**e) Result analysis:** Fig. 4(a) and Fig. 4(b) shows that the deformation of finite element mesh. From the work plane, 15 nodes are selected for the 2D analysis and 10 nodes were selected for 3D analysis.

**Fig. 4(a).** Deformed meshes. **Fig. 4(b).** Deformed meshes.

**f) Load-Settlement:** The load-settlement curves of rectangular footing for PLAXIS 2D are shown in Fig. 5(a) and Fig. 5(b). The calculated collapse load was 112.3 kN/m³ and 111.8 kN/m³.
Fig. 5(a). Load-settlement curve

Fig. 5(b). Load-settlement curve

(g) Failure mechanism: The obtained failure mechanism in the numerical analysis for corner and centre located modelled footing are shown in Fig. 6 (a1), Fig. 6(a2) and Fig. 6(b1), Fig. 6(b2). These Figures show that the total settlement and shear strain in two-dimensional analysis.

Fig. 6(a1). Total Displacement PLAXIS 2D

Fig. 6(a2). Shear Strain PLAXIS 2D
2.2 Three-Dimensional analysis

The PLAXIS 3D software was used to determine the 3D effects of the geotechnical structures. It is similar to 2D analysis but it is more accurate and more time consuming as compared to 2D analysis.

(a) Geometry and boundary condition: Firstly, soil model was created as shown in figures 7(a), Fig. 7(b). In this analysis, adopted geometry lines and structure for making the rectangular shape modeled footing. Fig. 7(a) and Fig. 7(b) represented the footing located at the left corner and center of the soil model. The decided coordinate of the left corner located and centre located footings are (0,0,0), (24,0,0), (24,18,0), (0,18,0) and (50,36,0), (50,54,0), (74,54,0), (74,36,0) respectively.

(b) Material model: The same materials properties of 2D model was adopted for the 3D analysis.
(c) Finite element meshing: In this analysis, PLAXIS software generates automatically 3D mesh. The Medium-mesh was selected with coarseness factor 0.1. The FE mesh as shown in Fig. 8 (a) and Fig. 8(b).
(d) Result analysis:- In the 3D analysis, the same 2D procedure is adopted for the calculation process. The load-settlement curve for 3D analysis are shown in Fig.9 and Fig. 10. The obtained failure load was 132.3 kN/m² and 131.7 kN/m².

(f) Failure mechanism:- The obtained failure mechanism in the 3D numerical analysis for corner and centre located modelled footing are shown in Fig. 10(a1) Fig. 10(a2) and Fig. 10(b1), Fig. 10(b2). These figures are indicate that the total settlement and shear strain of the model foundation at peak load.
3. Conclusion

The present study investigated the 2D and 3D analysis of the rectangular shape footing located on the horizontal ground surface. The following conclusions were drawn from the above study:

- Allowable bearing pressure of the rectangular footing located at the left corner and center of the soil model was 112.3 KN/m² and 111.8 KN/m² from 2D analysis and 132.3 kN/m² and 131.7 kN/m² from 3D analysis respectively.
- A comparison of 2D and 3D analysis gave a good estimation of the allowable bearing pressure of the soil. The 3D analysis gave a higher value of the ultimate bearing capacity as compared to 2D analysis. It is more accurate and can be used in soil engineering structures especially lightweight structure widely.
- PLAXIS software can be used to explain the settlement and soil behavior under different loading conditions.
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