Numerical analysis of bearing capacity of rectangular footing

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Abstract. Using PLAXIS software, this study examines the impacts of the soil bearing pressure values of the rectangular footing situated on the horizontal ground surface. This software, which is based on the finite element method, analyzes stability and deformation in engineering projects. It can be used more broadly in constitutive soil models (relationship between stress, strain, and time). The PLAXIS software is a useful instrument for elucidating the behavior of soil and settlement under various loading scenarios. An analysis and comparison were conducted between the two-dimensional (2D) and three-dimensional (3D) rectangular footing models. The outcomes demonstrated that the 3D analysis outperforms the 2D analysis in terms of accuracy and also reveals the soil model's failure mechanism. soil.

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

1. Introduction

The portion of a structure that transfers the weight of the structure to the ground is called the foundation. Understanding the kind of soil, how it behaves, and how much weight it can support is essential for foundation design. The design of the foundations must take into account the stresses that the soil can withstand. Overstressed soil can result in a shear failure, which would allow the soil to slide out from underneath the structure and bring it down. Thus, the most crucial stage in foundation design is estimating the footing's load-bearing capacity. The ultimate bearing capacity of shallow footing resting on a horizontal ground surface has been accurately predicted by a number of researchers [Terzaghi (1943), Meyerhof (1963), Hansen (1970), Vesic (1975)]. They either stem from 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, either through full-scale tests and models conducted experimentally, or through the use of numerical techniques like finite element analysis. Agrawal (1986) Saran and Agrawal (1991) predicted the bearing capacity of eccentric and inclined loaded footing on c-I soil using the limit equilibrium method and the upper bound technique of plastic limit analysis. Purba (2001) used elasto-plastic finite element analysis (FEA) to examine how a strip footing behaved when it was resting on a uniform clay surface in an undrained state. It was discovered that when the consistency of clay changes from hard to very soft and when the inclined load increases, the strip footings' ultimate bearing capacity decreases. Keskin and Laman (2012) performed numerical analysis to determine the bearing capacity using PLAXIS 3D.

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.

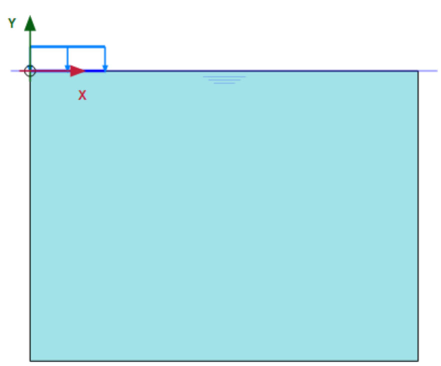

Fig. 1(a). Geometry model.

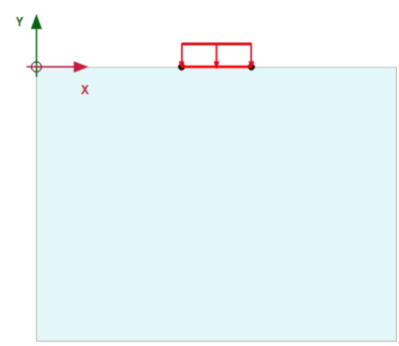

Fig. 1(b). Geometry model.

(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=500kN/m^3, ν= 0.33) and (C= 0 kN/m^3, ϕ= 30^0, C= 0 kN/m^3, Ψ= 0 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).

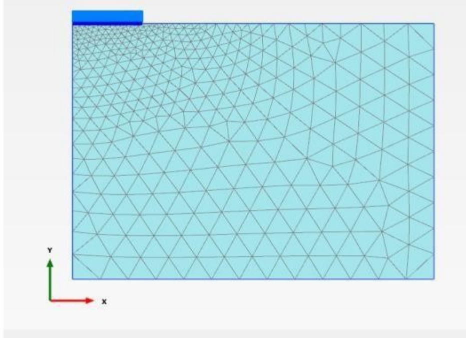

Fig. 2(a). Finite-element mesh

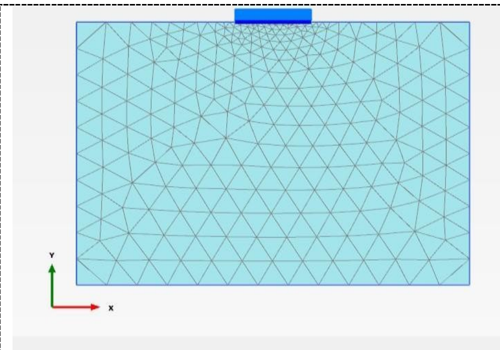

Fig. 2(b). Finite-element mesh

(d) **Calculations:-** The calculation process of this analysis are shown in Figure 3.

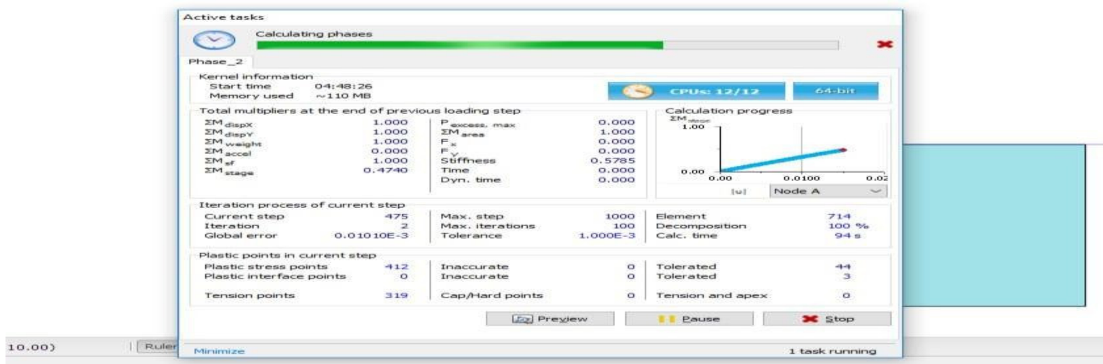

Fig. 3. calculating phases of the soil model

(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.

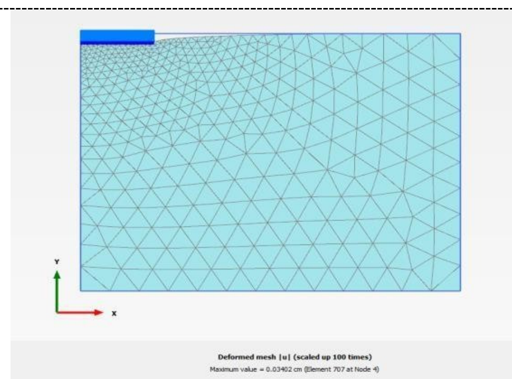

Fig. 4(a). Deformed meshes.

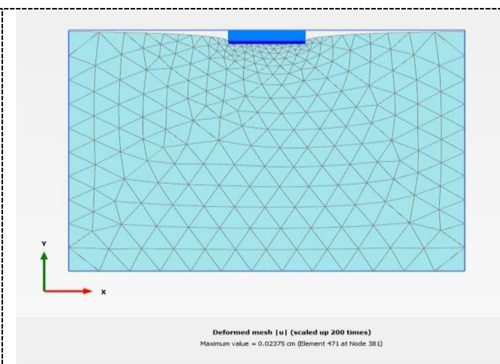

Fig. 4(b) Deformed meshes.

(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/m^3 and 111.8 kN/m^3.

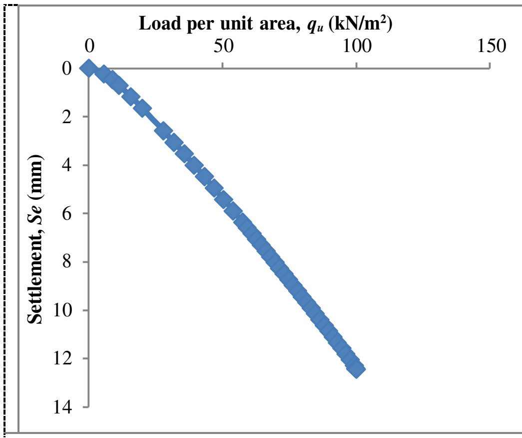

Fig. 5(a). Load- settlement curve

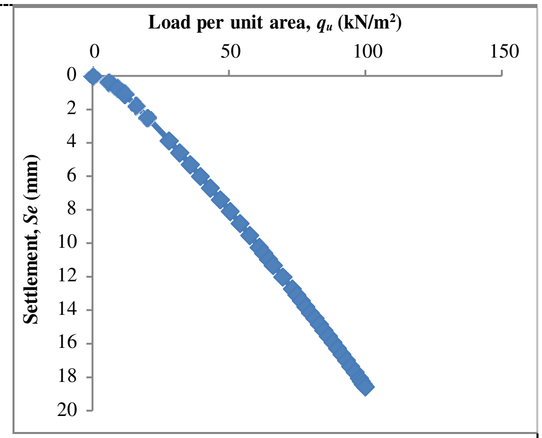

Fig. 5(b). Load-settlement curve

(g) **Failure mechanism: -** The obtained failure mechanism in the numerical analysis for corner and centre located modelled footing are shown in Fig. 6 (a_1), Fig. 6(a_2) and Fig. 6(b_1),Fig. 6(b_2). These Figures show that the total settlemet and shear strain in two-dimensional analysis.

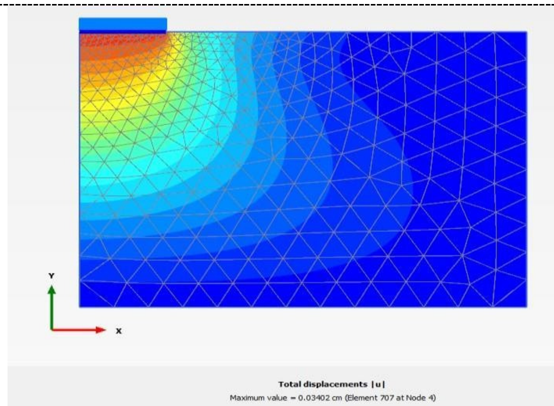

Fig. 6(a_1). Total Displacement PLAXIS 2D

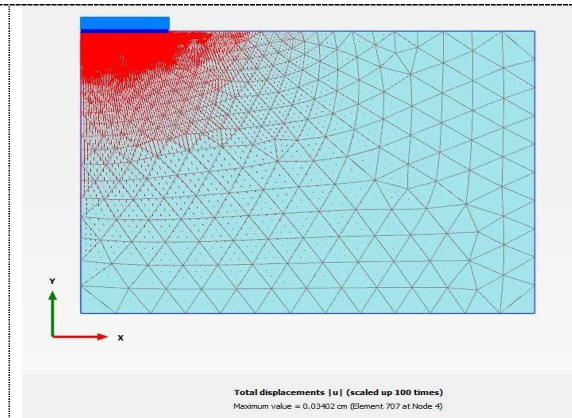

Fig. 6(a_2). Shear Strain PLAXIS 2D**.**

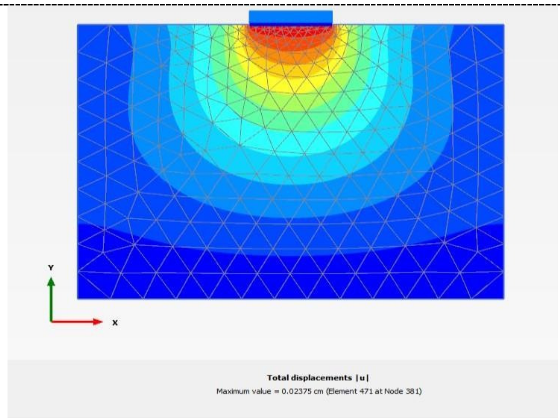

Fig. 6(b_1). Total Displacement PLAXIS 2D.

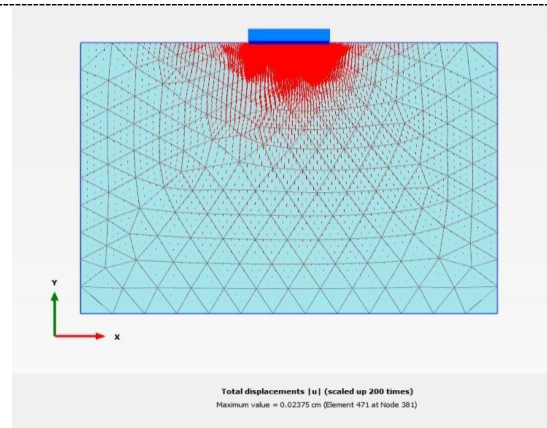

Fig. 6(b_2). Shear Stain PLAXIS 2D.

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.

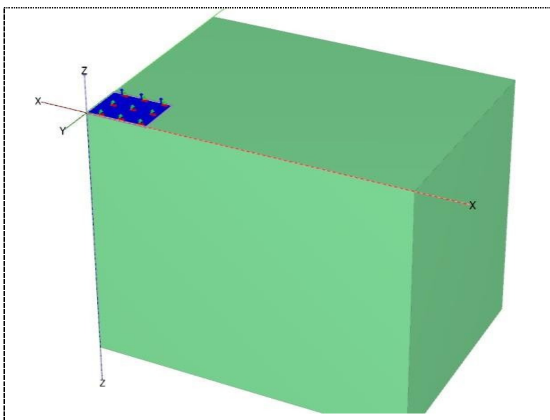

Fig. 7(a). Model geometry.

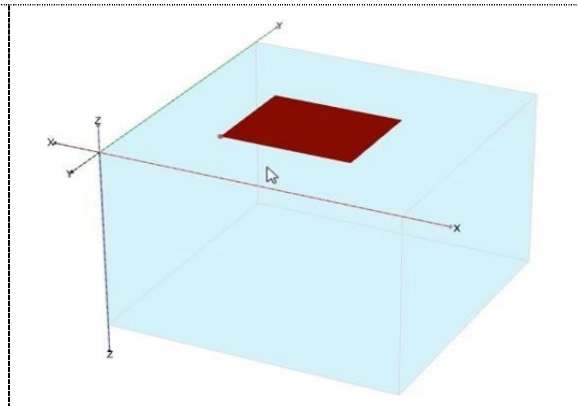

Fig. 7(b). Model geometry.

(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).

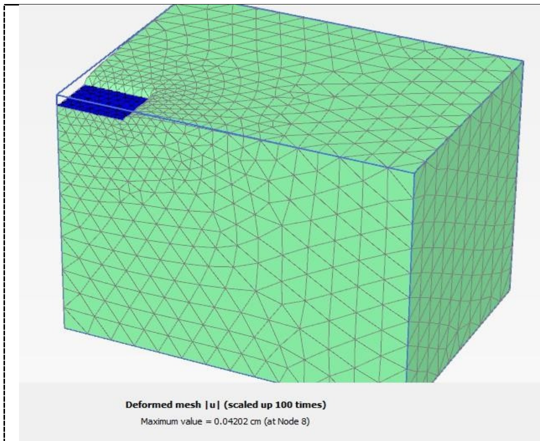

Fig. 8(a). Finite element mesh.

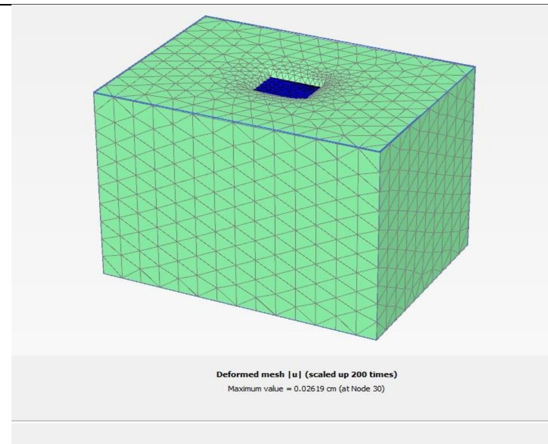

Fig. 8(b). Finite element mesh**.**

(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/m^2 and 131.7 kN/m^2.

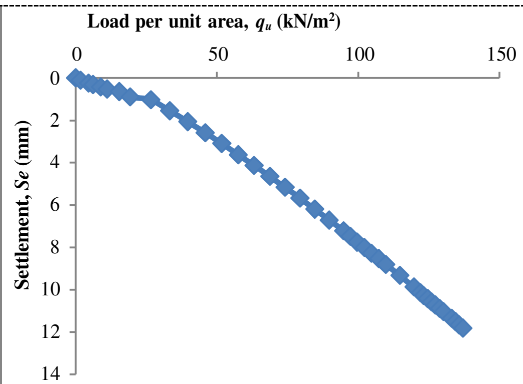

Fig. 9(a). Load- settlement curve

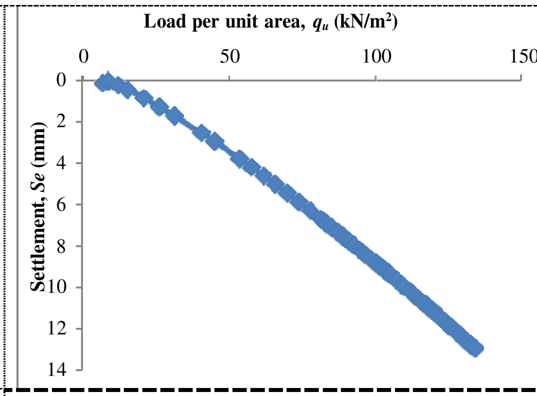

Fig. 9(b). Load-settlement curve

(f) Failure mechanism:- The obtained failure mechanism in the 3D numerical analysis for corner and centre located modelled footing are shown in Fig. 10(a_1) Fig. 10(a_2) and Fig. 10(b_1), Fig. 10(b_2). These figures are indicate that the total settlement and shear strain of the model founadtion at peak load.

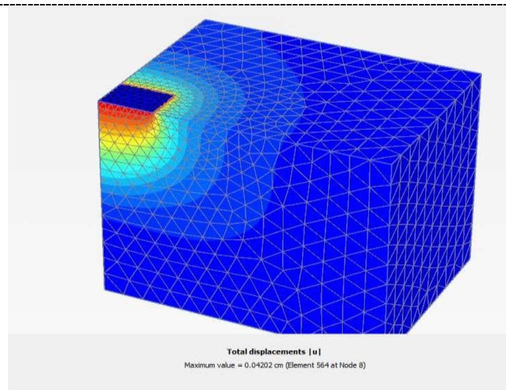

Fig. 10(a$_1$). Total Displacement of the corner located footing.

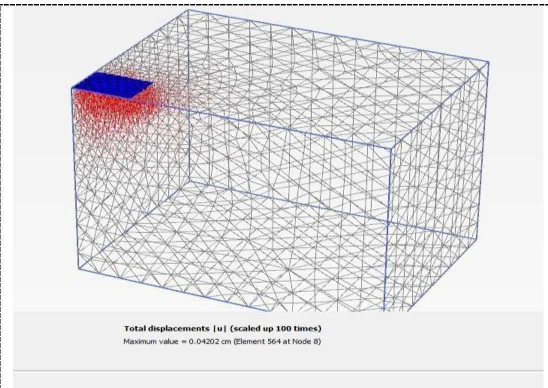

Fig. 10(a$_2$). Total Displacement of the corner located footing**.**

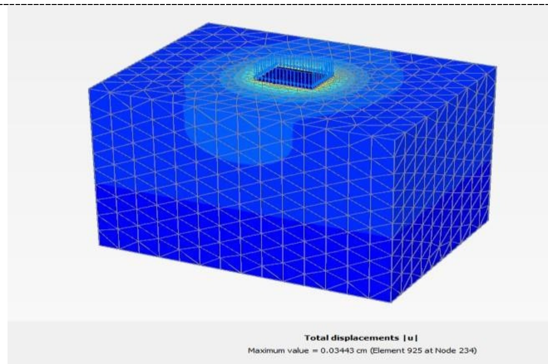

Fig. 10(b$_1$). Total Displacement of the center located footing.

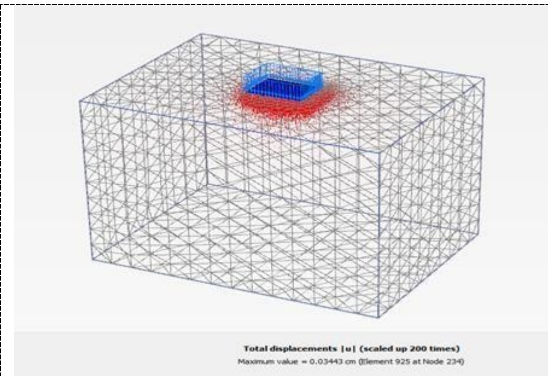

Fig. 10(b$_2$). Total Displacement of the center located footing**.**

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/m^2 and 111.8 KN/m^2 from 2D analysis and 132.3 kN/m^2 and 131.7 kN/m^2 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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