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Finite Element Analysis of Spread Footing Near Slops

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Basim Jabbar Abbas[1], Hussein Yousif Aziz[1], Baydaa Hussain Maula[2] and Raid Tarik Alkateeb[1]

[1]Muthanna University, College of Engineering, Sammawa, Iraq

[2] Institute of Technology-Baghdad, Middle Technical University, Baghdad, Iraq

Abstract. In this project the analysis of spread footing rested on the sand near the slope was conducted. The distances from the edge of the slope are considered variable started from 0.5m and limited to 4.5m. The applied loads on the footing are 100,200,300 and 400 kN. The related vertical and horizontal displacement were recorded on a point at the edge of the slope after finishing the analysis. The properties of the sand complied with actual soil investigation in a particular location in Al-Samawa city. The project was conducted to explain the effect of the slope on the bearing capacity up to the spread footing. The Analysis was achieved using 2D plaxis program Version 8 using large boundary conditions. The results showed that the vertical and horizontal displacements reduced when the distance from the edge of the slope Introduction.

1. Introduction

The issue of slope stability is one that has been carried out by significant research papers. Records of the research covered issues with a safety factor for a given slope [1-2]. Some existing methods can find the safety factor of a slope, one of the most popular ways is through the use of Taylor's Stability Charts. [3] Created a process for efficiently determining the minimum safety factor for a homogeneous slope. This method uses design charts that relate the stability number (N) to a slope angle (β). This method uses a total stress analysis and ignores the possibility of tension cracks [4].

[5] Developed a table for adjusted factors (Nc and Nq) based on the reduction in slip surface length and surcharge area, respectively. This paper aims to explore the combined effect of loading eccentricity and the slope on bearing capacity and to provide the geotechnical engineer with useful design charts.

To provide some basic understanding of the nature of the calculations involved in the behavior of spread footing near the slope, many cases of stability of an infinitely long slope is initially introduced. "Finite element (FE) techniques have been utilized as a part of the most geotechnical building to assess complex issues. 2D models can represent field conditions legitimately while conventional analysis is time wasting and complicated, also using the laboratory models need more effort and budget. In this work, the Plaxis 2D foundation version 8 was chosen" [6].

2. Materials and Methods

Depending on the pervious site investigation in Al-Samawah city, the results obtained from the laboratory test were shown in Table 1. The used soil was fine sand and silty soil, sandy soil according to the soil report. The unit weight of the soil was ranged between 17 to 20 kN/m3, and the drained friction angle was varied between 35 to 40º along the depth of the hole.
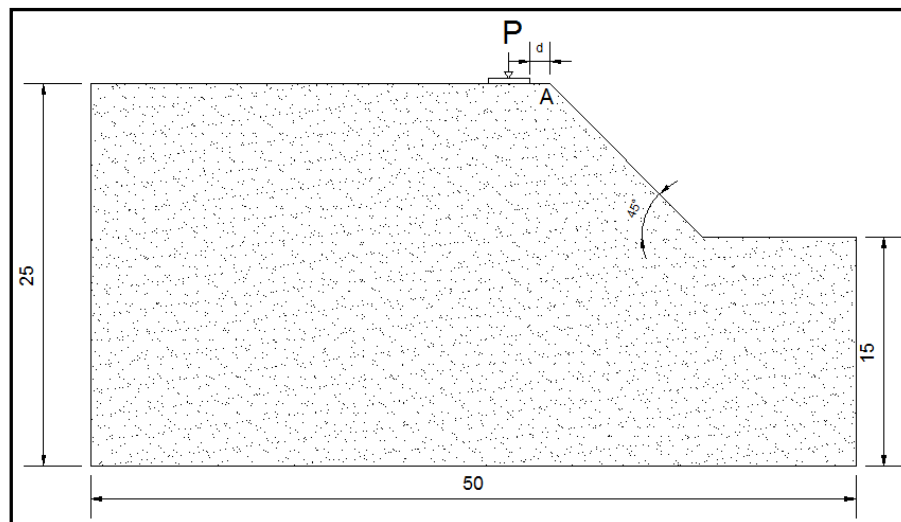
Table 1. Strength parameters (direct shear test results with depth)

| Depth (m) | Soil description | Direct shear test | | γ dry kN/m³ |
		Drained C T/m²	Drained φ	
1.5-3.0	Fine sandy soil	-	35	17
3.0-6.0		-	35	17.5
6.0-9.0		0.0	35	18
9.0-12		0.0	36	19
12-15	Silty sand soil	0.0	37	18.5
15-18		0.0	38	20
18-20		0.0	40	20

2.1. The finite element models of footing near the slope

The analysis was made to determine the allowable Bearing capacity of spread footing constructed on sandy soil near the slope. The geometric characteristics of the slope are as shown in Figure 1 with water table = 25m

Figure 1. General geometric model of the spread footing near a slope

2.2. Properties of used Soil

In this study, the linear elastic-perfectly plastic Mohr-Coulomb criteria were used to represent the materials of the general soil profile and the sand. To simulate the model of sand soil, input parameters were required: Young's modulus (E) as the basic stiffness parameter, Poisson's ratio (υ), internal friction angle (φ), cohesion (c) and dilatancy angle (ψ). There was no need to enter groundwater condition in the analyses because the soil layer in this study was dry. The physical and chemical parameters of soil used in this investigation are shown in Table 2.

Table 2. Physical properties of the soil used in Plaxis 2D

Parameter`	Name	Value or model	Unite
Material model	Model	Mohr-Coulomb	-
Type of material behavior	Drainage type	Drained	-
Unit weight of soil above phreatic level	$\gamma_{unsat.}$	19	kN/m^3
Unit weight of soil below phreatic level	$\gamma_{sat.}$	20	kN/m^3
Young' modulus (constant)	E	19000	kN/m^2
Poisson's ratio	ν	0.3	-
Cohesion (constant)	c_{ref}	1	kN/m^2
Friction angle	Ø	37	-
Dilatancy angle	Ψ	5	-

2.3. Properties of spread footing

The dimensions of the footing are 1.5×1.5 m, and a plate element is used to model the foundation. The physical parameters of the concrete footing used in this work are shown in Table 3.

Table 3. Physical properties of the concrete footing

Material property	Structural elements
Type	Linear, isotropic
γ	24
E' (kN/m2)	23.5E^6
ν'	0.15
d (m)	0.45

2.4. The Boundary Conditions of Models

Finite element (FE) methods have been used in the most design and analytical engineering problems to appraise complex problems. 3D modeling can simulate field conditions properly while traditional analysis is time-consuming and complicated, besides using the laboratory models cost more work and financial plan. The finite element software of PLAXIS 3D foundation version 2008, developed by the Delf technical university, is selected in this paper. In this study, the depth and width of the models are selected as sufficient so that they simulates real behavior in the field. The models consist of soil volume 50 m plan and 25 m in depth. The option of the standard boundary is selected in the program, where this boundary option considers the movement of the top surface to be free in all directions. When considering the model boundary in yz-plane, displacements in the x directions are limited to zero where displacements in the y and z directions are free [6]. The bottom boundary is fixed in all directions. The mesh was a medium generation, utilized as the global coarseness of model and the software automatically refines the critical areas in the model. The study consists of cases, where the vertical and horizontal displacements of footing under various surfaces stress are recorded when the footing is located at 0.5 m to 4.5m from the slope. The vertical and horizontal displacements recorded at point A which is located at the top of the slope as shown in Figure 1.

2.5. Effect of footing location

In this study cases were adopted where all parameters are fixed except the horizontal distance from the slope is variable. The main cases are (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, and 4.5 m).

The geometric design of the slope with different horizontal distances (X) from the slope is shown in Figure 1.

3. The Results and Discussion

The effect slope and the footing location on the settlement under concrete footings were investigated. Settlement for each case was determined. Figure 2 illustrates an example of the geometric model for footing located at 0.5 m from the slop on Plaxis 3D software.
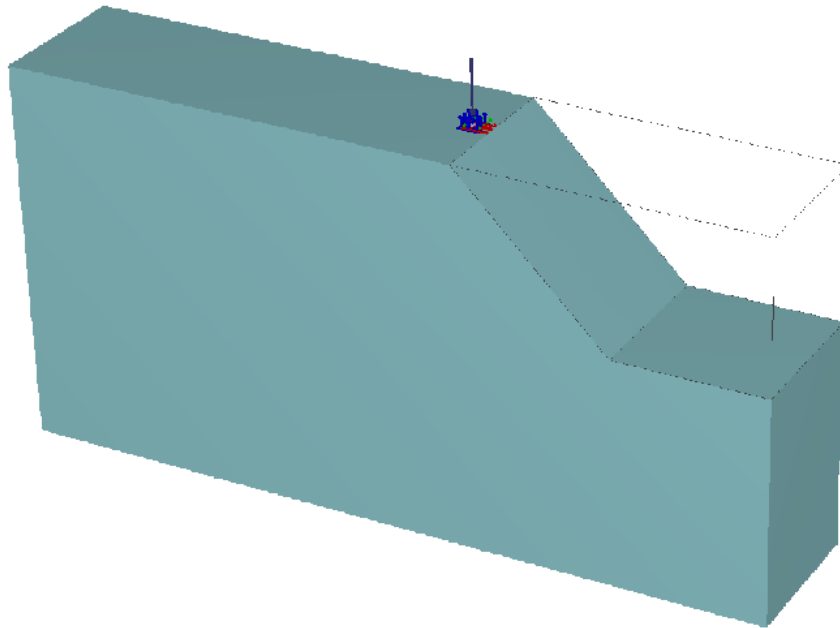

Figure 2. Geometric model of the slope stability for case 1

The results of spread footing near slope in sand soil located at different positions as the following:

3.1. The result for distance 0.5m

Figure 3 to 5 illustrates the pressure-displacement relation of spared footing located at 0.5 m from the inclination.

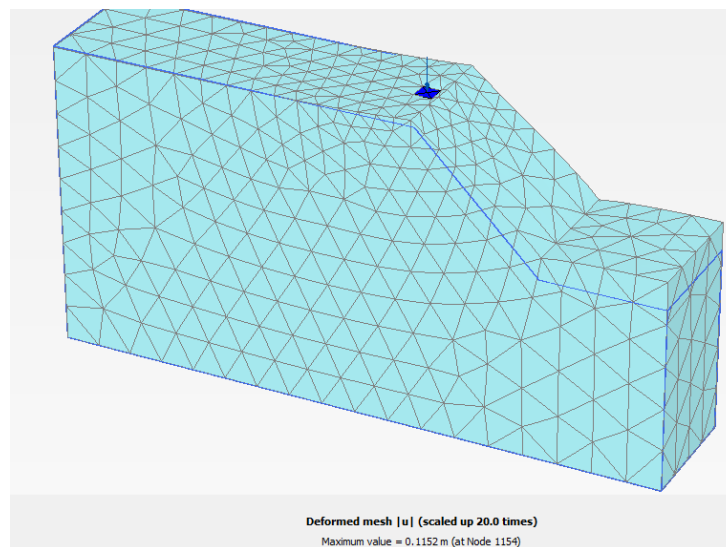**Figure 3.** displacement of spared footing located at 0.5 m from the inclination at a surface load equal to 100 kN.

Figure 4. deformation of spared footing located at 0.5 m from the inclination at a surface load equal to 300 kN.
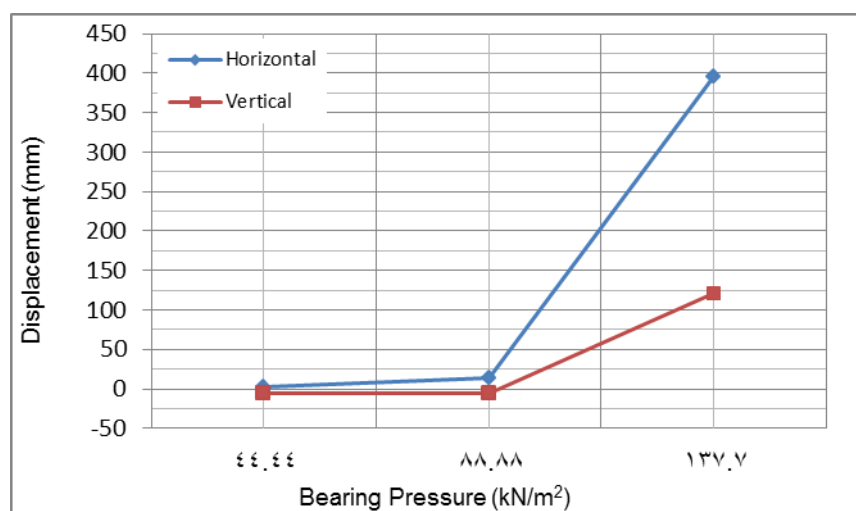

Figure 5. pressure-displacement relation of spared footing located at 0.5 m from the inclination.

The model's results clarify the great vertical displacement records at the top of slope matches to 121mm in surface pressure of 137.7 kPa. The maximum horizontal displacement at the top of slope equals to 395mm in surface pressure of 137.7 kPa.

3.2. The result for distances
Figures 6 and 7 illustrate the total displacement and deformation of spared footing located at 1m from the inclination at surface loads equal to 100 KN. Figure 6 to 8 illustrates the pressure-displacement relation of spared footing located at 1 m from the inclination.
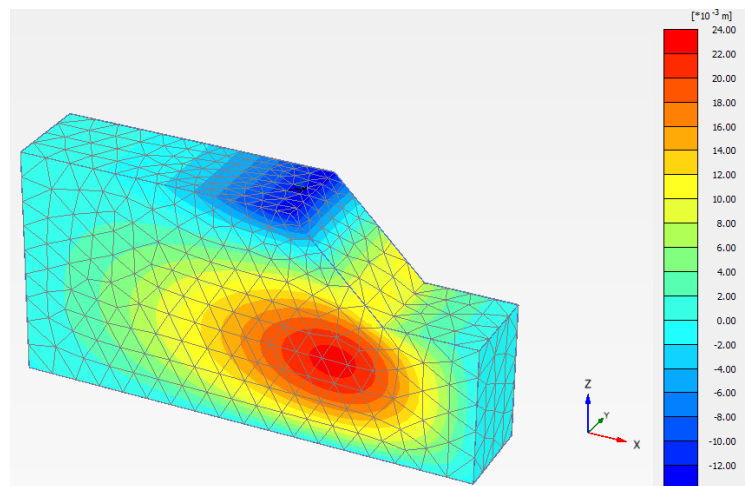
Figure 6. displacement of spared footing located at 1 m from the inclination at a surface load equal to 100 kN.
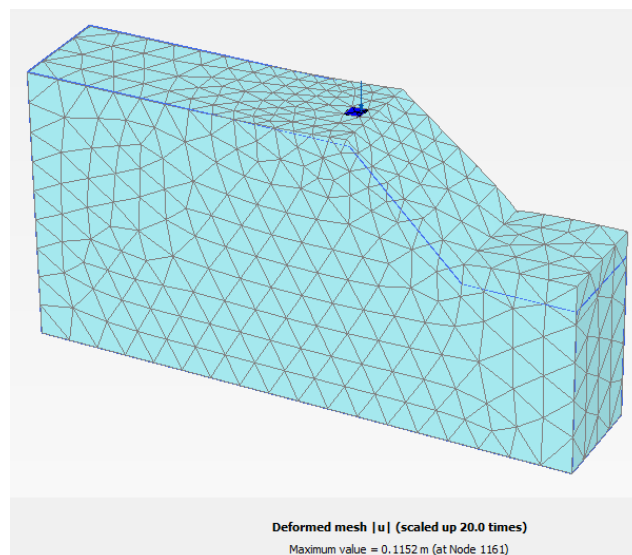

Deformed mesh |u| (scaled up 20.0 times)
Maximum value = 0.1152 m (at Node 1161)

Figure 7. deformation of spared footing located at 1 m from the inclination at a surface load equal to 100 kN.
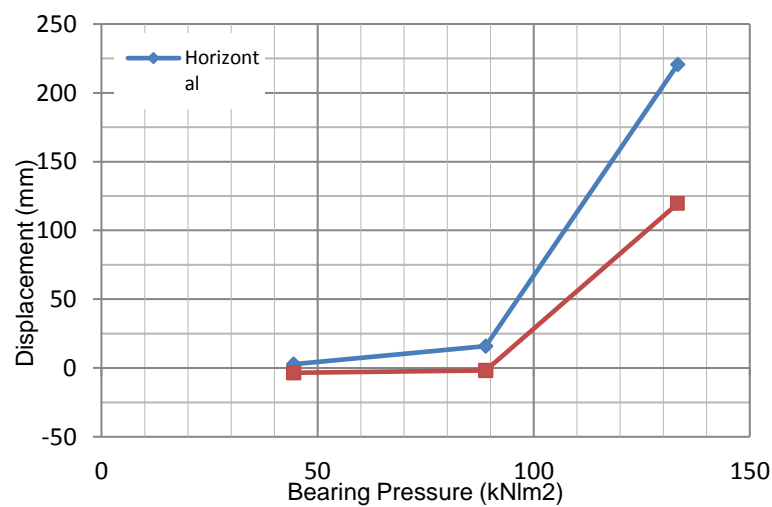

Figure 8. pressure-displacement relation of spared footing located at 1m from the inclination.

The results show the extreme vertical displacement at the top of slope equals to 119.5 mm in surface pressure of 137.7 kPa. The total displacement and deformation of spared footing located at 1.5m from the inclination at surface loads equal to 400. Figure 9 illustrates the pressure-displacement relation of spared footing located at 1.5 m from the inclination.

The simulations results explain the extreme vertical displacement at the top of slope equals to 78mm in surface pressure of 137.7 kPa. The maximum horizontal displacement at the top of slope equals to 55mm in surface pressure of 137.7 kPa.
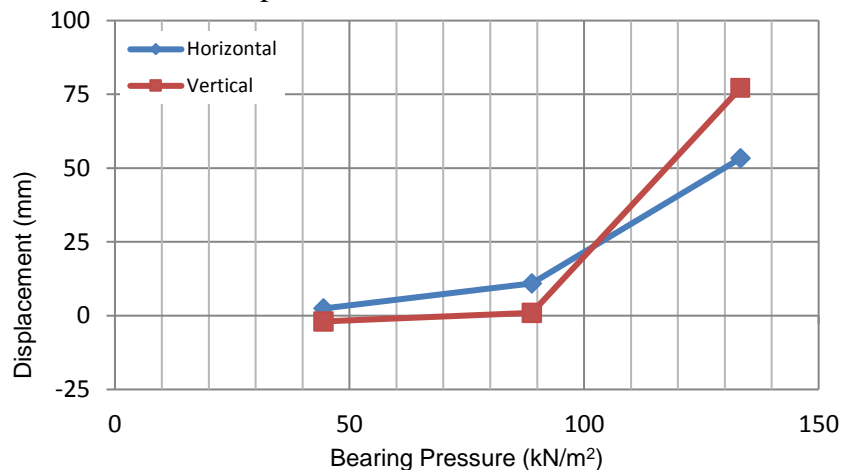

Figure 9. pressure-displacement relation of spared footing located at 1.5m from the inclination

The total displacement and deformation of spared footing located at 2.0m from the inclination at surface loads equal to 200. Figure 10 illustrates the pressure-displacement relation of spared footing located at 2 m from the slope. The results show the extreme vertical displacement at the top of slope equals to 79.4 mm in surface pressure of 137.7 kPa. The maximum horizontal displacement at the top of slope equals to 63.7 mm in surface pressure of 137.7 kPa. The total displacement and deformation of spared footing located at 2.5m from the inclination at surface loads equal to 200. Figure 11 illustrates the pressure-displacement relation of spared footing located at 2.5 m from the slope.
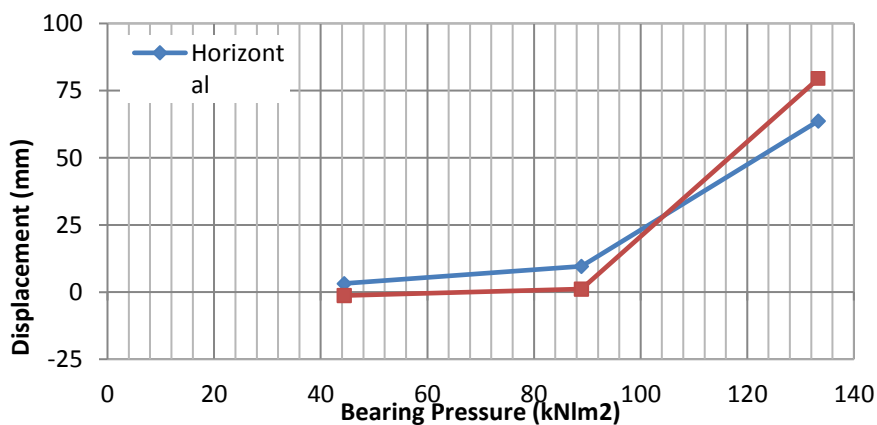

Figure 10. pressure-displacement relation of spared footing located at 2m from the inclination
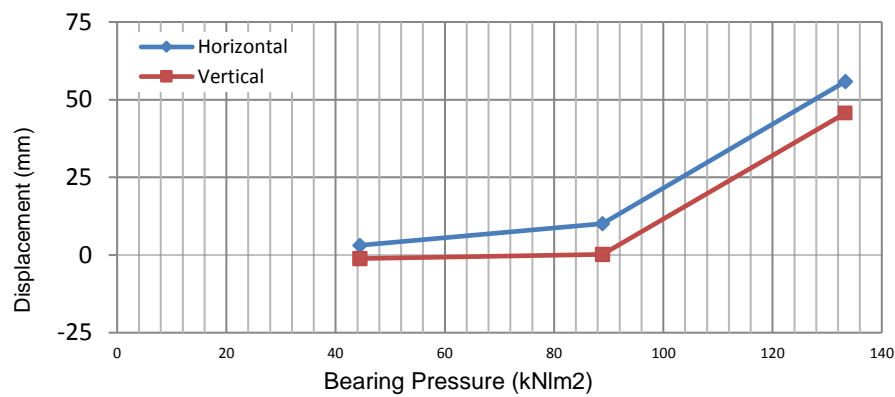
Figure 11. pressure-displacement relation of spared footing located at 2.5m from the inclination

The total displacement and deformation of spared footing located at 3m from the inclination at surface loads equal to 200. Figure 12, 13, and14 illustrates pressure-displacement relation of spared footing located at 3 m from the slope.
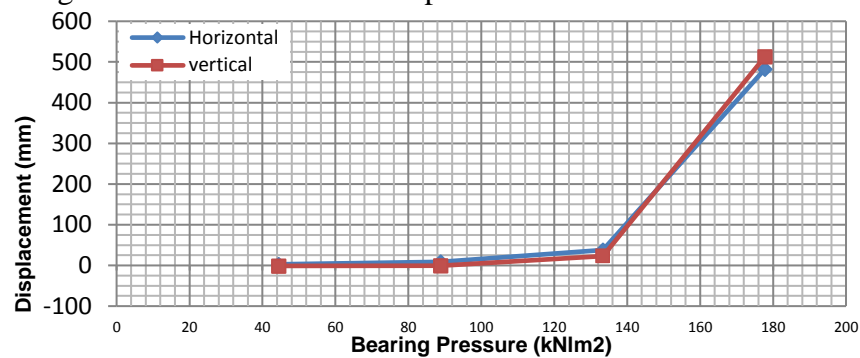

Figure 12. pressure-displacement relation of spared footing located at 3m from the inclination
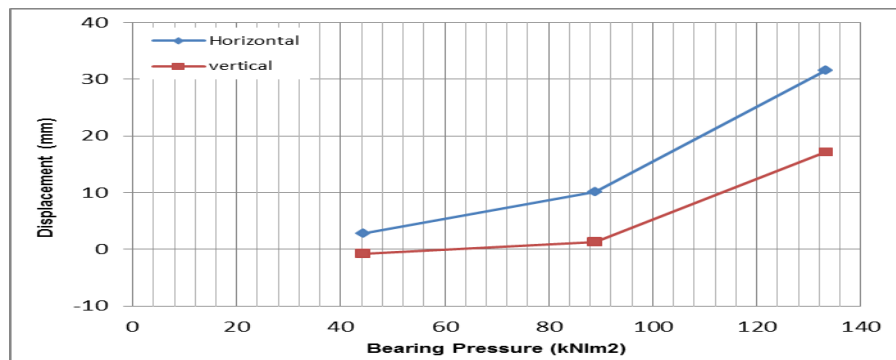

Figure 13. illustrates the pressure-displacement relation of spared footing located at 3.5 m from the slope
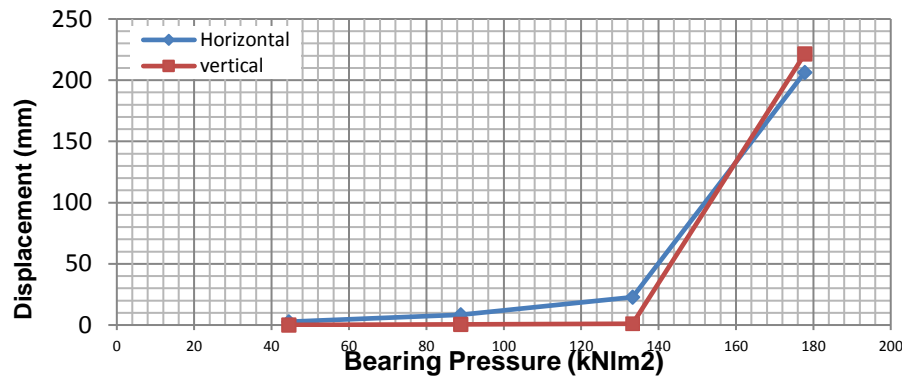
Figure 14. pressure-displacement relation of spared footing located at 4m from the inclination

The total displacement and deformation of spared footing located at 4m from the inclination at surface loads equal to 600. Figure 15 illustrates the pressure-displacement relation of spared footing located at 4 m from the slope.
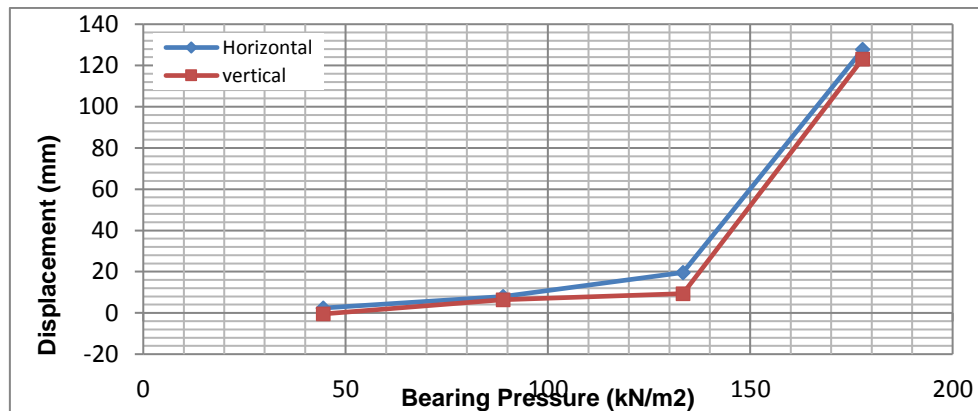

Figure 15. pressure-displacement relation of spared footing located at 4.5m from the inclination

3.3. The Effect of Horizontal Distance from Edge

The horizontal distance from the edge of the slope has a significant effect on the results of vertical and horizontal displacement of the slope after applying the load on the footing. Figure 16 illustrates the vertical displacement of spared footing versus the horizontal displacements from the inclination at surface pressure equal to 44.4 and 88.8 kPa. The result showed the when the horizontal distance from inclination increased the vertical displacements are decreased. Also, the vertical displacements were transferred from compression to swelling with increasing the value of horizontal distance (negative to positive values). The vertical displacements are increased and seem to be oscillated with increasing the pressure stress on the footing

Figure 17 illustrates the horizontal displacement of spared footing versus the horizontal displacements from the inclination at surface pressure equal to 44.4 and 88.8 kPa. The result showed the when the horizontal distance from inclination increased the horizontal displacements are decreased. Also, the vertical displacements were directed to inclination side (positive values). The horizontal displacements are increased and seem to be stable with increasing the pressure stress on the footing.
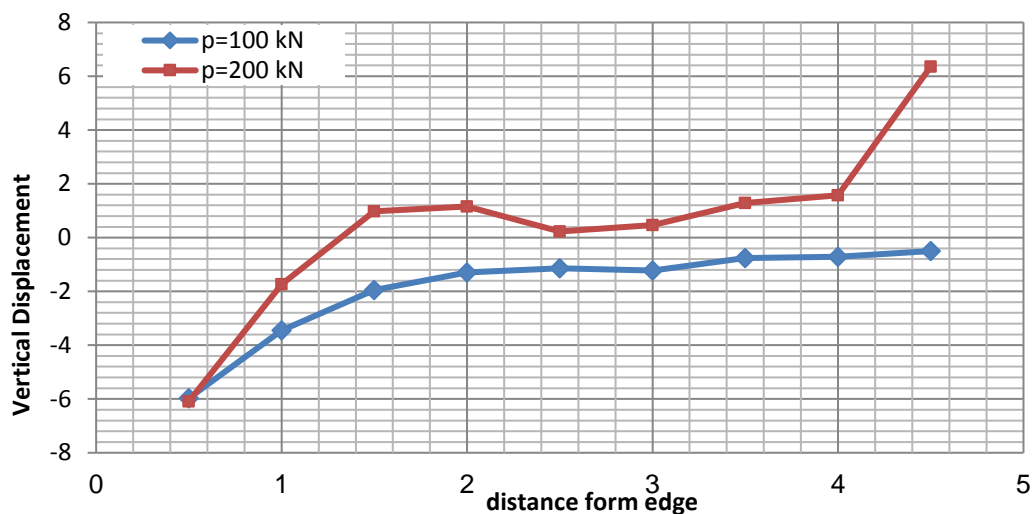
Figure 16. Vertical displacement versus horizontal distance from an edge of spared footing at surface pressure equal to 44.4 and 88.8 kPa.
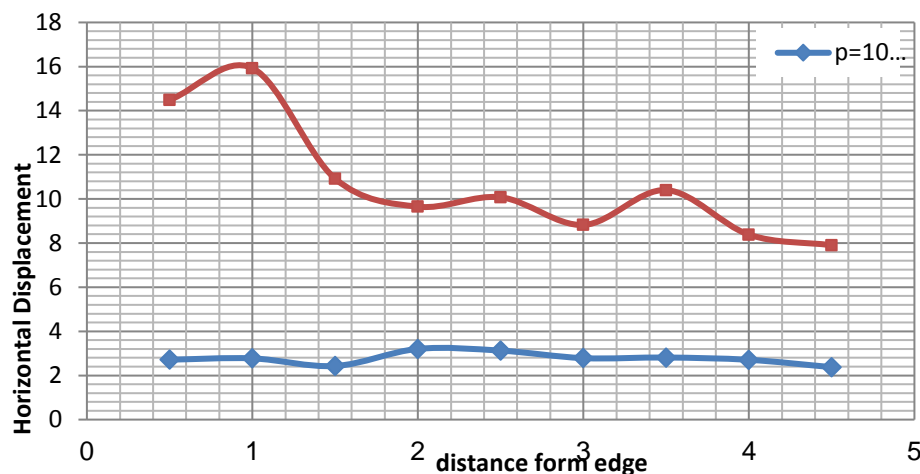

Figure 17. Horizontal displacements versus horizontal distances from the edge of spared footing at surface pressure equal to 44.4 and 88.8 kPa.

4. The comparison of the study with an analytical equation

The numerical models of the present work have been comprised with some results that obtained from Meyerhof's analytical equation. The results of the present work are plotted in the relationship between the ultimate bearing pressures with corresponding horizontal distance from the edge of the slope when settlements are 25 mm. To have accurate results the recorded settlement was under the center of footing, the reason because of the analytical equations of Meyerhof depends on the ultimate bearing pressure for allowable settlement under the center of footing.

Figure 18 illustrates the horizontal distance from the edge for spared footing versus the surface pressures for results obtained from Meyerhof's analytical equation and analytical method using Plaxis program. The behavior of upward surface pressures on spread footing from the PLAXIS analyses showed generally similar behavior with Meyerhof's analytical approach. There is some deviancy between the FEM results and analytical methods.

The results obtained from FEM are significantly smaller than that obtained from analytical methods when the distance from the edge is more than 1.25 m and are more significant than when the distance from the edge is less than 1.25 m. The results gotten from FEM are

considerably compatible with that found from analytical approaches when the distance from the edge is equal to 1.25.
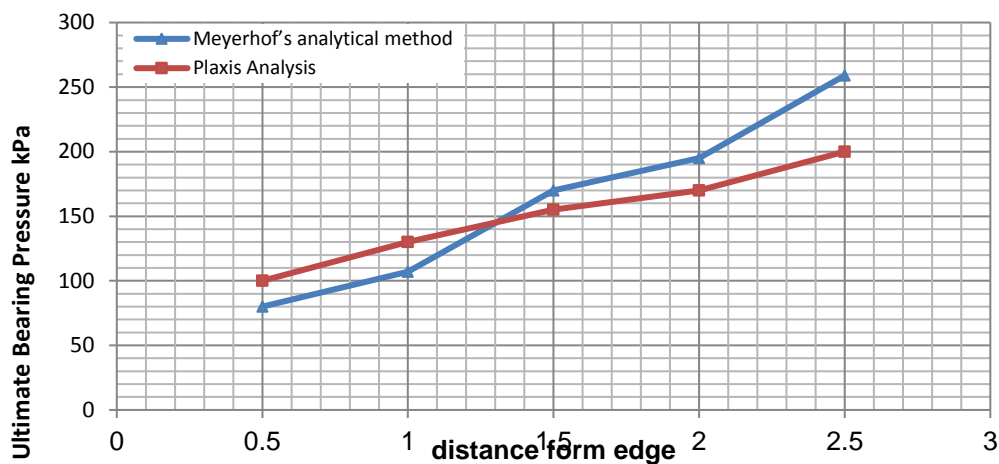

Figure 18. Finite element & analytical result of Bearing Pressure versus horizontal distances from the edge of spared footing.

5. Conclusion

The numerical analysis was carried out to estimate the slope on spread footing supports concerted loads. Horizontal and vertical displacements monitored the behavior of the footing near slope at the point under the center of footing. Also, the numerical models of the present work have been comprised with some results that obtained from Meyerhof's analytical equation. The results of the present work are plotted in the relationship between the ultimate bearing pressures with corresponding horizontal distance from the edge of the slope when settlements are 25 mm. It may be concluded from the obtained results that increasing the distance from the edge of the slope to the edge of footing decrease the horizontal and vertical displacements. Increasing the distance from the edge of the slope to the edge of footing will increase the bearing pressure which applied on the footing. The behavior of upward surface pressures on spread footing from the PLAXIS analyses showed generally similar behavior with Meyerhof's analytical method. There is some deviancy between the FEM results and analytical methods.

The results obtained from FEM are significantly smaller than that obtained from analytical methods when the distance from the edge is more than 1.25 m and are higher than when the distance from the edge is less than 1.25 m. The results obtained from FEM are considerably compatible with that achieved from analytical approaches when the distance from the edge is equal to 1.25.

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