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Effect of Over Consolidated Clay on the Behavior of Raft Foundation by using PLAXIS 3D Software

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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 over consolidated clay on the behavior of raft foundation. PLAXIS 3D, finite element software package was used to perform numerical modeling and analyses to evaluate the structural response and behavior of the raft foundation. The results show that the soil and bedrock conditions below the raft foundation may have a significant effect on the footing behavior such as vertical displacement (Uy), stresses, and shear strains and should be considered during the design of footing.

Keywords: Over consolidated clay, Finite element, Displacements, Stresses, Shear strains, Bedrock.

1. Introduction

A foundation is the lowest part of the structure which supports the structure by distributing its load on the soil. 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 raft foundation on over consolidated clay with using different bedrock depths. 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. Mohamed SaadEldin and Arafa El-Helloty [4] studied the effect of opening on behavior of raft foundations resting on different types of sand soil. Bienen, B., Ragni, R., Cassidy, M., and Stanier, S. [5] studied the effect of consolidation under a penetrating footing in carbonate silty clay. Yunfei Xie and Shichun Chi [6] studied a new method could be applied to large scale piled raft foundations with complex superstructure loads. So in this paper presented the knowledge and understanding of the behavior of raft foundation on over consolidated clay with using different subsurface conditions as represented in parametric study and to find the displacements , stresses and shear strains in soil.

1.1 Objective of this Research

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 raft foundations affect on the footing behavior such as vertical displacements Uy, stresses, and shear strains. 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 raft foundations as represented in figure (1) with using parametric studies for varying conditions. The conditions studied are: (1) Different water table depths (Y = 3m to 12m) below the footing at horizontal bedrock slope (θ = 0°) as shown in figure (2); (2) Different bedrock depths (D = 8m to 45m) at horizontal bedrock slope (θ = 0°) ; (3) Different young's modulus (E) (E = $4x10^7$ Kn/m^2 to $25x10^7$ Kn/m^2) for floor properties at horizontal bedrock slope (θ = 0); (4) Different Cohesion for soil (C = 4 Kn/m^2 to 18 Kn/m^2); (5) Different young's modulus (E) (E = $6x10^3$ Kn/m^2 to $20x10^3$ Kn/m^2) for soil properties at horizontal bedrock slope (θ = 0°) . The all properties are shown in Tables (1 to 3). 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 involved investigating displacements, stresses, and shear strains.

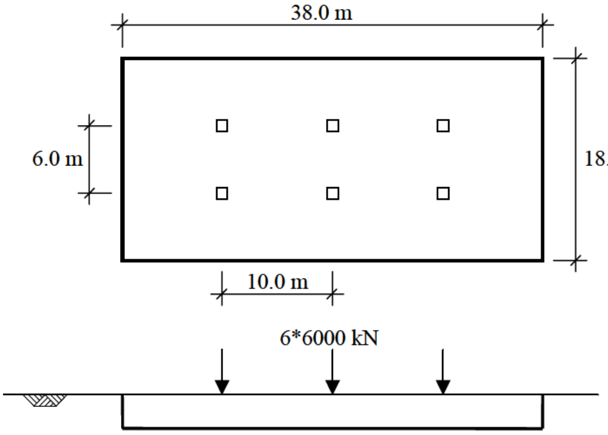

Figure 1: Top View and Simplified Geometry of the Building

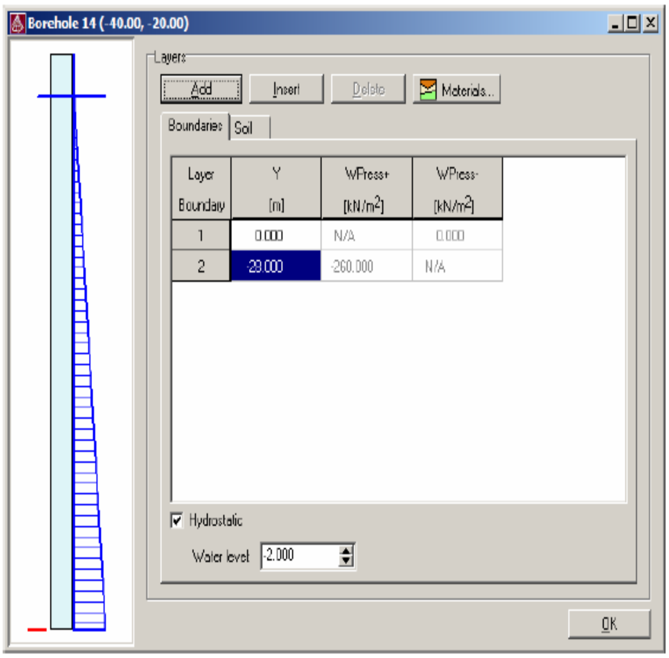

Figure 2: The water table depth below ground earth

Table 1: Material properties of the basement wall

Parameter	Name	Basement Wall	Unit
Type of material behavior	Type	Linear	-
Thickness	d	0.3	m
Weight	γ	24	KN/m³
Young's modulus	E	1.x107	KN/m²
Shear Modulus	G	4.167x106	KN/m²
Poisson's Ratio	υ	0.2	-

Table 2: Material properties of the basement floor

Parameter	Name	Basement Wall	Unit
Type of material behavior	Type	Linear	-
Thickness	d	0.5	m
Weight	γ	24	KN/m³
Young's modulus	E	1.x107	KN/m²
Shear Modulus	G	4.167x106	KN/m²
Poisson's Ratio	υ	0.2	-

Table 3: Material properties of the clay layer

Parameter	Name	Soil	Unit
Material model	Model	Mohr-Coulomb	-
Type of material behavior	Type	Drained	-
Soil unit weight above phreatic level	γ_{unsat}	17	KN/m³
Soil unit weight below phreatic level	γ_{sat}	18	KN/m³
Young's modulus	E	3000	KN/m²
Cohesion	C	10	KN/m²
Friction angle	Φ	30	°
Dilatancy angle	ψ	0	°
Poisson's Ratio	υ	0.3	-

2. Numerical Model

PLAXIS, 3-D finite element analysis software package, was used for the parametric study in this research. 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.

A total of ninety cases have been modeled and analyzed in this parametric study. Fifteen cases were carried out to investigate the effect of water table depths below the raft foundation on the footing behavior such as vertical displacements Uy (m), stresses (Kn/m^2), and shear strains (%).Fifteen cases were carried out to investigate the effect of different bedrock depths (D) at horizontal bedrock slope (θ=0°) on the footing behavior. Fifteen cases were carried out to investigate the effect of different young's modulus (E) for floor at horizontal bedrock slope (θ=0°) on the footing behavior. Fifteen cases were carried out to investigate the effect of different cohesion of soil (C) below the footing on the footing behavior. Lastly, fifteen cases were carried out to investigate the effect of different young's modulus (E) for soil at horizontal bedrock slope (θ=0°) on the footing behavior. For all the cases modeled and analyzed, the vertical displacements Uy, 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 chapter.

2.1 Effect of Water Table Depths (Y)

A parametric study was performed to investigate the effect of water table depths (Y) at (θ = 0°) below the ground level on the footing behavior by using (E = 3000 Kn/m^2 & C = 10 Kn/m^2). The depths, Y, analyzed were 3 m, 5 m, 8 m, 10 m, and 12 m. The width of each model was also adjusted based on the depth as shown in Figure 2.

2.2 Effect of Bedrock Depths (D)

A parametric study was performed to investigate the effect of different bedrock depths on the raft foundation behavior such as vertical displacements, shear strains, and stresses. The depths, D, analyzed were 8 m, 14 m, 20 m, 35 m, and 45 m. The building is composed of a basement level and 4 floors above ground level. In this research, only the basement will be modelled. The loads from the upper floor are transferred to the floor slab by columns. Each column bears a load of 6000 Kn. The width of each model was also adjusted based on the depth as shown in Figures 1&3.

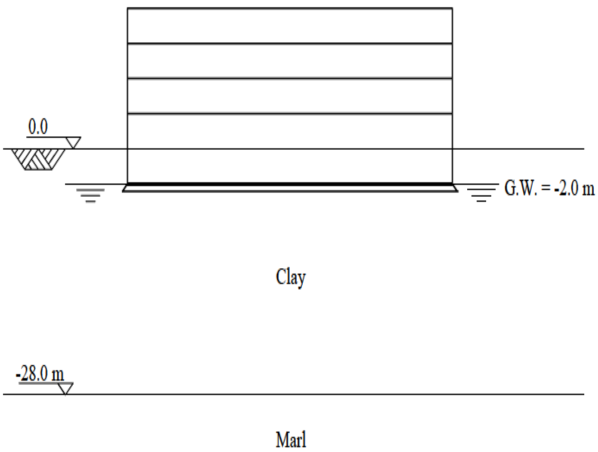

Figure 3: Side view of building on raft foundation

2.3 Effect of Young's Modulus (E) for Floor

A parametric study was performed to investigate the effect of different young's modulus for floor and (θ = 0°, D=28m) on the footing behavior such as (E = 4x107 Kn/m2 to 25x107 Kn/m2). Also, the soil properties used for the analyses are listed in Tables 3. The interface elements were introduced to simulate the soil-structure interaction behavior in order to predict the raft foundation behavior more accurately.

2.4 Effect of Soil Cohesion (C)

A parametric study was performed to investigate the effect of different cohesion of soil at depth 28m below the footing and (θ = 0°) on the footing behavior such as (C = 4 Kn/m^2 to 18 Kn/m2). Also, the soil properties used for the analyses are listed in Table 3. The interface elements were introduced to simulate the soil-structure interaction behavior in order to predict the raft foundation behavior more accurately.

2.5 Effect of Young's Modulus (E) for Soil

A parametric study was performed to investigate the effect of different young's modulus for soil depth and (θ = 0°, D=28m) on the footing behavior such as (E = 6000 Kn/m^2 to 20000 Kn/m^2). Also, the soil properties used for the analyses are listed in Table 3. The interface elements were introduced to simulate the soil-structure interaction behavior in order to predict the raft foundation behavior more accurately.

3. Result And Discussion

3.1 Effect of Water Table Depths (Y)

This case was established to investigate the effect of water table depths (Y) below the footing on the footing behavior by clay soil. Figures 4 through 9 show the vertical displacements vectors Uy, stresses, and shear strains for water table depths Y=3 m and 12m, at bedrock slope θ = 0° under the footing.
The analysis results in terms of maximum vertical displacements (Uy), maximum stresses, and maximum shear strains for all the depths (Y = 3, 5, 8, 10, and 12m) analyzed are given in Tables 4 through 6, shown in Figures 10 through 12, and discussed below.
The maximum vertical displacement Uy, shear strain, and stresses increase with increasing water table depths as shown in Figures 10 to 12.
So, the analysis results in terms of changing water table depths below the ground level have effect on the footing behavior due to the presence of more amount of dry soil below the footing .

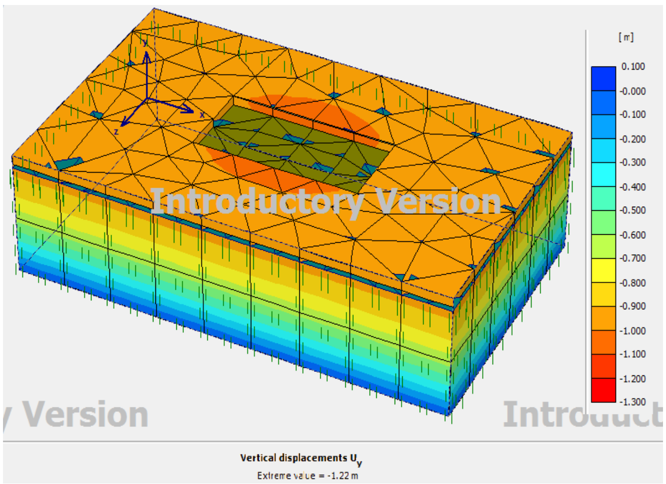

Figure 4: Vertical displacement (Uy) vectors for water table depths, Y=3 m

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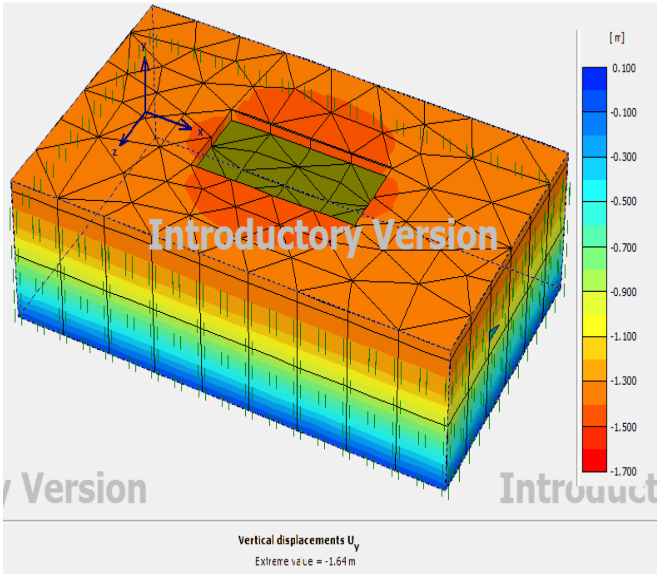

Figure 5: Vertical displacement (Uy) vectors for water table depths, Y=12 m

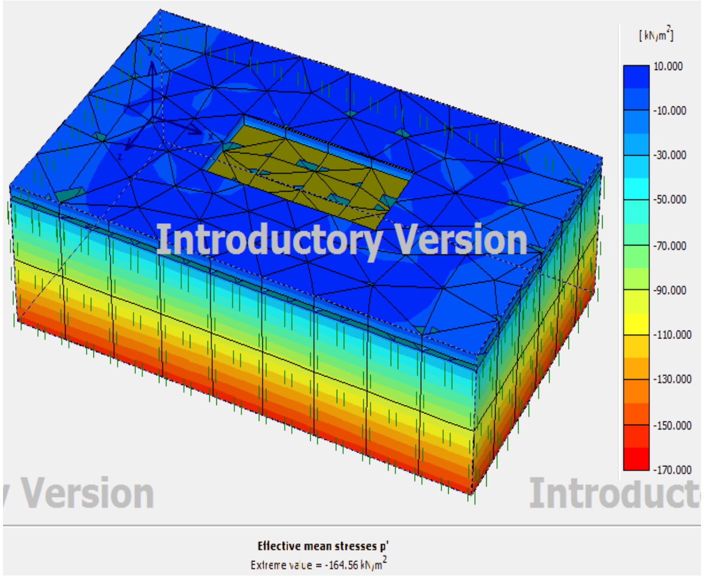

Figure 8: Stresses for water table depths, D= 3 m

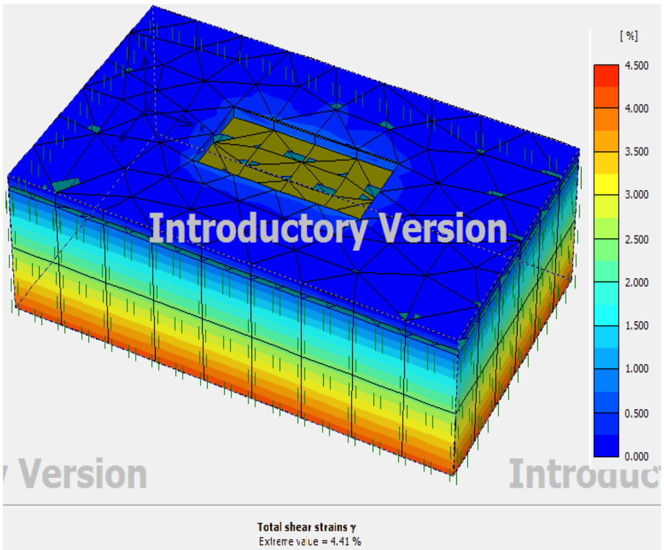

Figure 6: Shear strains (%) for water table depths, Y=3 m

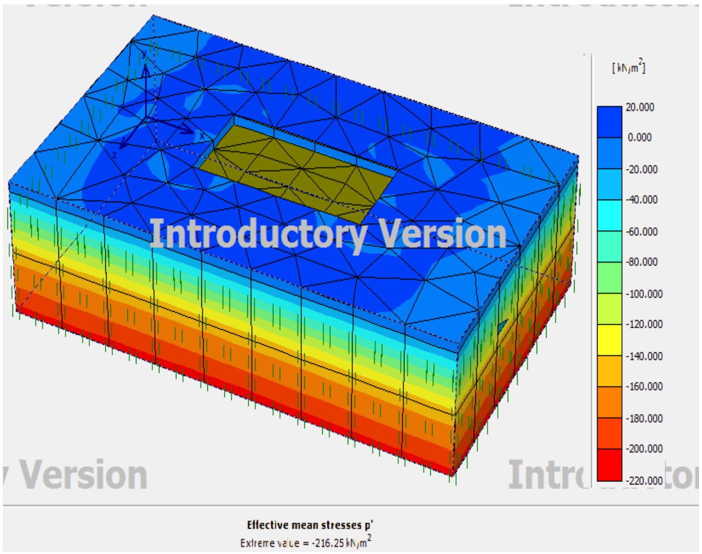

Figure 9: Stresses for water table depths, D= 12 m

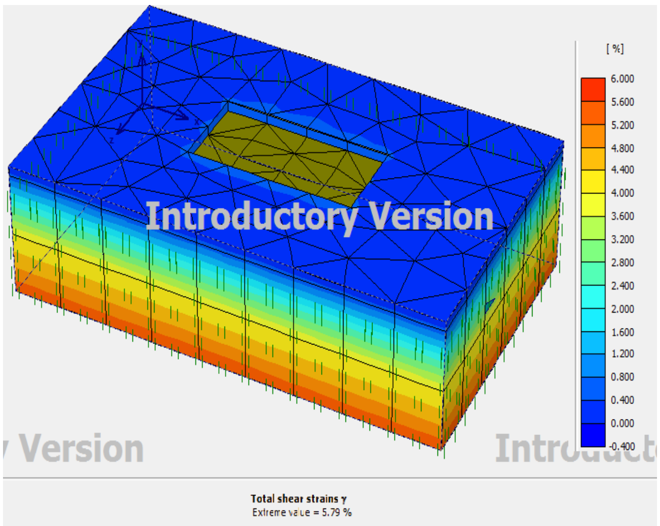

Figure 7: Shear strains (%) for water table depths, Y=12m

Table 4: Maximum vertical displacements for varying water table Depths

Y (m)	Maximum Vertical Displacement Uy (m)
	Ux at (θ = 0°)
3	-1.22
5	-1.47
8	-1.45
10	-1.54
12	-1.64

Table 5: Maximum shear strains for varying water table depths

Y (m)	Maximum Shear Strains (%)
	at (θ = 0°)
3	4.41
5	4.86
8	5.13
10	5.46
12	5.79

Table 6: Maximum stresses for varying water table depths

Y (m)	Maximum Stresses (Kn/m^2) at ($\theta = 0°$)
3	-164.56
5	-180.74
8	-191.49
10	-203.87
12	-216.25

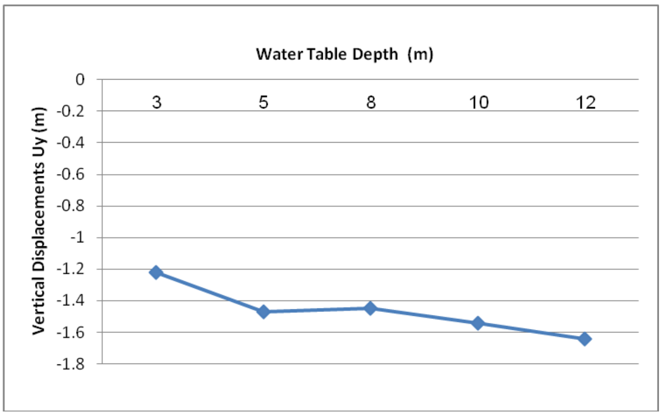

Figure 10: Maximum vertical displacement Uy (m) at varying water table depth

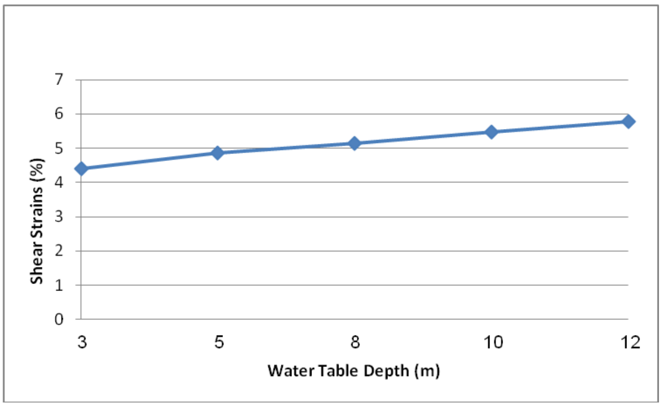

Figure 11: Maximum Shear Strains (%) at varying water table depth

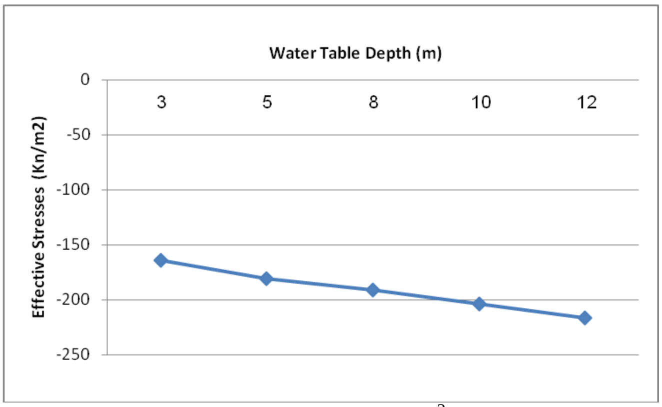

Figure 12: Maximum Stresses (Kn/m^2) at varying water table depth

3.2 Effect of Bedrock Depths (D)

Additional modeling and analysis were performed using relatively different bedrock depths under the raft foundation. Figures 13 through 21 show the vertical displacements vectors (Uy), stresses vectors, and shear strains for bedrock depths of D=8 m to 45m under the footing.

The analysis results in terms of maximum vertical displacements, maximum shear strains, and maximum stresses for varying bedrock depths analyzed are given in Tables 7 through 9, and discussed below.

The maximum vertical displacements, stresses, and shear strains below the footing increase with increasing the bedrock depths. This is due to the presence of more amount of soil below the footing which lead to increase soil stress below the footing and its effecting on the footing behavior.

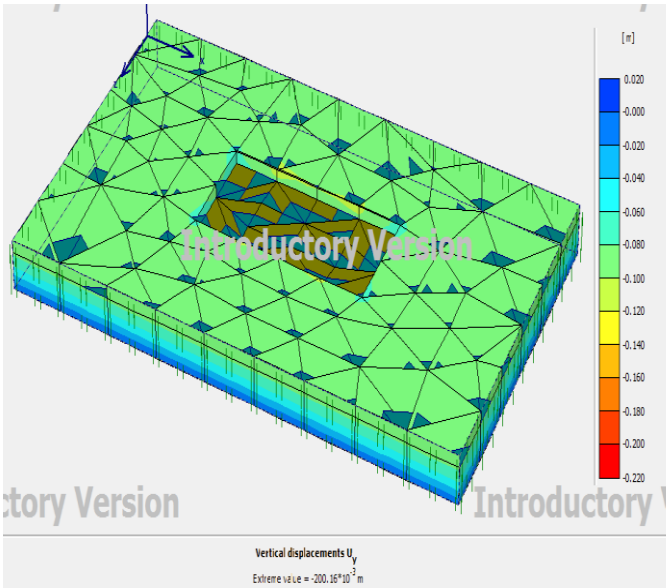

Figure 13: Vertical Displacement (Uy) for Varying Bedrock Depth, D= 8 m

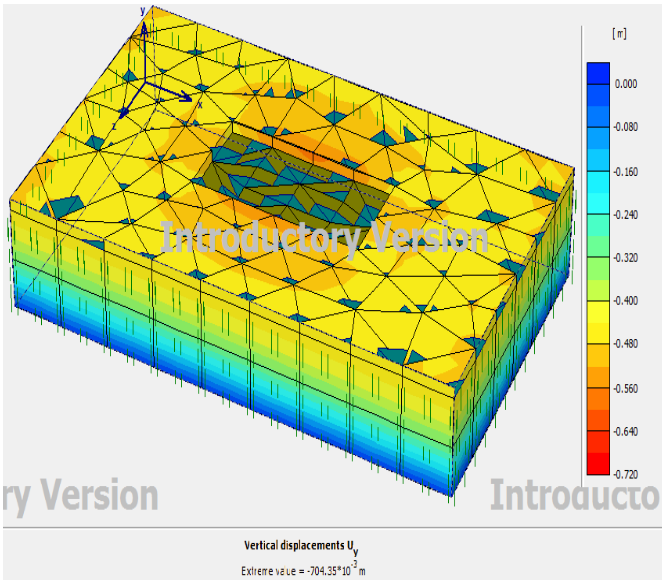

Figure 14: Vertical Displacement (Uy) for Varying Bedrock Depth, D= 20 m

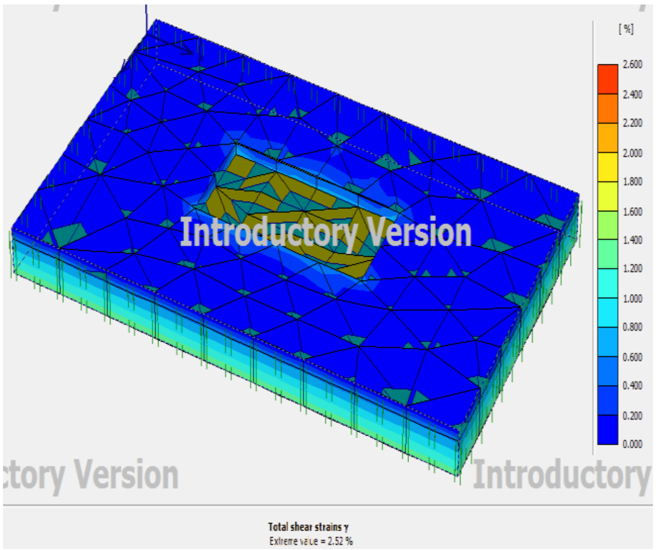

Figure 15: Shear Strains (%) for Varying Bedrock Depth, D=8 m

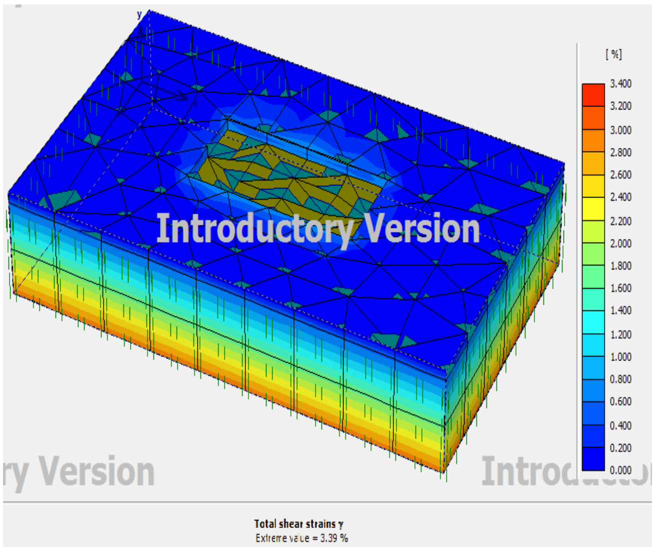

Figure 16: Shear Strains (%) for Varying Bedrock Depth, D=20 m

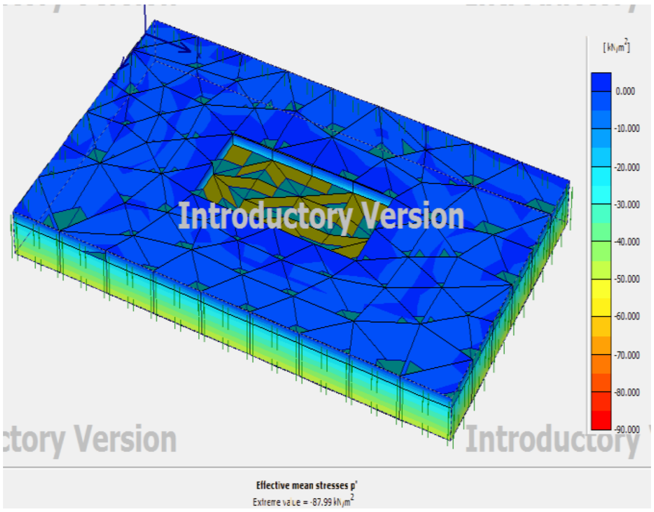

Figure 17: Stresses for Varying Bedrock Depth, D= 8 m

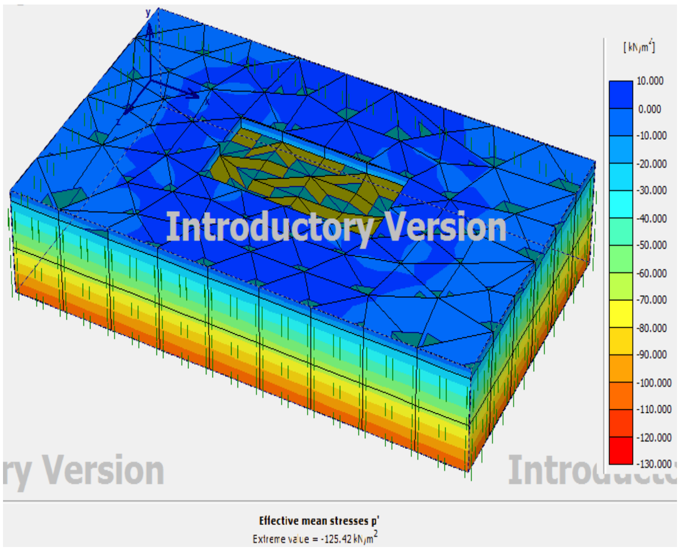

Figure 18: Stresses for Varying Bedrock Depth, D= 20 m

Table 7: Maximum vertical displacements for varying bedrock depths

Depth (m)	Maximum Vertical Displacement Uy (m) at (θ = 0°)
8	-2.00E-01
14	-4.32E-01
20	-7.04E-01
35	-1.64
45	-2.49

Table 8: Maximum shear strains for varying displacements for varying bedrock depths

Depth (m)	Maximum Shear Strains (%) at (θ = 0°)
8	2.52
14	2.96
20	3.39
35	5.09
45	6.36

Table 9: Maximum stresses for varying displacements for varying bedrock depths

Depth (m)	Maximum Stresses (Kn/m2) at (θ = 0°)
8	-87.99
14	-101.66
20	-125.42
35	-190.72
45	-238.31

In the tables above and the figures 19 through 21, we can see the behavior of the raft foundation by using different bedrock depths below the footing.

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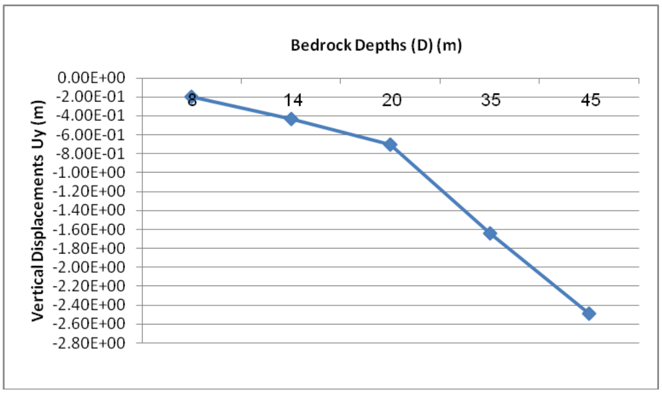

Figure 19: Maximum Vertical Displacement Uy (m) at Varying Bedrock Depth

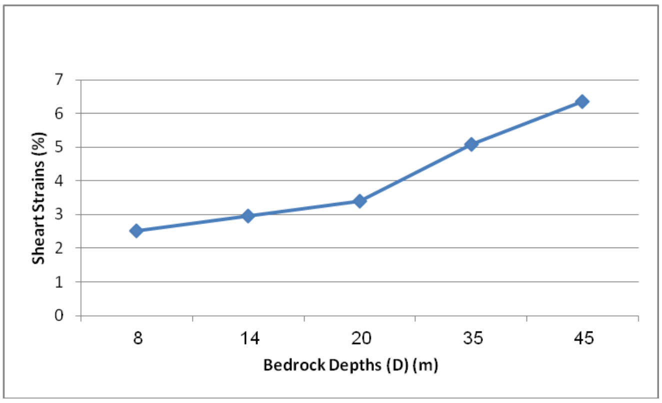

Figure 20: Maximum Shear Strains (%) at Varying Bedrock Depth

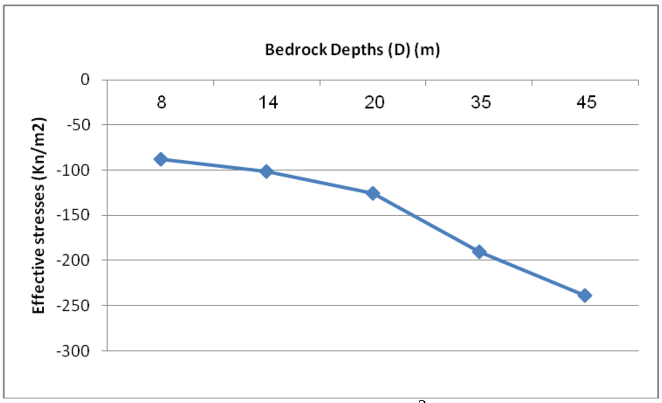

Figure 21: Maximum Stresses (Kn/m^2) at Varying Bedrock Depth

3.3 Effect of Young's Modulus (E) for Floor

Also, the modeling and analysis were performed using varying young's modulus (E) for floor to investigate the effect of soil below the footing on the footing behavior with using different floor properties as shown in Tables 10 to 12. Figures 22 through 24 show the vertical displacements vectors (Uy), stresses vectors, and shear strains for bedrock depths of D=28 m under the footing, and varying young's modulus (E= 4x10^7 Kn/m^2 to 25x10^7 Kn/m^2) at bedrock slope (θ =0°).

The maximum vertical displacements, stresses, and shear strains below the footing have a little effect with increasing young's modulus of floor. This is due to the stresses and shear strains have the similar behavior below the footing with using different floor properties.

Table 10: Maximum vertical displacements at varying (E) for floor

E (kn/m^2)	Maximum Vertical Displacement Uy (m)
	Ux at (θ = 0°)
4x10^7	-8.97E-01
9x10^7	-1.07E+00
15x10^7	-1.14E+00
20x10^7	-1.13
25x10^7	-1.12

Table 11: Maximum shear strains at varying (E) for floor

E (kn/m^2)	Maximum Shear Strains (%)
	at (θ = 0°)
4x10^7	4
9x10^7	4.21
15x10^7	4.24
20x10^7	4.24
25x10^7	4.23

Table 12: Maximum stresses at varying (E) for floor

E (kn/m^2)	Maximum Stresses (Kn/m^2)
	at (θ = 0°)
4x10^7	-149.82
9x10^7	-157.47
15x10^7	-158.22
20x10^7	-158.11
25x10^7	-158.03

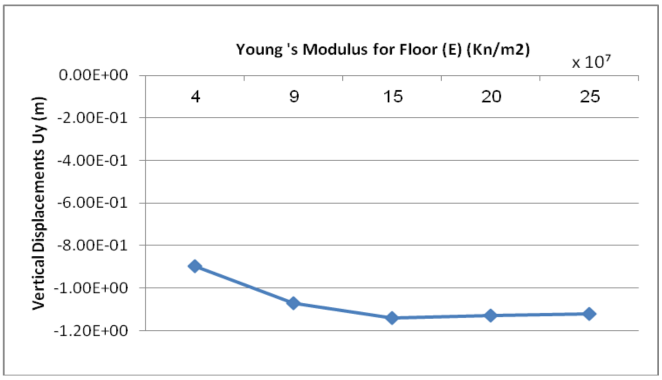

Figure 22: Maximum Vertical Displacement Uy (m) at Varying (E) for Floor

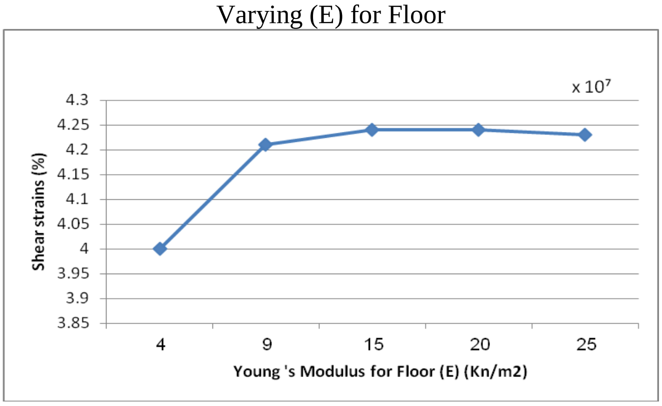

Figure 23: Maximum Shear Strains (%) at Varying (E) for Floor

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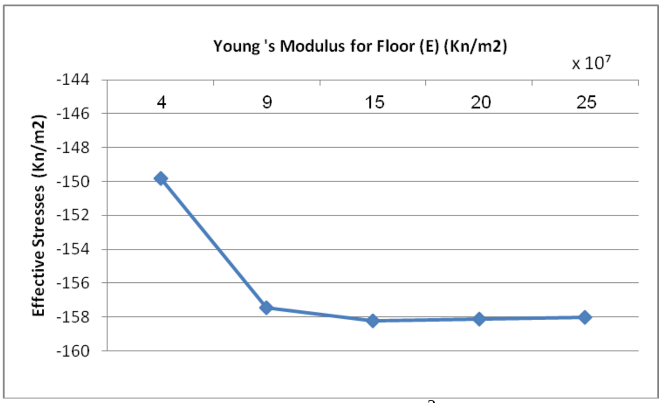

Figure 24: Maximum Stresses (Kn/m^2) at Varying (E) for Floor

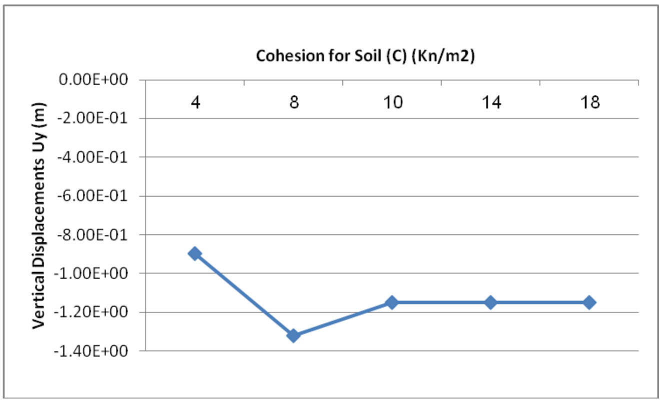

Figure 25: Maximum Vertical Displacement Uy (m) at Varying (C)

3.4 Effect of Soil Cohesion (C)

This case was established to investigate the effect of cohesion soil (C) below the footing on the footing behavior by using different values of (C). Figures 25 through 27 show the vertical displacements, stresses, and shear strains for using different (C) at D=28 m under the footing.

The maximum vertical displacements, stresses, and shear strains below the footing have a little effect on the footing behavior with increasing (C) at bedrock depths (D= 28m) as represented in Tables 13 through 15 and figures 25 through 27. The main reason is that the cohesion is the force that holds together molecules or like particles within a soil.

Table 13: Maximum vertical displacements at varying (C)

C (kn/m2)	Maximum Vertical Displacement Uy (m)
	Ux at (θ = 0°)
4	-8.97E-01
8	-1.32E+00
10	-1.15E+00
14	-1.15E+00
18	-1.15E+00

Table 14: Maximum shear strains at varying (C)

C (kn/m2)	Maximum Shear Strains (%)
	at (θ = 0°)
4	4
8	4.47
10	4.25
14	4.25
18	4.25

Table 15: Maximum stresses at varying (C)

C (kn/m2)	Maximum Stresses (Kn/m2)
	at (θ = 0°)
4	-149.82
8	-166.16
10	-158.37
14	-158.37
18	-158.37

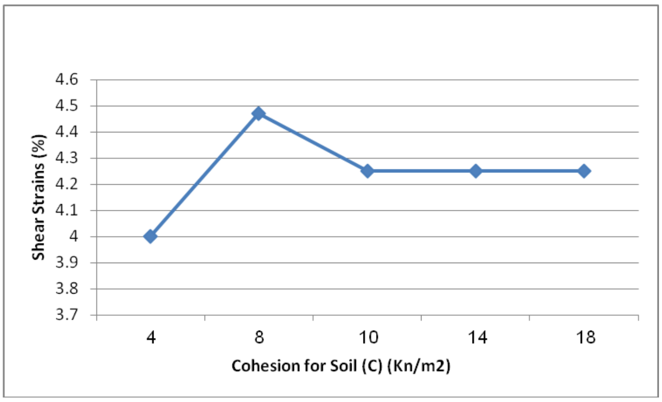

Figure 26: Maximum Shear Strains (%) at Varying (C)

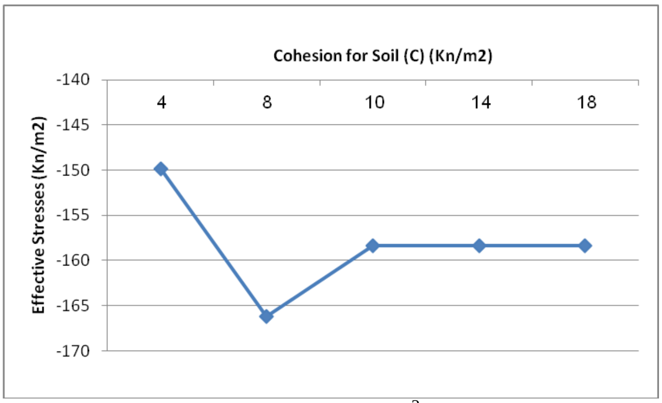

Figure 27: Maximum Stresses (Kn/m^2) at Varying (C)

3.5 Effect of Young's Modulus (E) for Soil

This modeling and analyses were performed to investigate the effect of varying (E) for soil on the footing behavior under bedrock depth 28m as shown in Table 16 through 18. Figures 28 through 30 show that the maximum vertical displacements, shear strains, and stresses below the footing decrease with increasing young's modulus of soil. This is due to the relationship between the stresses and strains within the soil when the E is increased.

Table 16: Maximum vertical displacements at varying (E) for soil

E (kn/m^2)	Maximum Vertical Displacement Uy (m)
	Ux at (θ = 0°)
6000	-5.85E-01
8000	-4.41E-01
12000	-2.96E-01
16000	-2.22E-01
20000	-1.78E-01

Table 17: Maximum shear strains at varying (E) for soil

E (kn/m^2)	Maximum Shear Strains (%)
	at (θ = 0°)
6000	2.13
8000	1.6
12000	1.07
16000	0.80016
20000	0.64

Table 18: Maximum stresses at varying (E) for soil

E (kn/m^2)	Maximum Stresses (Kn/m^2)
	at (θ = 0°)
6000	-158.59
8000	-158.67
12000	-158.76
16000	-158.82
20000	-158.85

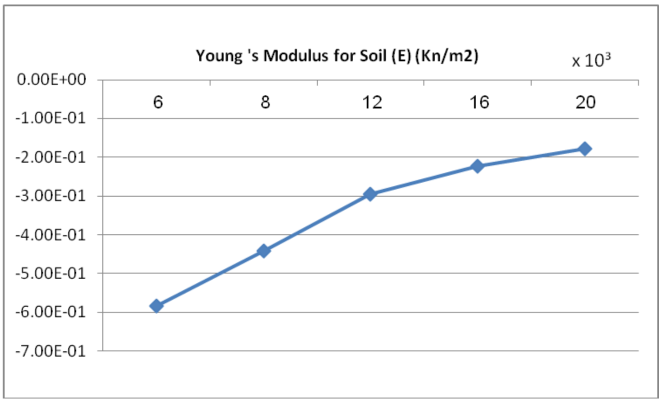

Figure 28: Maximum Vertical Displacement Uy (m) at Varying (E) for soil

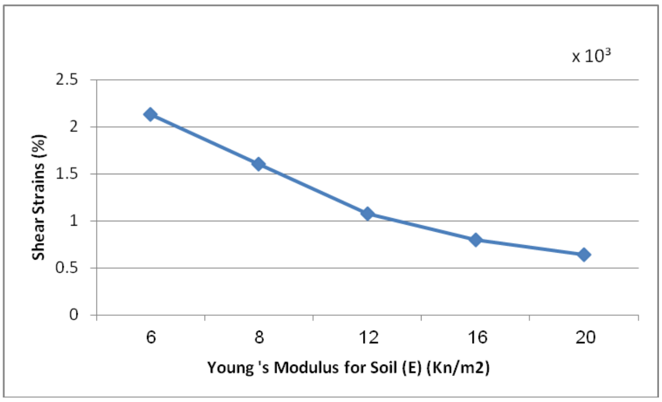

Figure 29: Maximum Shear Strains (%) at Varying (E) for soil

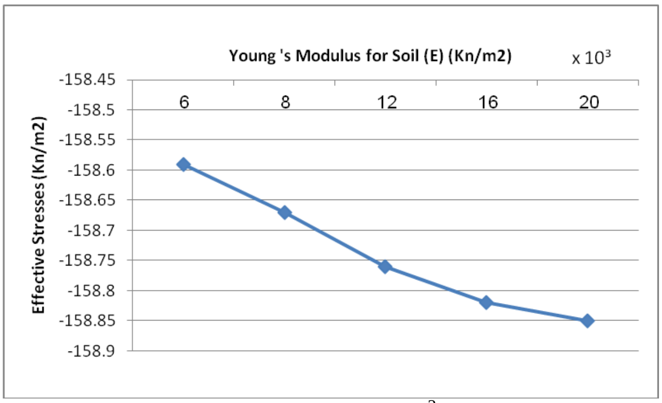

Figure 30: Maximum Stresses (Kn/m^2) at Varying (E) for soil

4. Conclusion & RECOMMENDATION

The effect of water table depths, soil strength, E for floor and soil, and bedrock depths below the footing on the behavior of a typical footing have been studied and presented in this research. The footing behavior was investigated through the vertical 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 raft fondation and should be considered during the design of the raft foundation. 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 vertical displacements, stresses, and shear strains below the footing with different water table depths, and different bedrock depths have significant effect on the footing behavior. This is due to the presence of more amount of soil below the footing which lead to increase soil stress below the footing and its effecting on the footing behavior.

2. When increasing Young Modulus of soil, the maximum vertical displacements, shear strains, and stresses below the footing decrease. The main reason is the relationship between the stresses and strains within the soil when the E is increased.

3. Increasing the Young Modulus of soil and soil cohesion lead to a little effect on the raft foundation. This is due to the stresses and shear strains have the similar behavior below the footing with using different floor properties. Also, the cohesion is the force that holds together molecules or like particles within a soil.

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 research.
Also, it should study the bedrock slopes below the footing and its effecting on the footing behavior

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