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Study the Effect of Soil and Bedrock Conditions below the Footing on the Footing Behavior

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Abstract : *Footings are structural elements that transmit column or wall loads to the underlying soil below the structure. Most of the buildings in Libya suffer from many problems, which are cracks in the buildings due to foundation settlement. The most common causes of foundation settlement are weak bearing soils and poor compaction. So, the purpose of this paper is to present the study on the effect of soil and bedrock conditions below footing on the footing behavior. PLAXIS 3D, finite element software package was used to perform numerical modeling and analyses to evaluate the structural response and behavior of the square footing. The results show that the soil and bedrock conditions below the footing may have a significant effect on the footing behavior such as horizontal displacements (Ux & Uz), stresses, and shear strains and should be considered during the design of footing.*

Keywords: *Footing, Numerical Modeling, Displacements, Stresses, Shear Strains, Soil, Bedrock.*

1.INTRODUCTION

A foundation is the lowest part of the structure which supports the structure by distributing its load on the soil as shown in figure (1). A properly designed foundation transfers the load throughout the soil without overstressing the soil. Overstressing the soil can result in either excessive settlement or shear failure of the soil, both of which cause damage to the structure. Thus, geotechnical and structural engineers who design foundations must evaluate the bearing capacity of soils (Das, 2010). Foundation design involves a soil study to establish the most appropriate type of foundation and a structural design to determine footing dimensions and required amount of reinforcement. In this paper studies the behavior of footing on different properties of soil. Mohamad Gabar [1] studied the effect of subsurface conditions (different soil and footing properties) on the behavior of footing by using PLAXIS software. Hany Farouk and Mohammed Farouk [2] studied the effect of soil model on contact stress under strip footing. Aarash Hosseini [3] investigated the effect of confinement pressure on bearing capacity of two samples of square and strip footing. H.V. Phuong Truong [4] studied the effect of damping and dynamic soil mass on footing. Bienen, B., Ragni, R., Cassidy, M., and Stanier, S. [5] studied the effect of consolidation under a penetrating footing in carbonate silty clay. Sang-Sup Lee, Jiho Moon, Keum-Sung Park, and Kyu-Woong Bae [6] studied a new method to increase the strength and ductility of the footing was proposed by inserting the punching shear preventers (PSPs) into the footing. So in this paper presented the knowledge and understanding of the behavior of footing (square Footing) on the different conditions under footing as represented in parametric study and to find the displacements , stresses and shear strains in the soil.

1.1 Objective of this Paper

Current structural design of a footing studies the effect of bearing capacity on the footing behavior. Therefore, this paper studies how the soil and bedrock conditions below the footing affect on the footing behavior such as horizontal displacements Ux & Uz, stresses, and shear strains. Earlier studies have taken an experimental approach to investigate the effects of consolidation around a footing penetrating into carbonate silty clay and, following detailed discussion of the response, offers a framework to predict the changes to the load-penetration curve (Bienen, Ragni, Cassidy, and Stanier, 2015) and have taken a modeling to investigate the effects of using different young's modulus with different footing properties on footing behavior (Mohamad Gabar, 2016). In addition, the effect of soil and bedrock conditions below footing on footing behavior have also been investigated during this study.

1.2 Scope and Parametric Study

The primary focus of this paper is to investigate the structural response of footing using parametric studies for varying conditions. The conditions studied are: (1) Different bedrock depths (D = 4m to 20m) below the footing at horizontal bedrock slope (θ = 0°); (2) Different friction angles (Φ) for all bedrock depths at horizontal bedrock slope (θ = 0°) as shown in Table (1); (3) Different bedrock slopes (θ = 11.3° to 70.3°) at depths (D = 8m & 16m). (4) Different friction angles (Φ) for different bedrock slopes at (D = 8m) as shown in Table (1). (5) Different young's modulus (E) for different bedrock slopes at (D = 8m) as shown in Table (2). Not all the parameters and ranges are considered for all possible combinations. Some of the parameters are studied by only with limited combinations of other parameters just to investigate the effect of that parameter. Parametric studies were performed by numerical modeling and analysis using commercially available general purpose 3-D finite element software for geotechnical engineering applications. The structural analysis by PLAXIS software involved investigating displacements, stresses, and shear strains.

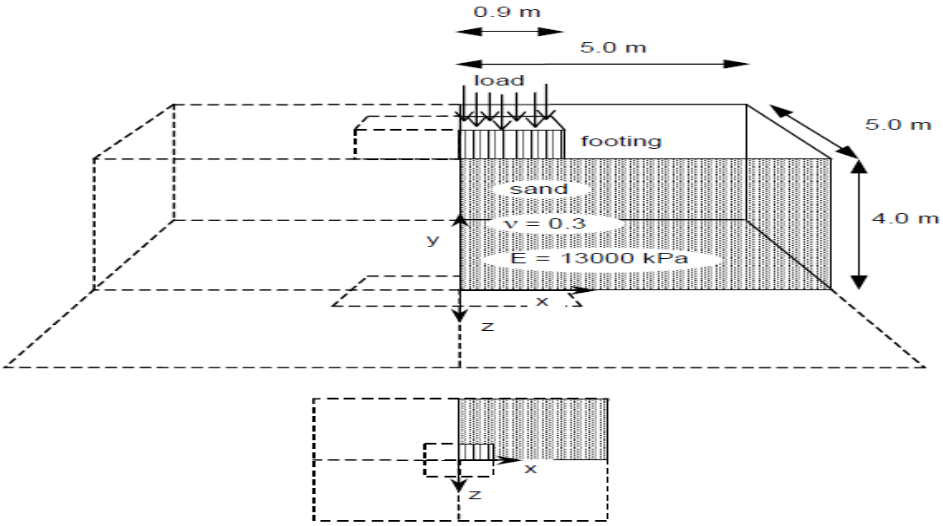


Figure 1. Geometry of A square Footing on A sand Layer, Only One-Quarter of the Footing is Modeled

2- NUMERICAL MODEL

PLAXIS, **3**-D finite element analysis software package, was used for the parametric study in this paper. PLAXIS has been developed specifically for the analysis of deformation and stability in geotechnical engineering projects. The calculation itself is fully automated and based on robust numerical procedures (PLAXIS 3D, 2011). It should be noted that the simulation of geotechnical problems by means of the finite element method implicitly involves some inevitable numerical and modeling errors (PLAXIS 3D, 2002). Finite element methods adopted in commercial software PLAXIS has been used in the analysis of structural elements involving excavation procedures. However, past failures indicated that the successful analysis using the codes is essentially depended on the selection of constitutive model used to represent soil behavior and the selection of the related soil properties. With PLAXIS, it is possible to model different element types such as anchors to support the retaining wall, different footing properties, various types of loads on the footing, and the interface elements between the footing and the soil.

The parametric study is focused primarily on studying the effect of different depths of the bedrock (D) below the footing at (θ=0°), different friction angle (Φ) at horizontal bedrock slope (θ=0°), different bedrock slopes (θ) below the footing, and using different (Φ & E) at different (θ) on the footing behavior. The study was performed using the PLAXIS 3D version 8 finite element program employing 15-noded triangular elements.

A total of seventy-two cases have been modeled and analyzed in this parametric study. Four cases were carried out to investigate the effect of depths of the bedrock below the footing on the footing behavior such as horizontal displacements Ux & Uz (m), stresses (Kn/m^2), and shear strains (%). Twenty cases were carried out to investigate the effect of different friction angle (Φ) at horizontal bedrock slope (θ=0°) on the footing behavior. Eight cases were carried out to investigate the effect of different bedrock slopes (θ) below the footing. Lastly, forty cases were carried out to investigate the effect of different (Φ & E) at different (θ) on the footing behavior. For all the cases modeled and analyzed, the horizontal displacements Ux & Uz, stresses, and shear strains were investigated to understand the effect of various factors on the footing behavior as described above. Numerical analyses and results are presented and discussed in the following part.

2.1 Effect of Bedrock Depth (D)

A parametric study was performed to investigate the effect of bedrock depth (D) at (θ = 0°) below the ground level on the footing behavior by using (E = 13000 Kn/m^2 & Φ = 30°). The bedrock depths, D, analyzed were 4 m, 8 m, 12 m, 16 m, and 20 m. The width of each model was also adjusted based on the bedrock depth as shown in Figure (1).

2.2 Effect of Friction Angle (Φ)

A parametric study was performed to investigate the effect of different friction Angle for all bedrock depth and (θ = 0°) on the footing behavior such as dense sand soil (with ϕ = 40°) to loose sand soil (with ϕ = 32°). The model has one soil layer for the entire model. Also, the soil properties used for the analyses are listed in Table (1). The interface elements were introduced to simulate the soil-structure interaction behavior in order to predict the wall behavior more accurately.

Table (1) Material Properties for the Soil Types Studied (Φ)

Parameter	Name	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Unit
Material model	**Model**	**Mohr-Coulomb**	**Mohr-Coulomb**	**Mohr-Coulomb**	**Mohr-Coulomb**	**Mohr-Coulomb**	**-**
Type of material behavior	**Type**	**Drained**	**Drained**	**Drained**	**Drained**	**Drained**	**-**
Soil unit weight above phreatic level	γ_{unsat}	**17**	**17**	**17**	**17**	**17**	**KN/m³**
Soil unit weight below phreatic level	γ_{sat}	**20**	**20**	**20**	**20**	**20**	**KN/m³**
Permeability	K_y, K_x K	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**m/day**
Young's modulus	E	**13000**	**13000**	**13000**	**13000**	**13000**	**KN/m²**
Poisson's ration	**N**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**-**
Cohesion	**C**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**KN/m²**
Friction angle	**Φ**	**32**	**34**	**36**	**38**	**40**	**°**
Dilatancy angle	**ψ**	**0**	**0**	**0**	**0**	**0**	**°**
Strength reduction factor interface	R_{inter}	**1**	**1**	**1**	**1**	**1**	**-**

2.3 Effect of Bedrock Slopes (θ)

The effect of bedrock slope was investigated by studying different bedrock depths (D = 8m & 16m) and soil property (soil1) with using E = 13000 Kn/m^2 as represented in Table (1). The objective was to compare the horizontal displacements Ux & Uz, stresses, and shear strains below the footing. The bedrock slopes (θ) used in PLAXIS below the footing are (11.30° to 70.30°).

2.4 Effect of (Φ) at Different (θ)

A parametric study was performed to investigate the effect of different friction angle for all bedrock slopes (θ) on the footing behavior such as (Φ = 32° to 40°). Also, the soil properties used for the analyses are listed in Table (1).

2.5 Effect of (E) at Different (θ)

A parametric study was performed to investigate the effect of different young's modulus for all bedrock slopes (θ) on the footing behavior such as (E = 8000 Kn/m^2 to 25000 Kn/m^2). Also, the soil properties used for the analyses are listed in Table (2). The interface elements were introduced to simulate the soil-structure interaction behavior in order to predict the wall behavior more accurately.

Table (2) Material Properties for the Soil Types Studied (E)

Parameter	Name	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Unit
Material model	**Model**	**Mohr-Coulomb**	**Mohr-Coulomb**	**Mohr-Coulomb**	**Mohr-Coulomb**	**Mohr-Coulomb**	**-**
Type of material behavior	**Type**	**Drained**	**Drained**	**Drained**	**Drained**	**Drained**	**-**
Soil unit weight above phreatic level	γ_{unsat}	**17**	**17**	**17**	**17**	**17**	**KN/m³**
Soil unit weight below phreatic level	γ_{sat}	**20**	**20**	**20**	**20**	**20**	**KN/m³**
Permeability	$K_y, K_x\ K$	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**m/day**
Young's modulus	E	**8000**	**12000**	**15000**	**20000**	**25000**	**KN/m²**
Poisson's ration	**N**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**-**
Cohesion	**C**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**KN/m²**
Friction angle	**Φ**	**30**	**30**	**30**	**30**	**30**	**°**
Dilatancy angle	**ψ**	**0**	**0**	**0**	**0**	**0**	**°**
Strength reduction factor interface	R_{inter}	**1**	**1**	**1**	**1**	**1**	**-**

3- RESULT AND DISCUSSION

This case was established to investigate the effect of bedrock depth (D) below the footing on the footing behavior by using loose sand soil (ϕ=30°). Figures (2) through (9) show the horizontal displacements vectors Ux & Uz, stresses, and shear strains for bedrock depth D=4 m, at bedrock slope θ = 0° under the footing. The analysis results in terms of maximum horizontal displacements (Ux,Uz), maximum stresses, and maximum shear strains for all the depths (D = 4, 8, 12, 16, and 20m) analyzed are given in Tables (3) through (5), shown in Figures (10) through (12), and discussed below.

The maximum horizontal displacement Ux increases with increasing bedrock depths as shown in Figure (10). Also, the maximum horizontal displacement Uz decreases with increasing bedrock depths as shown in Figure (10). In figures (11) and (12) show that the maximum stresses and shear strains decrease with increasing the bedrock depth. So, the analysis results in terms of changing bedrock depths have significant effect on the footing behavior due to the presence of more amount of soil below the footing.

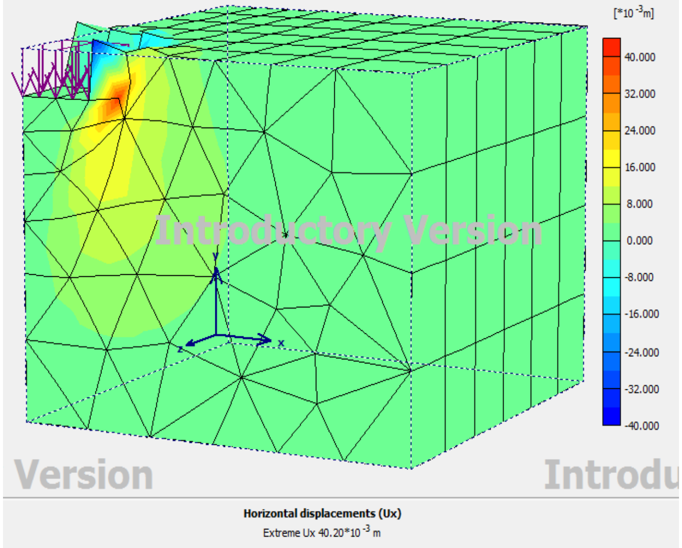


Figure 2. Horizontal Displacement (Ux) Vectors for Depth, D=4 m at (θ=0°)

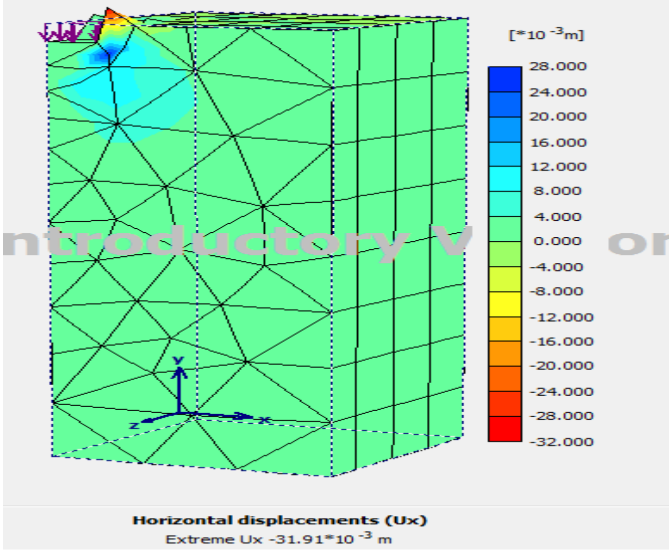


Figure 3. Horizontal Displacement (Ux) Vectors for Depth, D=12 m at (θ=0°)

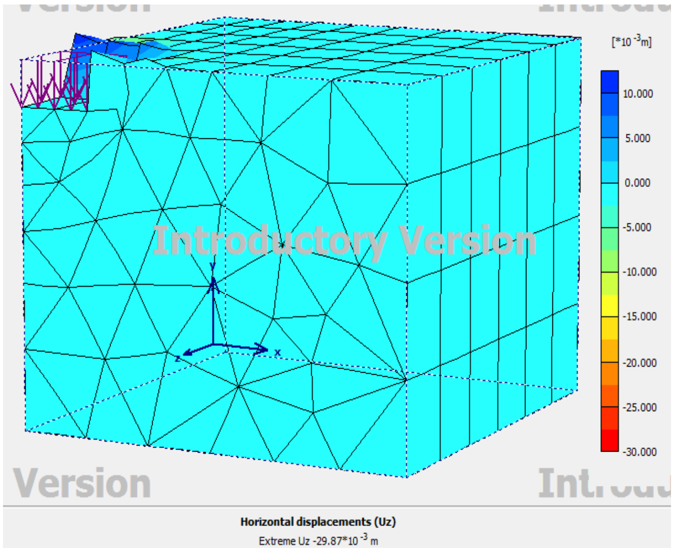


Figure 4. Horizontal Displacement (Uz) Vectors for Depth, D=4 m at (θ=0°)

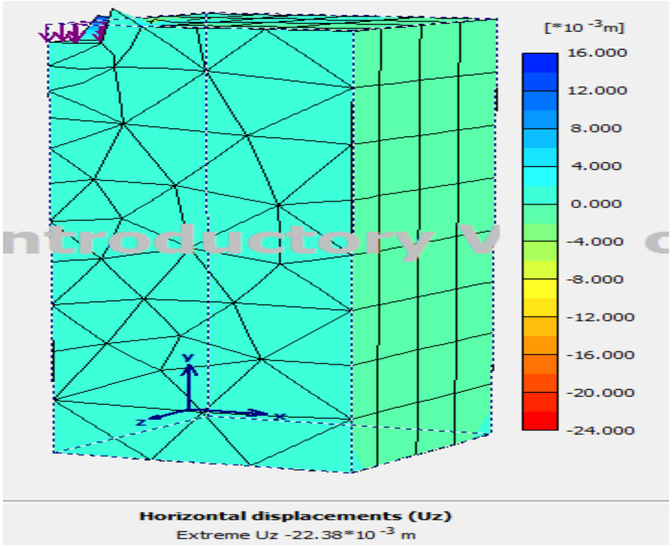
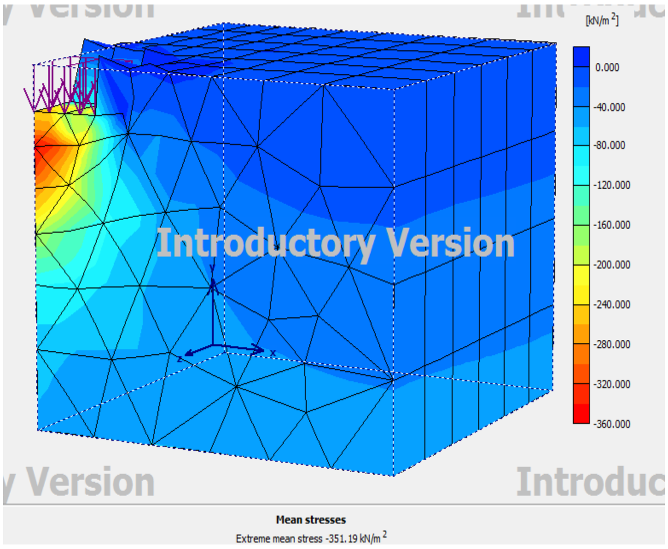
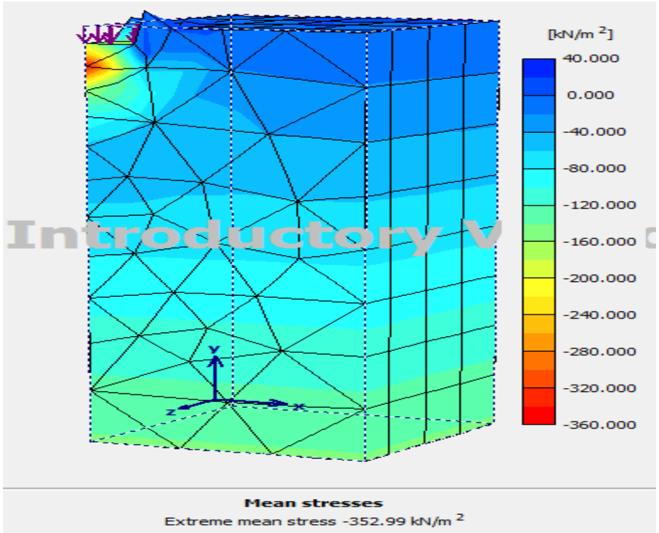


Figure 5. Horizontal Displacement (Uz) Vectors for Depth, D=12 m at (θ=0°)



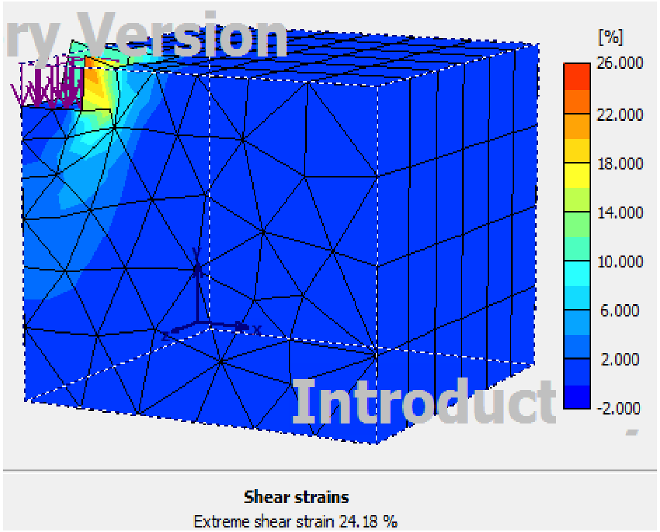
Mean stresses
Extreme mean stress -351.19 kN/m²

Figure 6. Stresses Vectors for Depth, D= 4 m at (θ=0°)



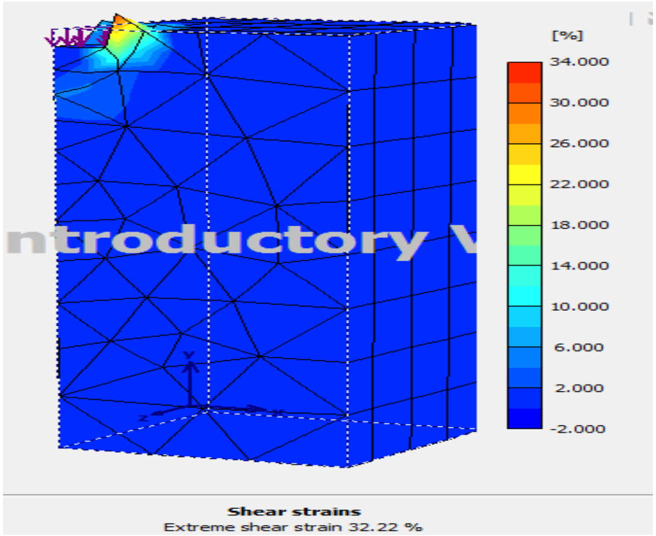
Mean stresses
Extreme mean stress -352.99 kN/m²

Figure 7. Stresses Vectors for Depth, D= 12 m at (θ=0°)



Shear strains
Extreme shear strain 24.18 %

Figure 8. Shear Strains Vectors for Depth, D= 4 m at (θ=0°)



Shear strains
Extreme shear strain 32.22 %

Figure 9. Shear Strains Vectors for Depth, D= 12 m at (θ=0°)

Table (3) Maximum Horizontal Displacements for Varying Bedrock Depths

Depth (m)	Maximum Horizontal Displacement Ux & Ux (m)	
	Ux at (θ = 0°)	Uz at (θ = 0°)
4	4.02E-02	-2.99E-02
8	-4.17E-02	-2.81E-02
12	-3.19E-02	-2.24E-02
16	-4.94E-02	-1.55E-02
20	-4.60E-02	-1.38E-02

Table (4) Maximum Stresses for Varying Bedrock Depths (By Author)

Depth (m)	Maximum Stresses (Kn/m2)
	at (θ = 0°)
4	-3.51E+02
8	-3.82E+02
12	-3.53E+02
16	-2.76E+02
20	-2.70E+02

Table (5) Maximum Shear Strains for Varying Bedrock Depths (By Author)

Depth (m)	Maximum Shear Strains (%)
	at (θ = 0°)
4	24.18
8	29.45
12	32.22
16	12.35
20	11.72

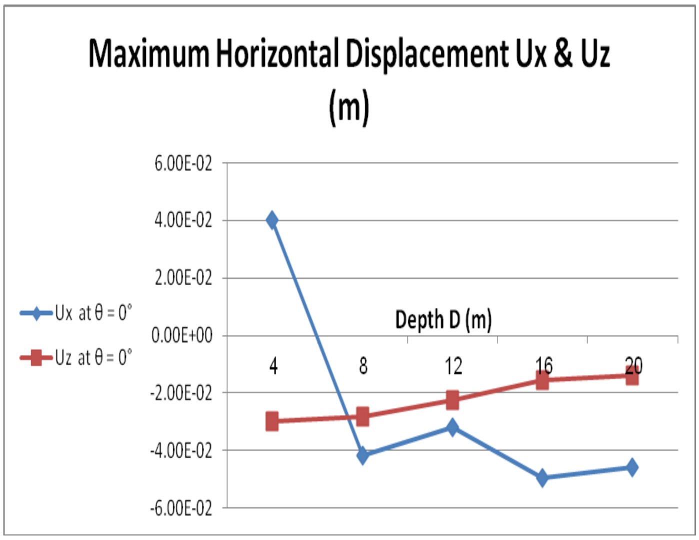


Figure 10. Maximum Horizontal Displacement Ux & Uz (m) at Varying Bedrock Depth & (θ = 0°)

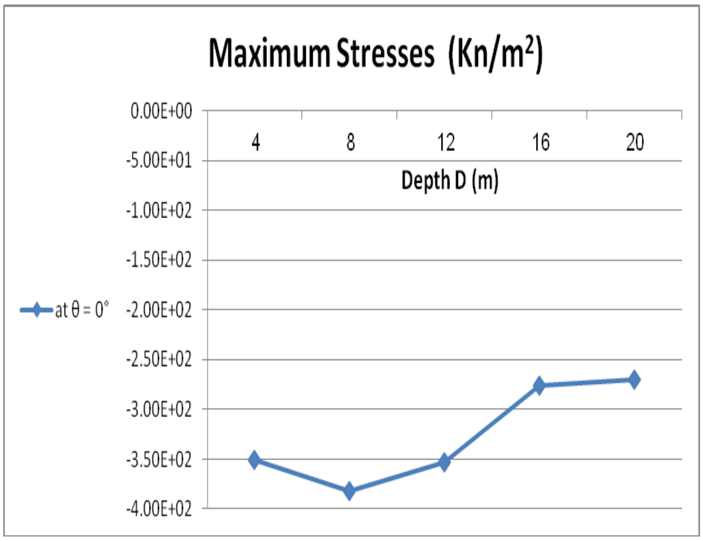


Figure 11. Maximum Stresses (Kn/m2) at Varying Bedrock Depth

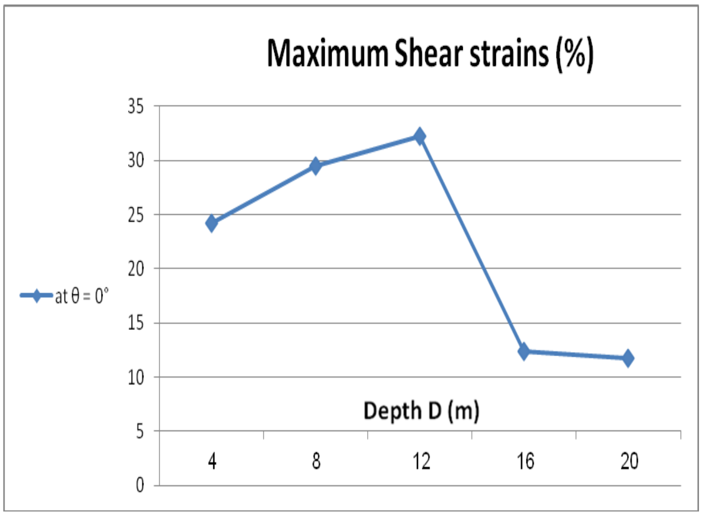


Figure 12. Maximum Shear Strains (%) at Varying Bedrock Depth & (θ = 0°)

3.2 Effect of Friction Angle (Φ)

Additional modeling and analysis were performed using relatively stronger soils (dense soil) to investigate the effect of soil strength on the footing behavior and to study if the behavior observed for relatively less stronger soils (loose soil) under varying bedrock depths as shown in Table (1). The maximum horizontal displacements, stresses, and shear strains below the footing with different friction angle and different bedrock depth have the similar behavior on the footing behavior that mean when the friction angles increase at different bedrock depths, the displacements, stresses and shear strains have little effect on the footing behavior due to changing the soil property (Φ) below the footing that lead to decreasing shear strains as shown in Figure (13) through (16), respectively.

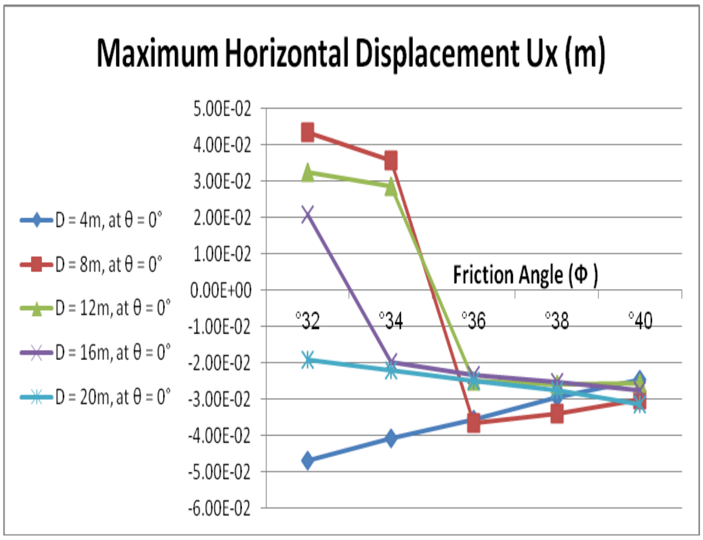


Figure 13. Maximum Horizontal Displacement Ux (m) at Varying Friction Angle & (θ = 0°)

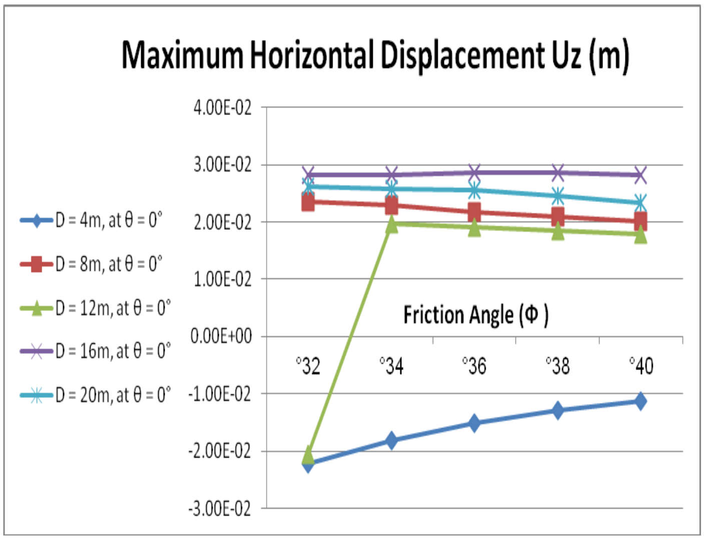


Figure 14. Maximum Horizontal Displacement Uz (m) at Varying Friction Angle & (θ = 0°)

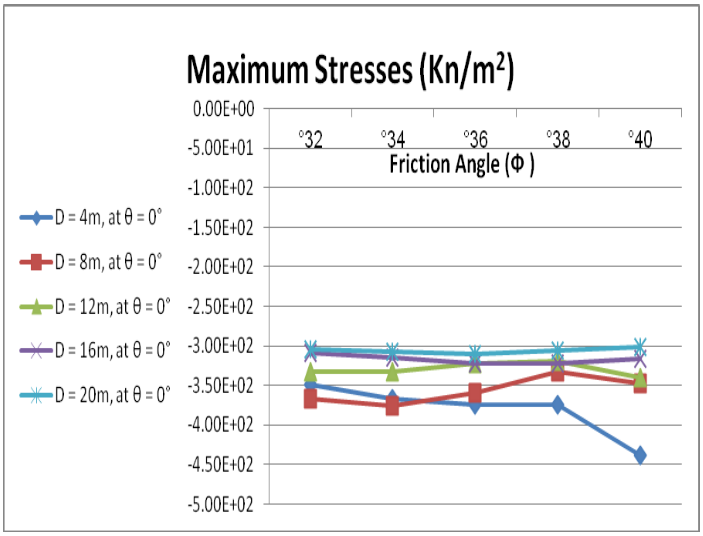


Figure 15. Maximum Stresses (Kn/m2) at Varying Friction Angle & (θ = 0°)

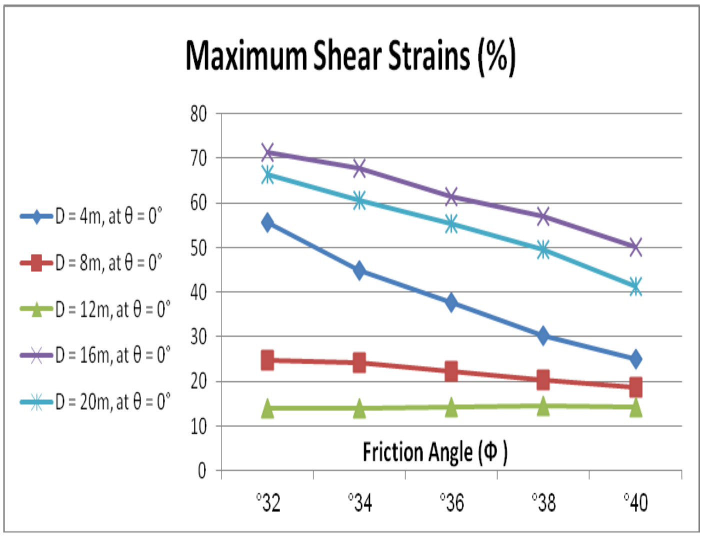


Figure 16. Maximum Shear Strains (%) at Varying Friction Angle & (θ = 0°)

3.3 Effect of Bedrock Slopes (θ)

This case was established to investigate the effect of bedrock slope (θ) below the footing on the footing behavior by using loose sand soil (ϕ=30°). In figures (17) through (24) show the horizontal displacements, stresses, and shear strains for bedrock depths of D=8 m and 16 m under the footing. The maximum horizontal displacements, maximum stresses, and maximum shear strains are shown in Figures 17 through 24 for varying bedrock slopes (θ).

The analysis results in terms of maximum horizontal displacements, maximum stresses, and maximum shear strains for varying (θ) analyzed are given in Tables (6) through (11), and discussed below.The maximum horizontal displacements, stresses, and shear strains below the footing have significant effect on the footing behavior with increasing bedrock slopes at varying bedrock depths (D= 8m & 16m). This is due to the presence of lesser amount of soil below the footing which lead to increasing soil stress below the footing as shown in Figure (25) through (30), respectively.

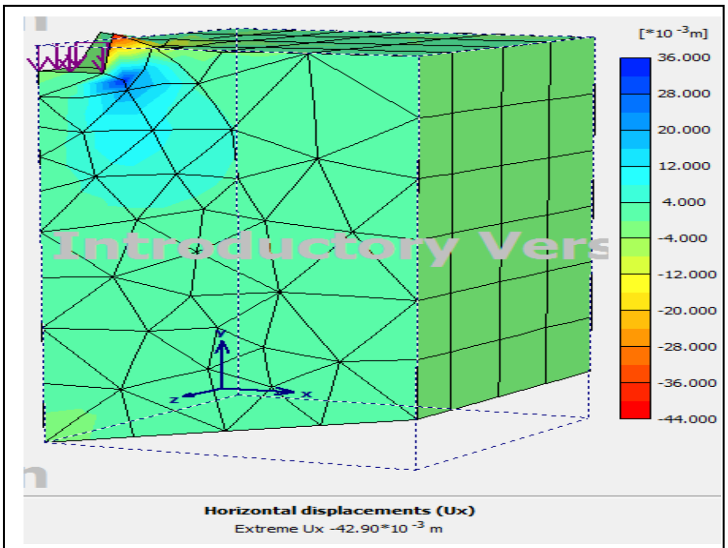


Figure 17. Horizontal Displacement (Ux) Vectors for Depth, D=8 m at (θ=11.3°))

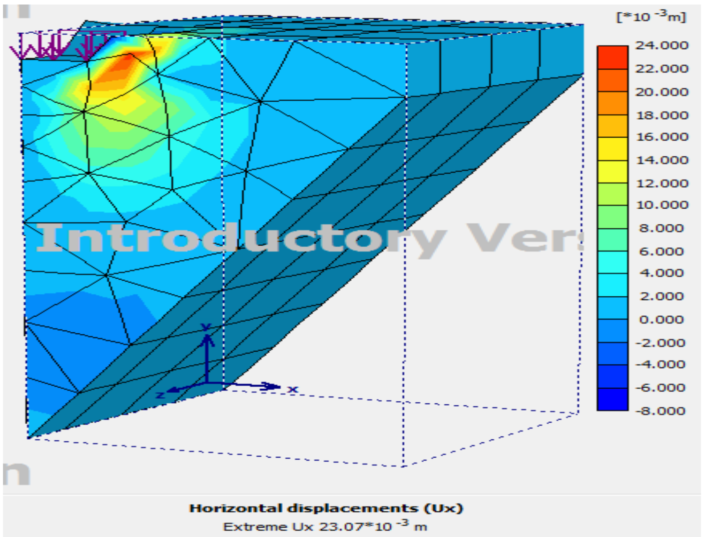


Figure 18. Horizontal Displacement (Ux) Vectors for Depth, D=8 m at (θ=54.5°)

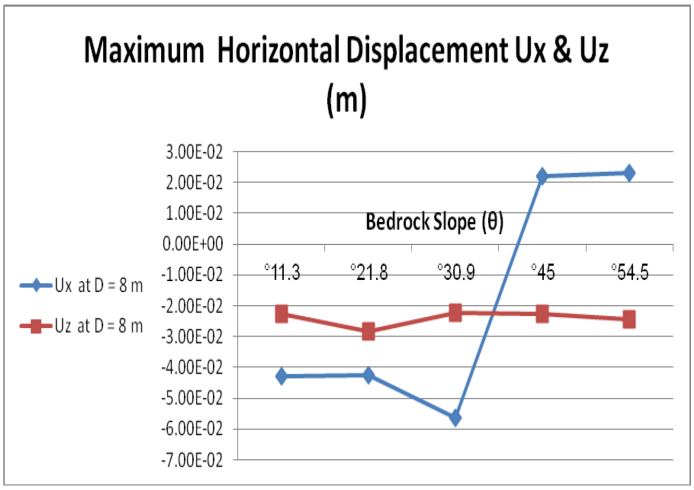


Figure 19. Maximum Horizontal Displacement Ux & Uz (m) at Varying Bedrock Slope & (D = 8m)

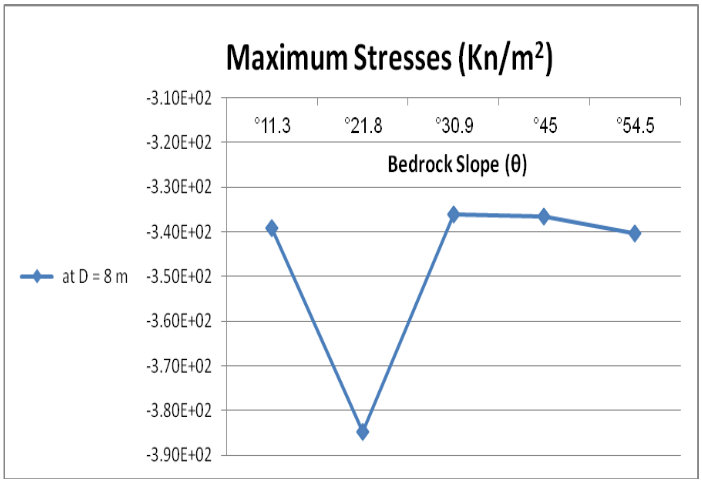


Figure 20. Maximum Stresses (Kn/m2) at Varying Bedrock Slope & (D = 8m)

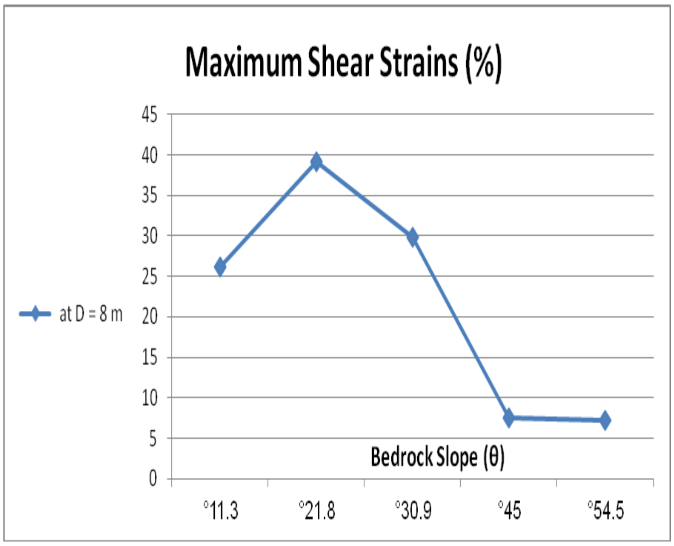


Figure 21. Maximum Shear Strains (%) at Varying Bedrock Slope& (D = 8m)

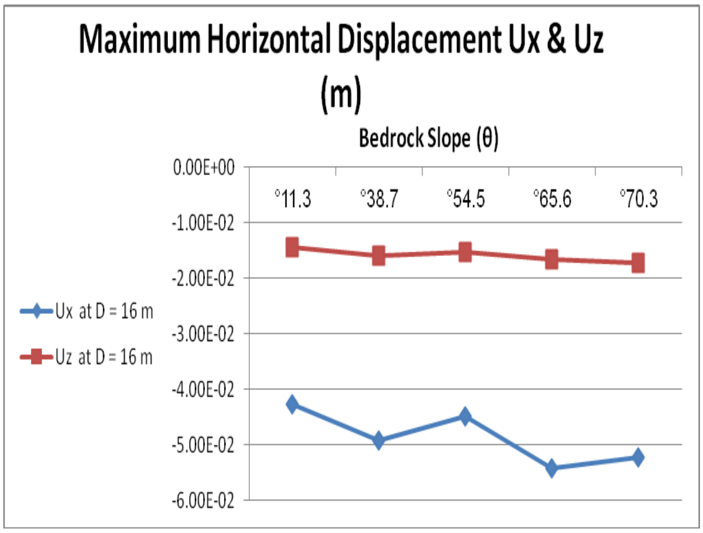


Figure 22. Maximum Horizontal Displacement Ux & Uz (m) at Varying Bedrock Slope & (D = 16m)

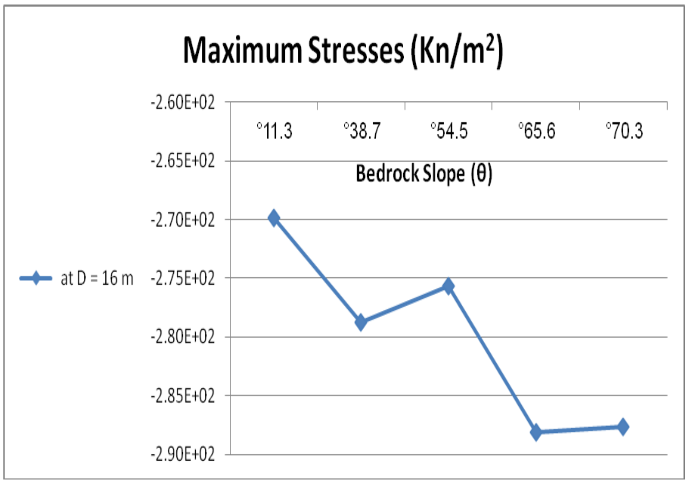


Figure 23. Maximum Stresses (Kn/m2) at Varying Bedrock Slope & (D = 16m)

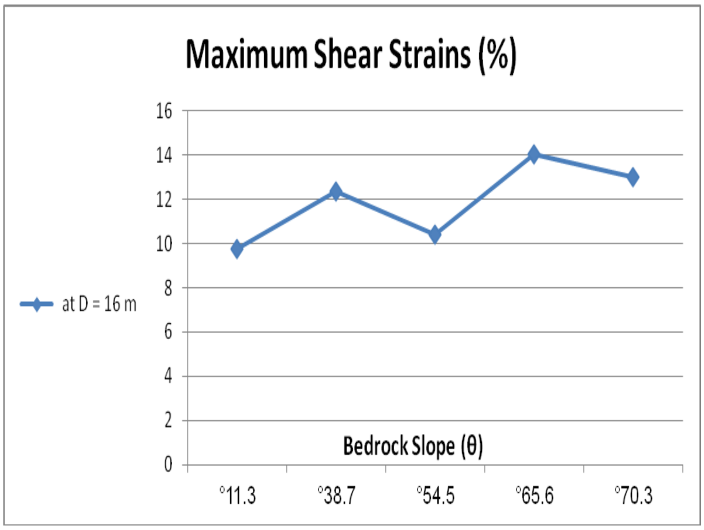


Figure 24. Maximum Shear Strains (%) at Varying Bedrock Slope & (D = 16m)

3.4 Effect of Friction Angle (Φ) at Different Bedrock Slope (θ)

This modeling and analyses were performed to investigate the effect of varying friction angle (Φ) at different (θ) on the footing behavior under bedrock depth 8m

Figures (25) through (28) show that the maximum horizontal displacements, shear strains, and stresses below the footing decrease with increasing friction angle at varying bedrock slopes (θ = 11.30° to 54.5°). This is due to the increasing soil granules friction with each other with using varying (Φ) below the footing.

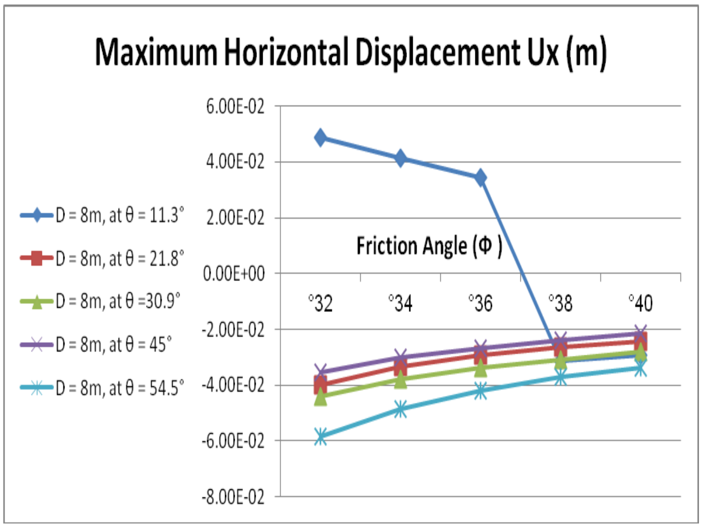


Figure 25. Maximum Horizontal Displacement Ux (m) at Varying (Φ & θ)

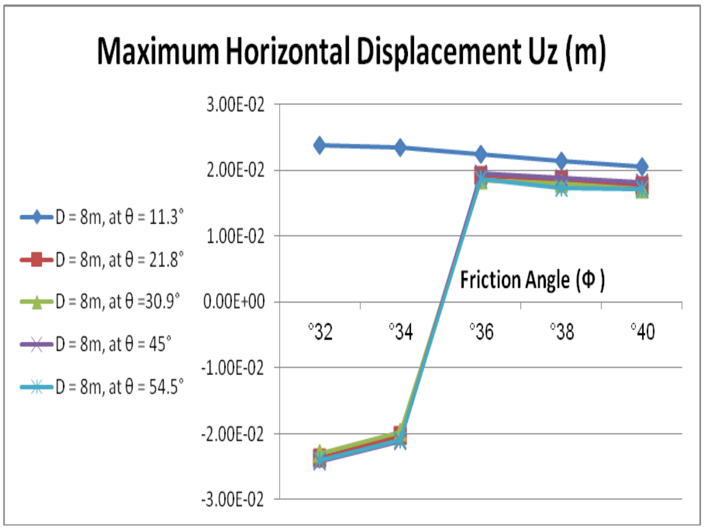


Figure 26. Maximum Horizontal Displacement Uz (m) at Varying (Φ & θ)

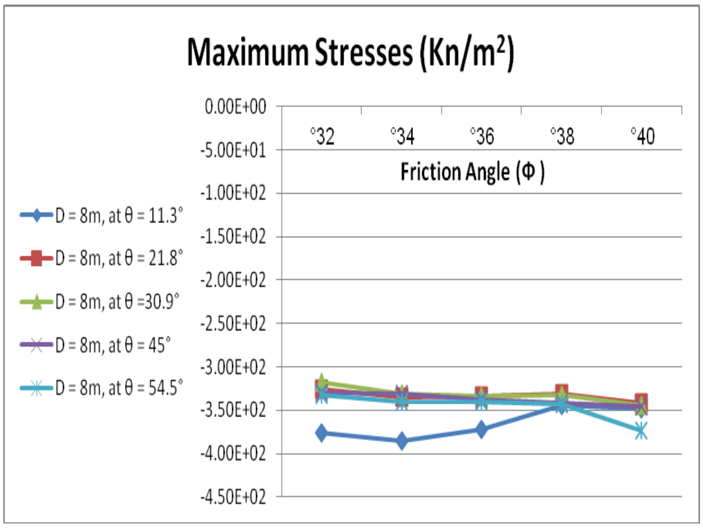


Figure 27. Maximum Stresses (Kn/m2) at Varying (Φ & θ)

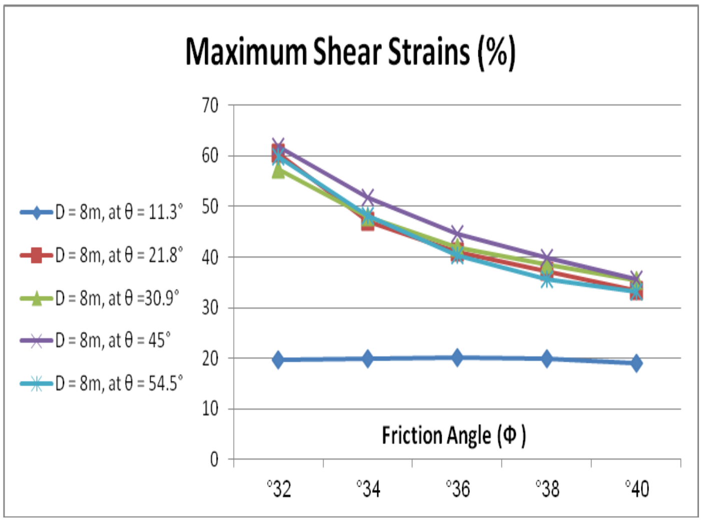


Figure 28. Maximum Shear Strains (%) at Varying (Φ & θ) & (D=8m)

3.5 Effect of Young's Modulus (E) at Different Bedrock Slope (θ)

This modeling and analyses were performed to investigate the effect of varying young's modulus (E) at different (θ) on the footing behavior under bedrock depth 8m.

Figures (29) through (32) show that the maximum horizontal displacements, shear strains, and stresses below the footing increase with increasing young's modulus at varying bedrock slopes (θ = 11.30° to 54.5°). This is due to the increasing soil stress below the footing behavior.

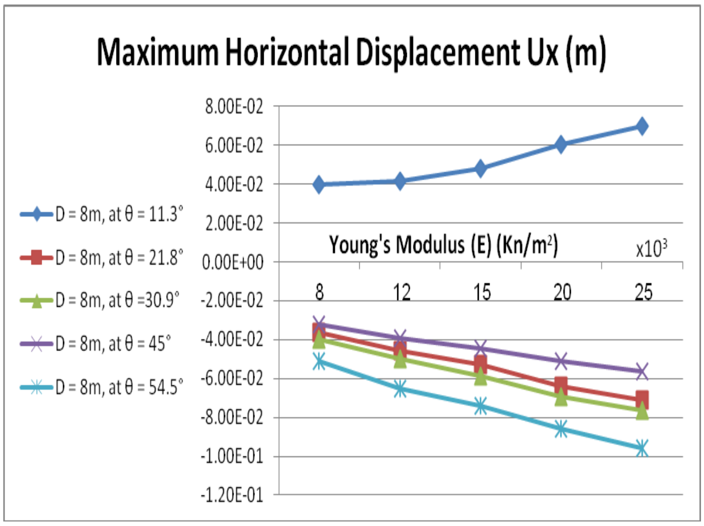


Figure 29. Maximum Horizontal Displacement Ux (m) at Varying (E & θ) & (D=8m)

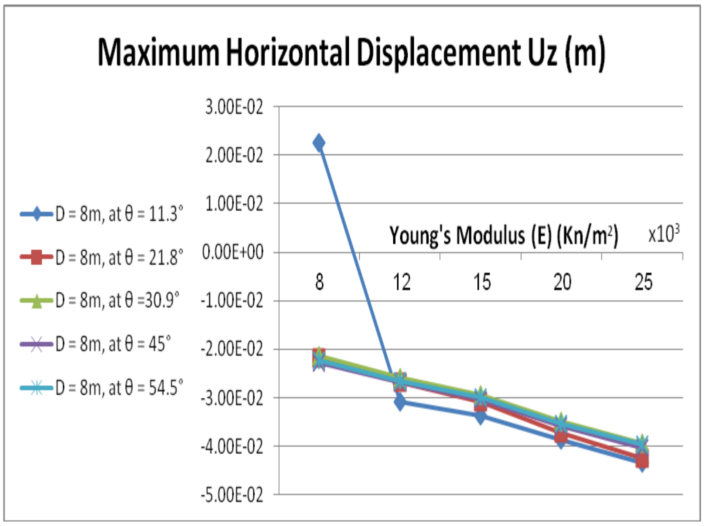


Figure 30. Maximum Horizontal Displacement Uz (m) at Varying (E & θ) & (D=8m)

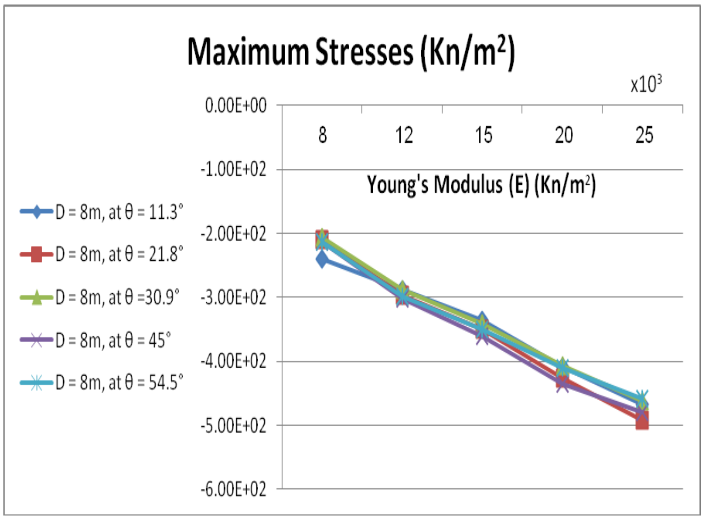


Figure 31. Maximum Stresses (Kn/m2) at Varying (E & θ) & (D=8m)

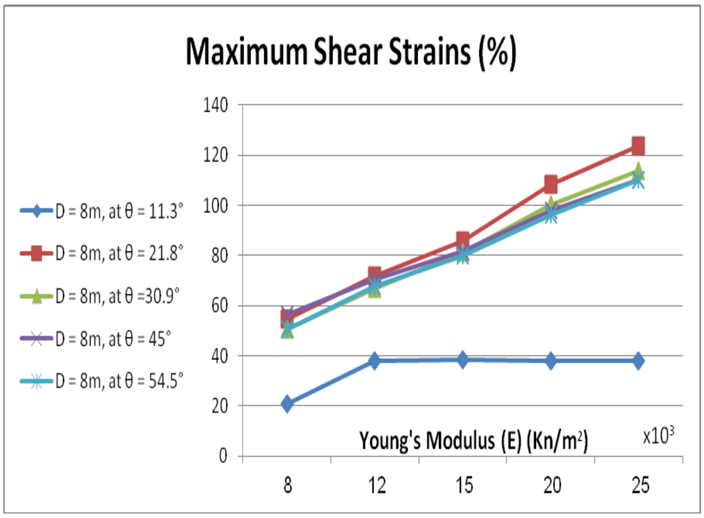


Figure 32. Maximum Shear Strains (%) at Varying (E & θ) & (D=8m)

4-CONCLUSION

The effect of bedrock depths, soil strength, and bedrock slopes below the footing on the behavior of a typical footing have been studied and presented in this paper. The footing behavior was investigated through the horizontal displacements, stresses, and shear strains. A finite element analysis, using PLAXIS software, were utilized to perform the analyses. The overall findings of the study indicate that the soil and bedrock conditions below the footing affect the structural behavior of the footing and should be considered during the design of the footings. The results of this study will help engineers in designing the foundations. For the parameter ranges and the cases studied the following conclusions are reached from this study:

1. The maximum horizontal displacements, stresses, and shear strains below the footing with different friction angles, different bedrock slopes and different bedrock depths have significant effect on the footing behavior due to the presence of more and lesser amount of soil below the footing which lead to increasing and decreasing soil stresses below the footing.

2. The maximum horizontal displacements, stresses, and shear strains below the footing have the most effect on footing behavior with increasing young's modulus at varying bedrock slopes. This is due to the increasing soil stresses below the footing and its effecting on the footing behavior.

3. When increasing friction angle at varying bedrock slopes, the maximum horizontal displacements, shear strains, and stresses below the footing decrease. This is due to the increasing soil granules friction with each other that leads to control the friction resistance of soils together with the normal effective stress.

As a recommendation for future research, it would be very valuable to perform some field monitoring to accompany this study and confirm some of the findings of this paper.

REFERENCES

[1] Aarash Hosseini, 2014. "Effect of confinement pressure on bearing capacity of two samples of square and strip footing", NCBI (National Center for Biotechnology Information), Bethesda MD, USA.

[2] Arnold Verruijt, 2001, " Soil Mechanics." Department of Civil Engineering, Delft University of Technology, Holland.

[3] Bienen, B., Ragni, R., Cassidy, M., and Stanier, S. (2015). "Effects of Consolidation under a Penetrating Footing in Carbonate Silty Clay." J. Geotech. Geoenviron. Eng., 10.1061/(ASCE)GT.1943-5606.0001339, 04015040.

[4] Braja M. Das. 2010. “Principles of Geotechnical Engineering.” Seventh Edition, Stamford, CT, USA.

[5] Hany Farouk, A.M.ASCE, and Mohammed Farouk, Ph.D., 2014. "Effect of soil model on contact stress under strip footing" ASCE (American Society of Civil Engineers), Cairo, Egypt.

[6] Hoe, NG.. Numerical modeling of diaphragm wall in kuala lumpur limestone formation. Faculty of Civil Engineering, University Teknology: Malaysia; 2007.

[7] H.V. Phuong Truong, Ph.D., P.E., 2010. "Effects of damping and dynamic soil mass on footing" ASCE (American Society of Civil Engineers), Califorina, USA.

[8] Hsai, Yang Fang. 2002. “Foundation engineering handbook-Second Edition.” Van Nostand Reinhold.

[9] Komitu Architects, 2012, " Casting the concrete footings." Agroup of young finnish architects and architecture, Phnom Penh, Cambodia.

[10] Mohamad Gabar, (2016) " Effect of subsurface conditions on the behavior of footing by using Plaxis software." University of Benghazi, faculty of arts and science - Al Marj. Under Number 284/2014 (ISSN: 2312-4962) (Issue: Twenty - 15, Nov. 2016).

[11] Punmia, B. C. (2005) “Soil Mechanics and Foundations”, Laxmi Publications Pvt. Ltd., Bangalore.

[12] PLAXIS 2D 2002.www.thepiratebay.se/torrent/plaxis-professional8.2, “PLAXIS civil engineering geotechnical CAD.” Version 8,.

[13] PLAXIS 2 &3D 2011. “Essential for geotechnical professionals.” Tutorial Manual.

[14] Som, N. N. and Das, S. C. (2003) “Theory and Practice of Foundation Design”, Prentice Hall of India, New Delhi.

[15] Sang-Sup Lee, Jiho Moon, Keum-Sung Park, and Kyu-Woong Bae (2014)" Strength of Footing with Punching Shear Preventers." The Scientific World Journal Volume 2014 (2014), Article ID 474728, 15 pages.

[16] Smoltczyk, Ulrich 2003. “Geotechnical engineering handbook.” Ernst and Sohn A Wiley Company.

[17] Tsinker, Gregory P. 2004. “Planning construction, maintenance, and security.” Wiley and Sons, Inc.

[18] The constructor, 2017, "Types of Shallow Foundations." Civil Engineering Home for Civil Engineers.

[19] Terzaghi, K. and Peck, R.B 1967. “Soil mechanics in engineering pracice.” Wiley, New York.

[20] Waterman, Dennis 2006. “Structural elements in PLAXIS.” CG1 Chile.

[21] Woodward, John 2005. “An Introduction to geotechnical processes.” Spon Press in the USA and Canada.