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Anchor Angle and its Role on Stability of Anchored Retaining Walls

Mohamad Gabar[1], Asma Muhmed[2], Rabh Salem[3], Suad Abulgsem Tleish[4], Idress Saad[5], Ibtisam F. Abou-ajaila[6] Mohamed Ali[7], Osama Saleh[7], Muwayyid Abdullah[7], & Hafsah Mohammed[7]

[1]E-mail: mohamadg980@tu.edu.ly

[1,2,3,7] Department of Civil Engineering, Faculty of Engineering, Tobruk University, Libya
[4] Department of Civil Engineering, Faculty of Engineering, Sabratha University, Libya
[5] Department of Roads and Landings, Faculty of Engineering, Bright Star University, Libya
[6] Department of Civil Engineering, Faculty of Engineering, Derna University, Libya

Abstract

The purpose of this research is applying PlAXIS 2D in modeling of an anchored retaining wall with different combinations of behavior of the anchored wall and prepare data base that can serve the design requirements of anchored retaining walls in Libya. The structural design of the anchored wall by PLAXIS finite element software, considers soils on the back and front of the wall as well as the soil under the wall. So, this research takes into account the effect of soil under wall on wall behavior. The effect on wall is studied in terms of wall displacement, wall bending moments, wall shear forces, and soil stresses. The effect of anchor angles by using varying soil properties, wall & anchor properties, and loads behind the wall on the wall behavior has been investigated as well. The results proved the applicability of Plaxis model in responding to different combinations of wall and soil parameters, and showed different structural behavior by the anchored wall with every change in wall and soil parameters. So, findings corresponding to different combinations of parameters were prepared for the sake of any related future research.

Keywords: *Anchored Wall - Anchor Angles - Wall Properties - Soil Strength*

1. Introduction

Deep excavations are usually performed near to high-rise buildings especially in urban areas. Libya has many old buildings that need safety and stability stages during excavation operations, especially in urban areas. So, engineering challenges are to safely perform the excavation stages and the security of surrounded buildings. This research is studied the dry construction of an excavation. The excavation is supported by concrete diaphragm walls using a tie back by pre-stressed ground anchors. Tie backs are used to provide the lateral resisting force for many of the excavation support systems and anchored retaining walls as shown in Fig. 1. An anchored wall is a structure designed and constructed to resist the lateral pressure of soil when there is a desired change in ground elevation that exceeds the angle of repose of the soil.

Chehade et al., 2008 [1] showed an important variation of the maximal bending moment in the structure after excavation and in particular for the rigid structures.

Nikiforova 2005 [2] Results obtained during scientific accompaniment by the Scientific-Research Institute of Foundations and Underground Structures have made it possible to lower geotechnical risk during the construction of projects with deep trenches in the dense urban setting of Moscow.

Dinakar 2014 [3] revealed that sheet pile wall method is viable to limit ground movements due to the excavation. Besides, the parametric study shows that considerable reduction in wall deformation and bending moment can be achieved and safe excavation to greater depths is possible.

Abdelrahman E. Aboelela, et al., 2022 [4] the Modulus of subgrade reaction value ks is affected by de-stressing due to excavation.

National Cooperative Highway Research 2008 [5] anchors are installed when the wall height exceeds 6m or the wall supports heavy loads from a structure.

Mohamad Gabar & Ömer Bilgin 2016 [6] studied the effect of soil below the wall, sloping bedrock, and different wall height on the wall behavior.

Dawkins, William P. 2001 [7] investigated the effects of wall friction, surcharge loads, and moment reduction curves for anchored sheet-pile walls.

EL-Sayed et al., 2018 [8] studied the behavior of inclined anchor by varying the inclination and elevation of tie. The anchors are used to protect wall from overturning and to reduce wall displacements. The lateral earth pressures and/or water pressures that might have caused additional pressures on the wall could have been the cause for the cracks.

Therefore, this research presented the knowledge and understanding of the behavior of different wall properties, different anchor properties, loads behind wall, and anchor angle behaviors on the wall behavior.

1.1 Objective of this Paper

Current structural design of a retaining wall considers soils in the back and front of the anchored wall. Some earlier studies showed that the effect of increasing inclination of tie on the wall behavior is the same for all wall heights and have similar trends (EL-Sayed et al, 2018). Nevertheless, in many previous studies, less consideration has been given to the effect of soils below the anchored wall. Therefore, the aim of this research is investigating the effects of the anchor angle on the wall behavior by using the different wall and anchor properties and loads behind the wall in terms of displacements, bending moments, stresses, and shear forces.

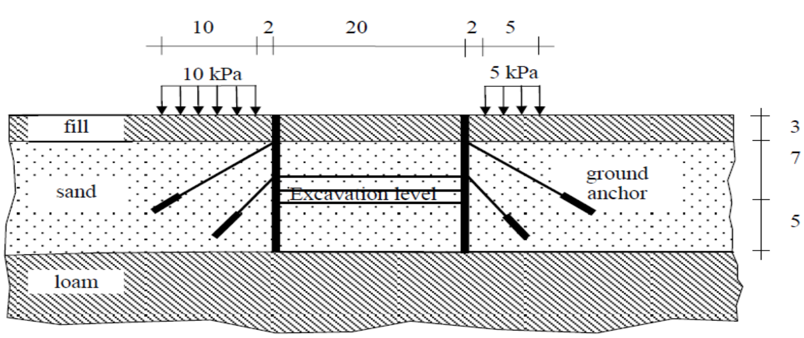
1.2 Scope and Parametric Study

The primary focus of this research is to investigate the structural response of anchored wall using parametric studies for varying conditions. The condition is:

Different anchor angles ($\alpha = 45°, 60°, 75°, \& 90°$) by using different properties:

a) Different Young Modulus (E) = 20,000 , 25,000 , 30,000 , 35,000 , 40,000 (kn/m^2),
b) Different friction angle (ϕ) = 30° , 33° , 35° , 38° , 40°,
c) Flexural rigidity (EI) of the wall = (10, 12, 15, 20, 30)*104 ($kn.m^2/m$),
d) Axial stiffness (EA) of the anchor = (02, 06, 10, 14, 20)*105 (kn),
e) Distribution load (q) behind wall = (10, 20, 30, 40, 50 (kn).

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 2-D finite element software for geotechnical engineering applications. The structural analysis by PLAXIS involved investigating wall displacements, bending moments, wall shear forces, and stresses.



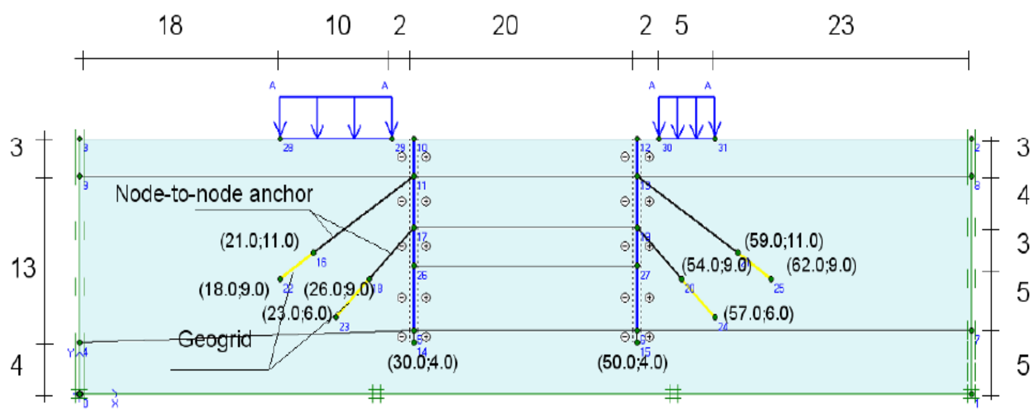


Figure 1 Geometry Model of the Situation of A dry Excavation at Depth 5m (By Author

2. NUMERICAL MODEL

PLAXIS, 2-D finite element analysis software package, was used for the parametric study in this study. 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 2D, 2011). It should be noted that he simulation of geotechnical problems by means of the finite element method implicitly involves some inevitable numerical and modeling errors (PLAXIS 2D, 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 wall types such as sheet pile walls and diaphragm walls, various types of loads behind the wall, and the interface elements between the anchored retaining wall and the soil.

The parametric study is focused primarily on studying the effect of different anchor angles on the wall behavior. The study was performed using the PLAXIS 2D finite element program employing 15-noded triangular elements. For all the cases modeled and analyzed, the wall total displacement, wall bending moments, stresses, and wall shear forces were investigated to understand the effect of various factors on the wall behavior as described above.

Effect of Anchor Angles (α)

A parametric study was performed to investigate the effect of anchor angle (α) behind the wall on the wall behavior. The anchor angles, α, analyzed were (45°, 60°, 75°, & 90°) with using different of (E, ϕ, EI, EA, & q) as mentioned before, such as total displacement, wall bending moment, wall shear forces, and soil stresses.. The width of each model was also adjusted based on the anchor angles as shown in Figs. 2 (a & b).

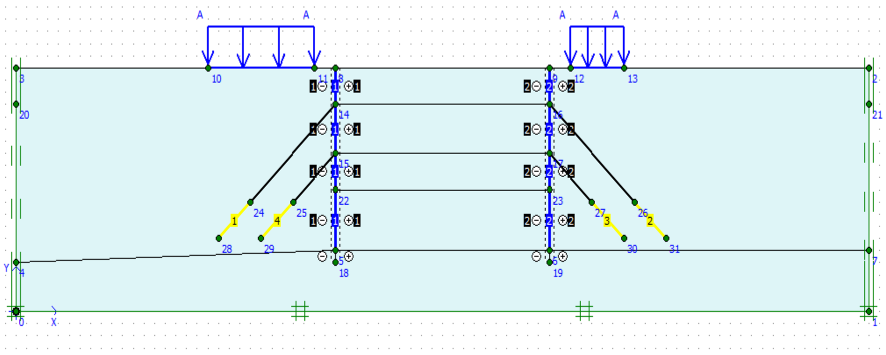


Figure 2a. Geometry Model of the Situation of anchor angle (α = 45°) (By Author)

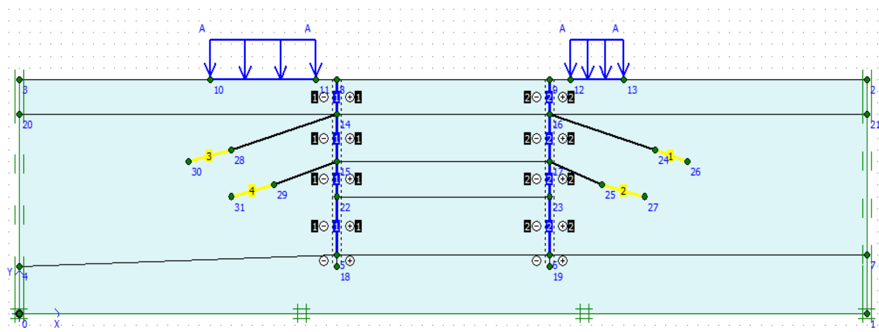


Figure 2b. Geometry Model of the Situation of anchor angle (α = 75°) (By Author)

The properties of the concrete diaphragm wall are entered in a material set of the plate type. The concrete has a Young's modulus of 35 GN/m^2 and the wall is 0.35m thick and soil properties are presented in Fig. 3. The properties of the wall are listed in Table 1.

For the properties of the ground anchors, two material data sets are needed: One of the Anchor type and one of the Geogrid type. The Anchor data set contains the properties of the anchor rod and the Geogrid data set contains the properties of the grout body. The data are listed in Tables 2 & 3.

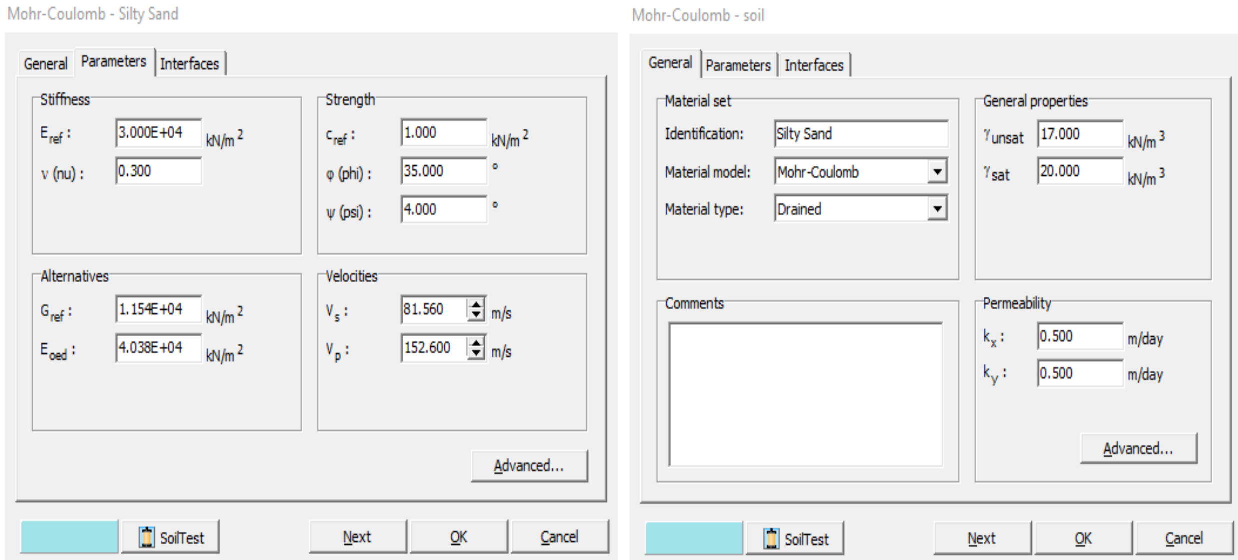


Figure 3 Material Properties for Silty Sand (By Author)

Table 1: Material Properties of the Anchored Wall (Plate) (By Author)

Parameter	Name	Value	Unit
Type of behavior	**Material type**	**Elastic *10^6**	**-**
Axial stiffness	EA	12	kN/m
Flexural rigidity	EI	0.12	kN.m²/m
Equivalent thickness	d	0.346	m
Weight	W	8.3	kN/m/m
Poisson's ratio	ν	0.15	-

Table 2: Material Properties of the Anchor rod (node to node anchor) (By Author)

Parameter	Name	Value	Unit
Type of behavior	**Material type**	**Elastic**	**-**
Axial stiffness	EA	2.10^5	kN
Spacing out of plane	L_s	2.50	m
Maximum force	$F_{max,comp.}$ $F_{max,tens}$	1.10^{15}	kN

Table 3: Material Properties of the grout body (geogrid) (By Author)

Parameter	Name	Value	Unit
Type of behavior	**Material type**	**Elastic**	**-**
Axial stiffness	EA	1.10^5	kN/m

3. Results and Discussion

Effect of Anchor Angles (α)

This research used PLAXIS program for finite element modeling and analysis of anchored wall (A tie back wall) with different cases. This case was established to investigate the effect of anchor angle (α) behind the wall on the wall behavior by using different of (E, ϕ, EI, EA, & q) such as total wall displacement, wall bending moment, wall shear forces, and soil stresses. Figs 4 to 6 show the total displacements, soil stresses, wall bending moments, and wall shear forces for anchor angles of α = 45° and 75° behind the wall by (PLAXIS figures) and (α = 45° to 90°) by Charts.
The analysis results in terms of total wall displacement, wall bending moment, wall shear forces, and soil stresses by using different of anchor angles (α = 45°, 60°, 75°, & 90°) analyzed are given in Tables 4 through 23, shown in Figs 7 through 26, and discussed below.

Wall Displacements: The maximum total wall displacements decrease with increasing anchor angles with using different of (Young's Modulus, Friction angles, Flexural rigidity of wall, & Distribution loads behind the Wall) as presented in Figs (7, 11, 15, and 19). But the wall displacement has fluctuated slightly at using varying axial stiffness of anchor. In Fig. (23) has little effect on the wall behavior by using different loads behind of the wall.

Soil Stresses: There is a noticeable increase in soil stresses behind the wall with using different of (E) as shown in Fig. (8). But in Figs (12 & 16) the soil stresses decrease with increasing friction angles and flexural rigidity of wall. For the loads behind the wall with using varying of anchor properties (EA) have a trend of slight effect on the wall behavior as shown in Figs (20 &.24).

Wall Shear force & Wall Bending Moment: The shear force and bending moment of the wall decrease with increasing Young's Modulus and friction angle of the soil as presented in Figs (9, 10, 13, & 14). While the shear force and bending moment of the wall increases with increasing the flexural rigidity of the wall and axial stiffness of anchor as shown in Figs (17, 18, 21, & 22). For the loads behind the wall have a trend of slight effect on the wall behavior as shown in Figs (25 & 26).

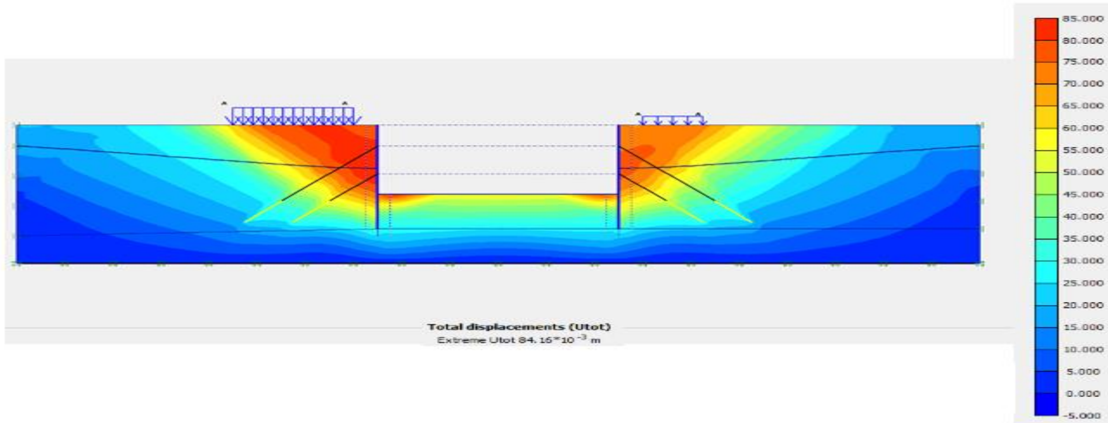


Figure 1 Total Wall Displacement for Anchor Angle, $\alpha = 45°$ (E=20000 Kn/m^2 & ϕ=35°) (By Author)

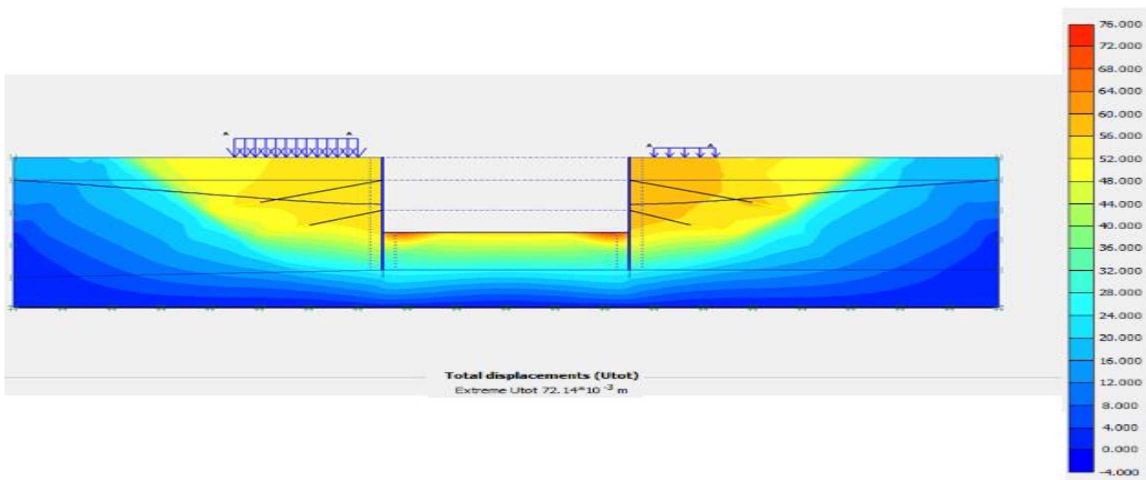


Figure 2 Total Wall Displacement for Anchor Angle, $\alpha = 75°$ (E=20000 Kn/m^2 & ϕ=35°) (By Author)

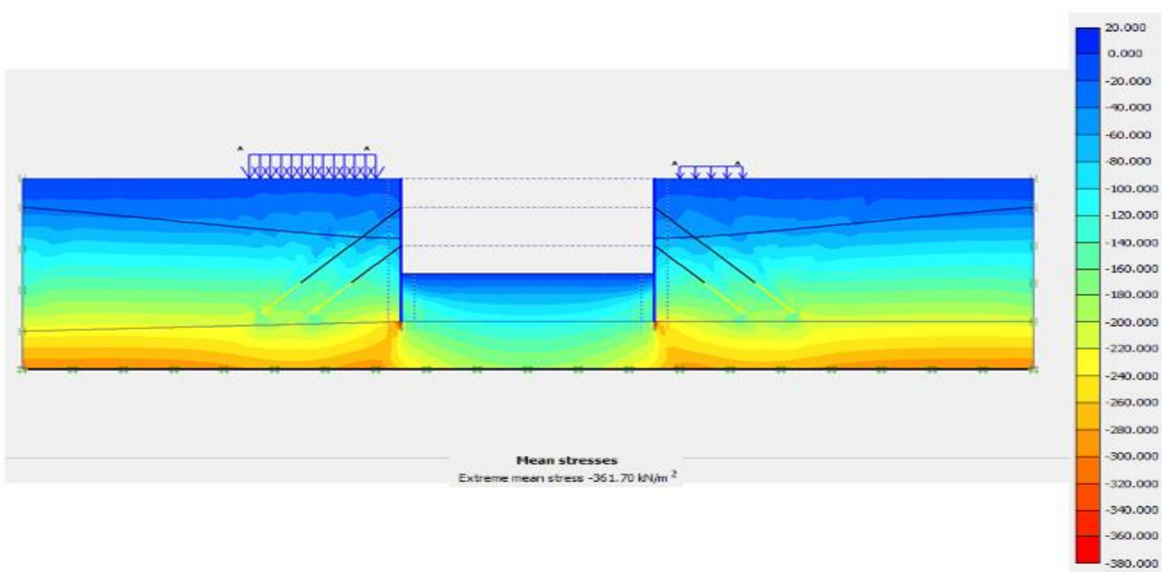


Figure 3 Mean Stresses for Anchor Angle, $\alpha = 45°$ (E=20000 Kn/m^2 & ϕ=35°) (By Author)

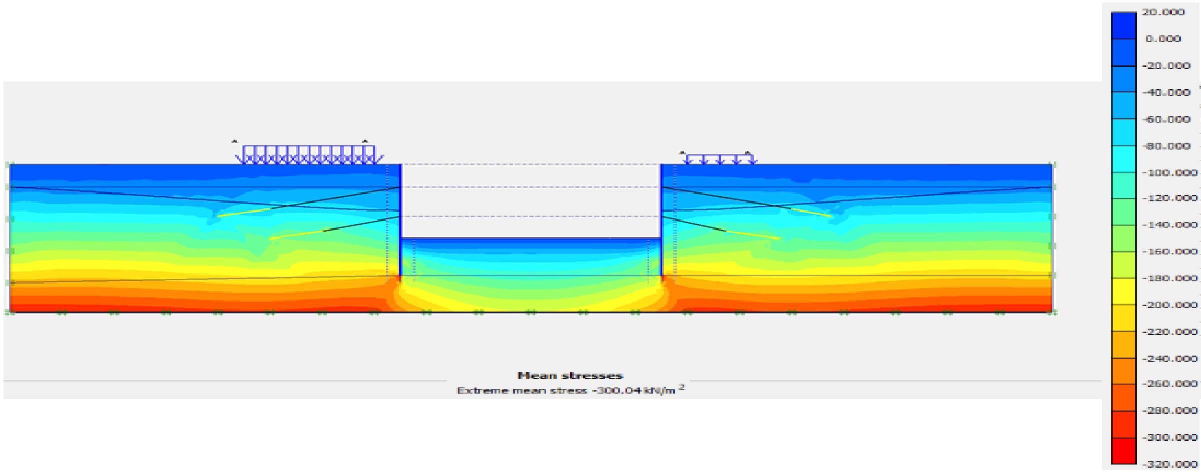
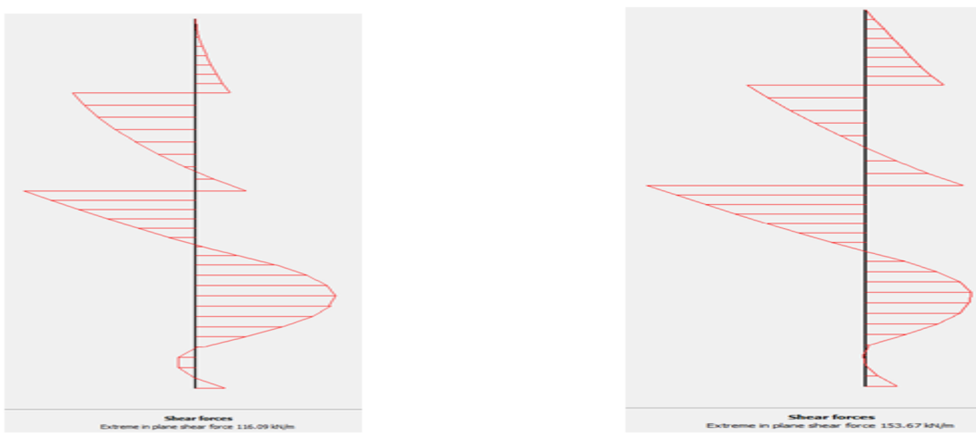
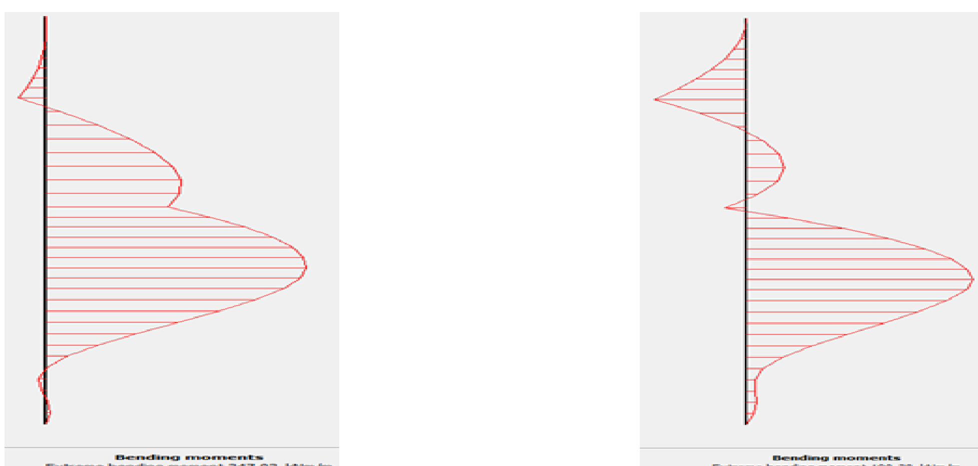


Figure 4 Mean Stresses for Anchor Angle, α = 75° (E=20000 Kn/m^2 & ϕ=35°) (By Author)



(α = 45°) (α = 75°)

Figure 5 Wall Shear Forces for Anchor Angles, α = (45°&75°) (E=20000 Kn/m^2 & ϕ=35°) (By Author)



(α = 45°) (α = 75°)

Figure 6 Wall Bending Moments for Anchor Angles, α = (45°&75°) (E=20000 Kn/m^2 & ϕ=35°) (By Author)

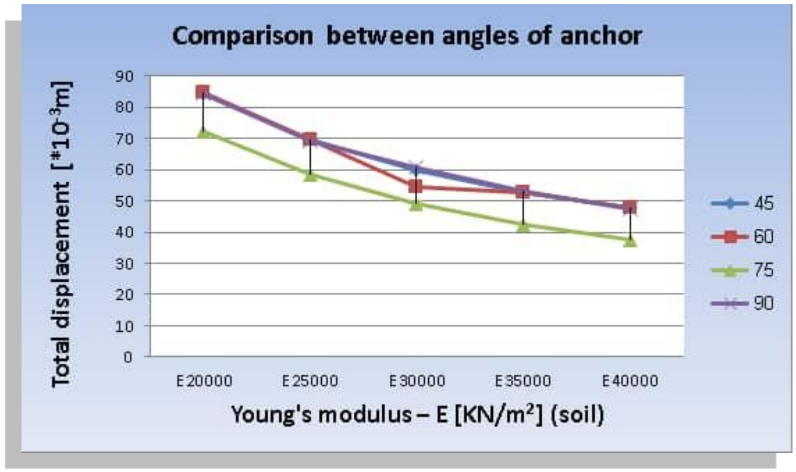


Figure 7 Total Wall Displacement Ut (m) at Varying Anchor Slopes (α) and (E) (By Author)

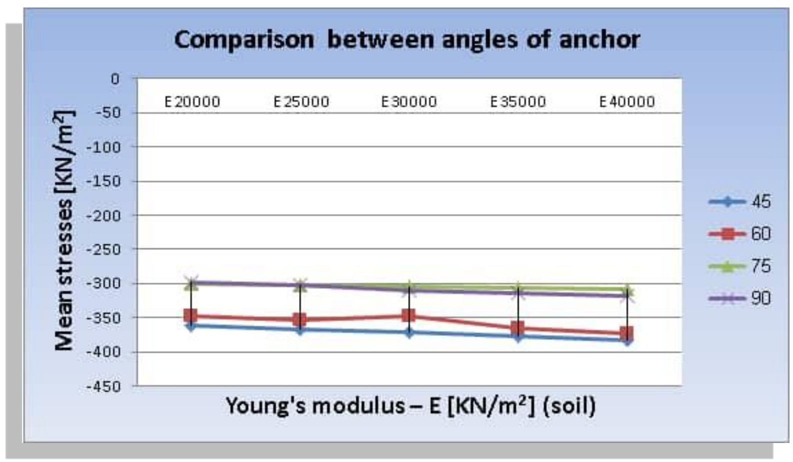


Figure 8 Soil Stresses (Kn/m^2) at Varying Anchor Slopes (α) and (E) (By Author)

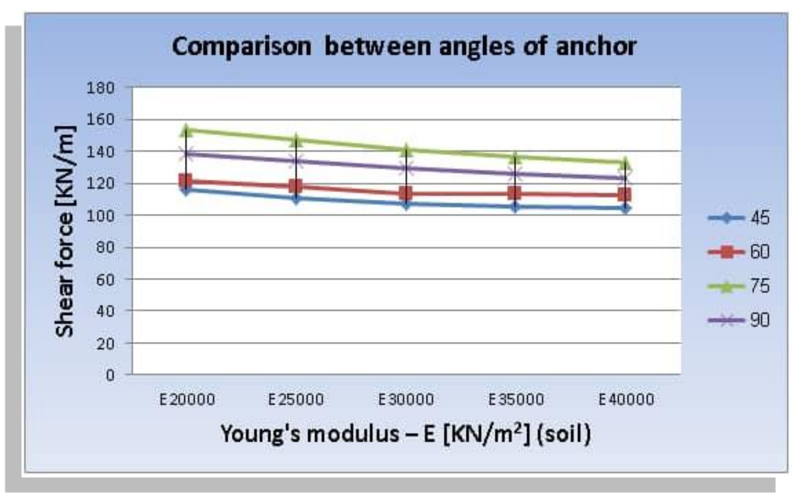


Figure 9 Wall Shear Force (Kn/m) at Varying Anchor Slopes (α) and (E) (By Author)

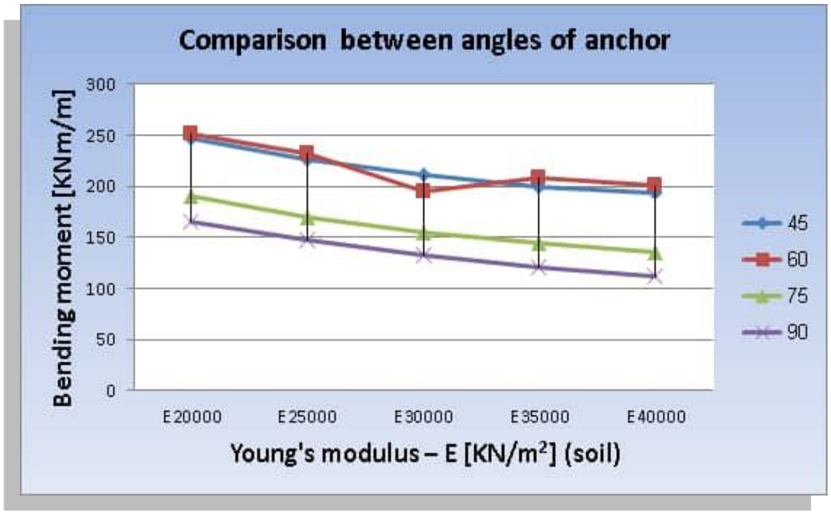


Figure 10 Wall Bending Moment (Kn.m/m) at Varying Anchor Slopes (α) and (E) (By Author)

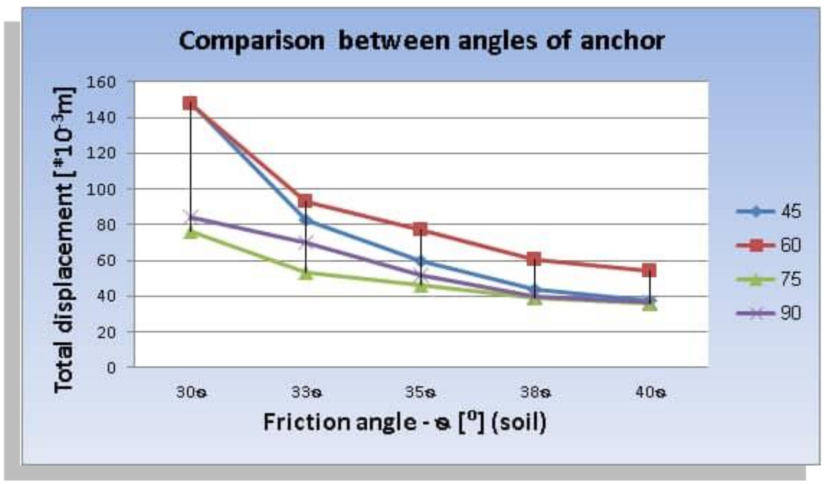


Figure 11 Total Wall Displacement Ut (m) at Varying Anchor Slopes (α) and (ϕ) (By Author)

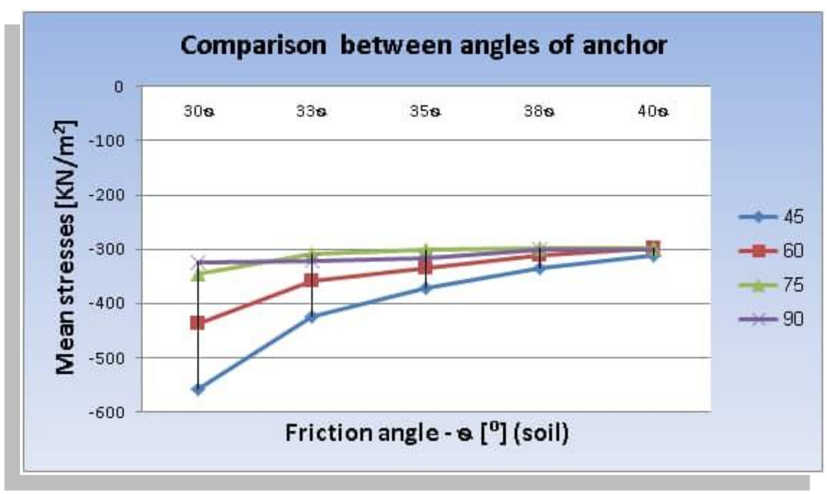


Figure 12 Soil Stresses (Kn/m^2) at Varying Anchor Slopes (α) and (ϕ) (By Author)

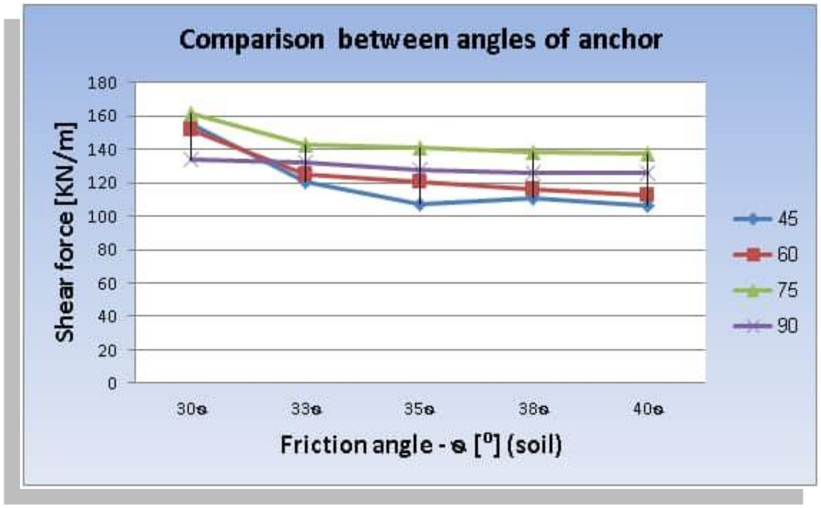


Figure 13 Wall Shear Force (Kn/m) at Varying Anchor Slopes (α) and (ϕ) (By Author)

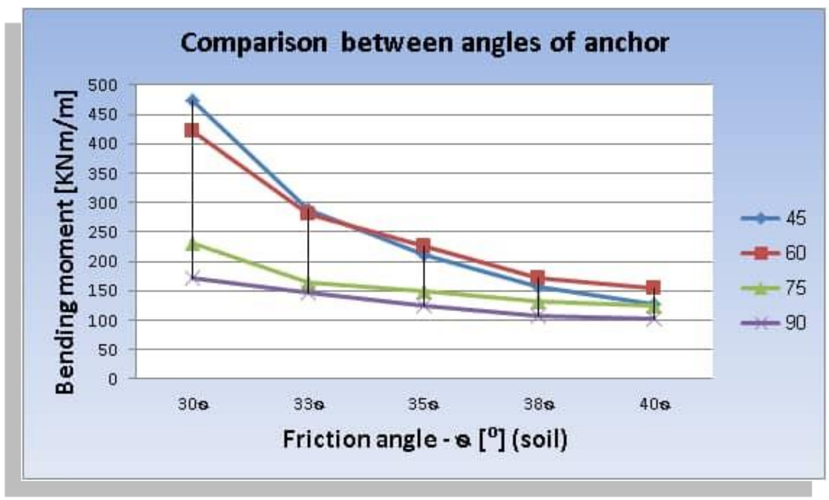


Figure 14 Wall Bending Moment (Kn.m/m) at Varying Anchor Slopes (α) and (ϕ) (By Author)

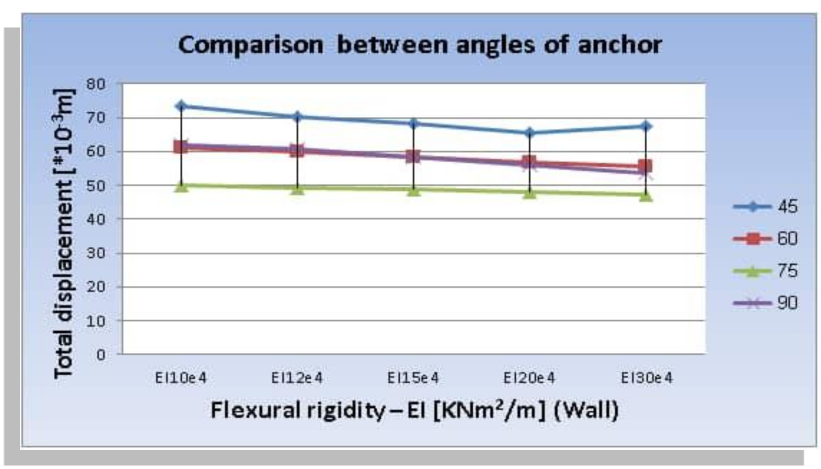


Figure 15 Total Wall Displacement Ut (m) at Varying Anchor Slopes (α) and (EI) (By Author)

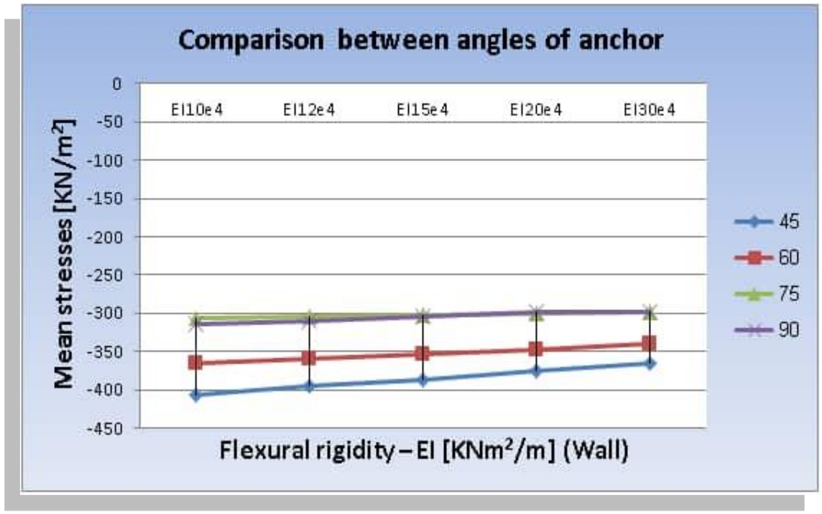


Figure 16 Soil Stresses (Kn/m^2) at Varying Anchor Slopes (α) and (EI) (By Author)

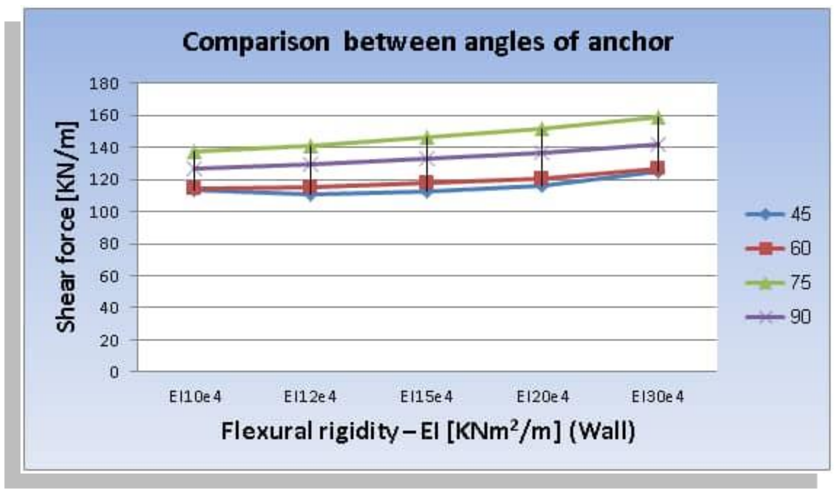


Figure 17 Wall Shear Force (Kn/m) at Varying Anchor Slopes (α) and (EI) (By Author)

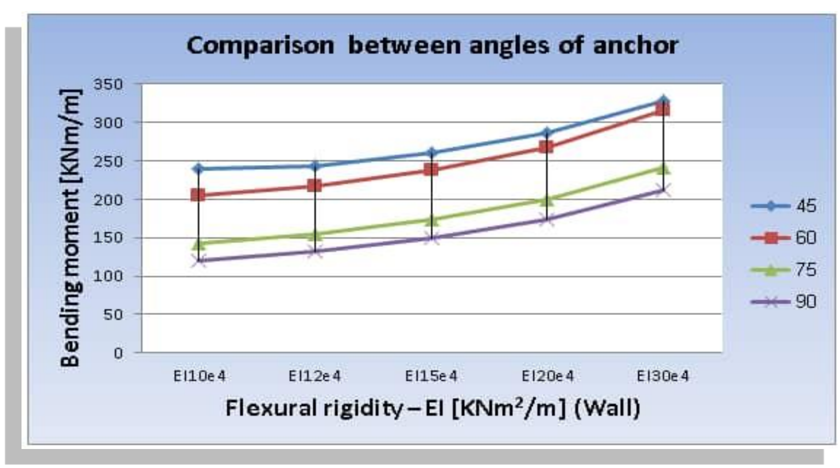


Figure 18 Wall Bending Moment (Kn.m/m) at Varying Anchor Slopes (α) and (EI) (By Author)

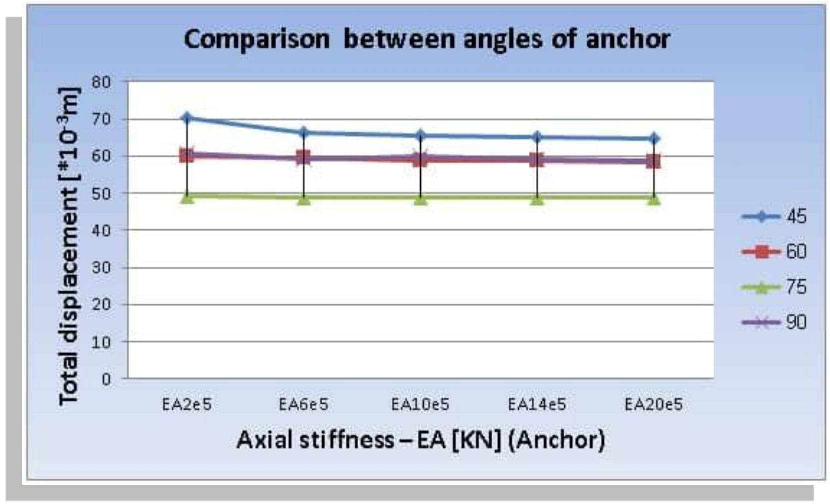


Figure 19 Total Wall Displacement Ut (m) at Varying Anchor Slopes (α) and (EA) (By Author)

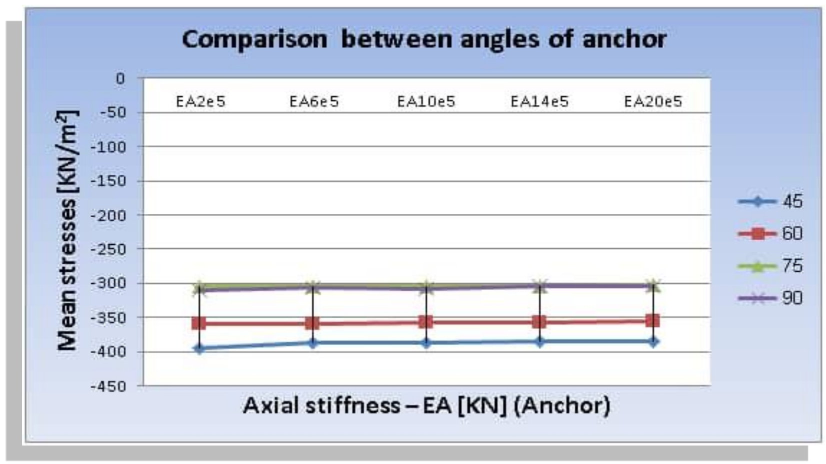


Figure 20 Soil Stresses (Kn/m^2) at Varying Anchor Slopes (α) and (EA) (By Author)

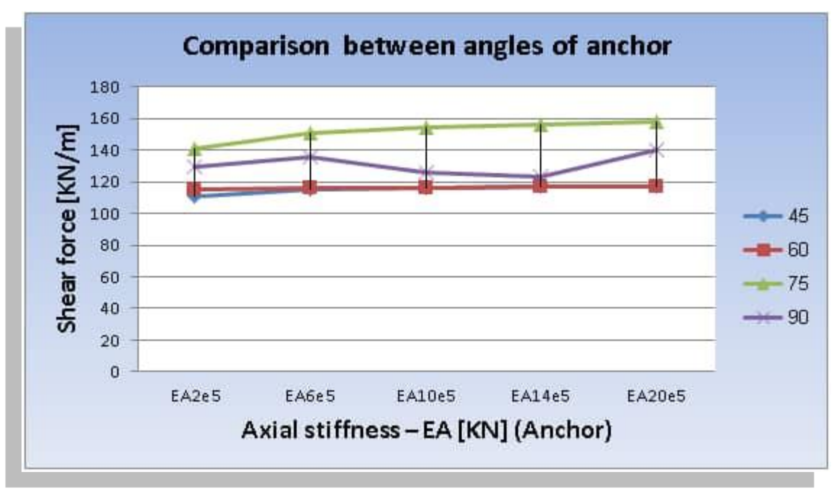


Figure 21 Wall Shear Force (Kn/m) at Varying Anchor Slopes (α) and (EA) (By Author)

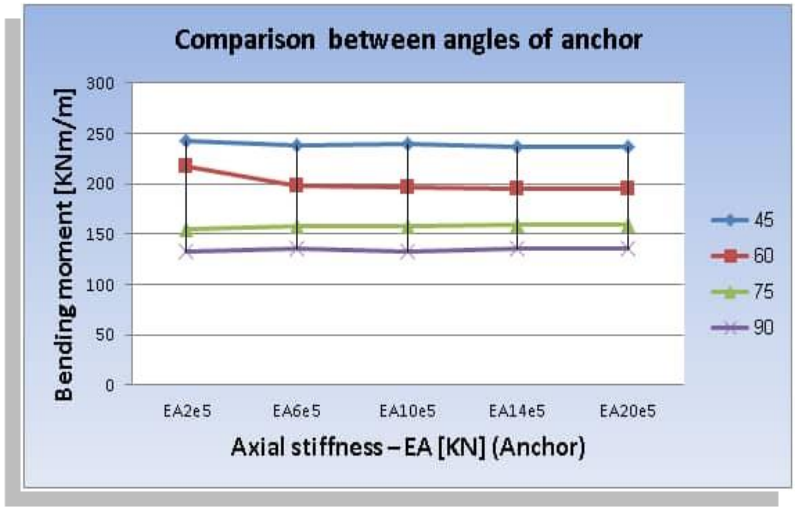


Figure 22 Wall Bending Moment (Kn.m/m) at Varying Anchor Slopes (α) and (EA) (By Author)

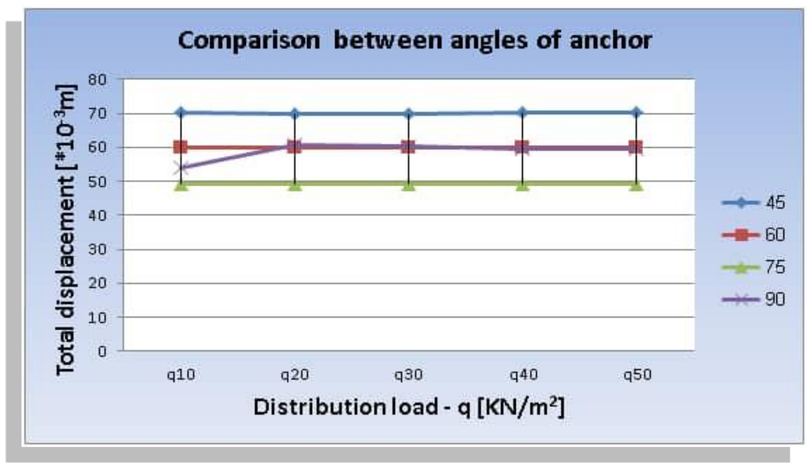


Figure 23 Total Wall Displacement Ut (m) at Varying Anchor Slopes (α) and (q) (By Author)

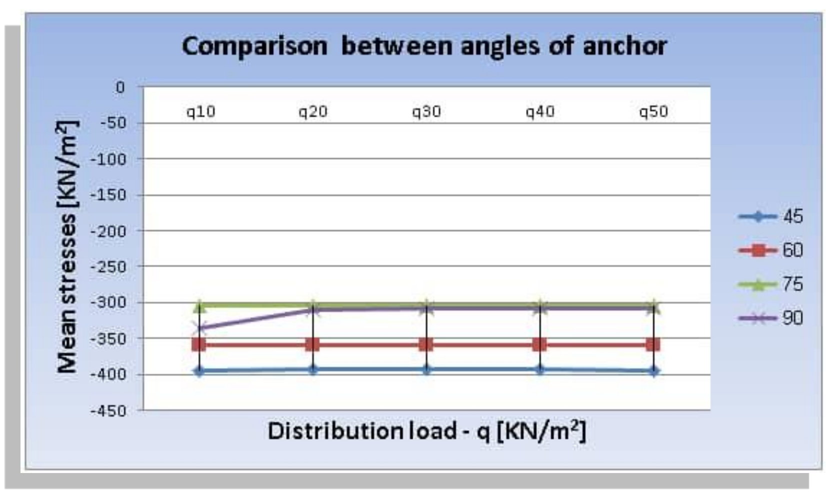


Figure 24 Soil Stresses (Kn/m^2) at Varying Anchor Slopes (α) and (q) (By Author)

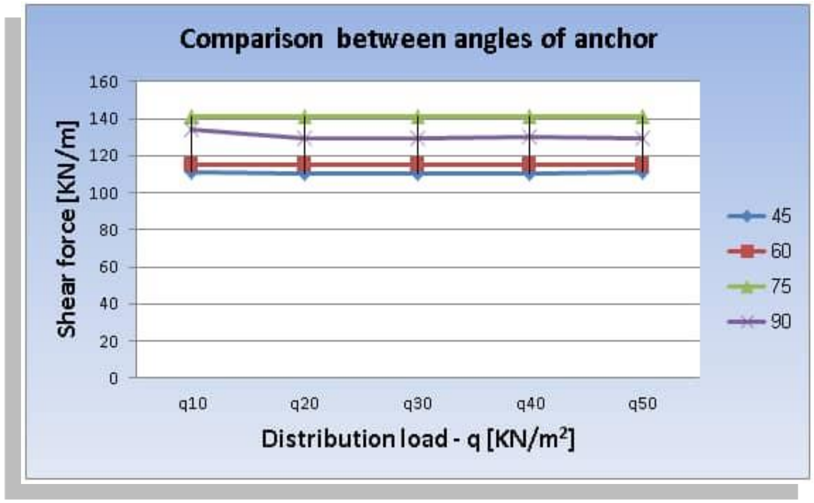


Figure 25 Wall Shear Force (Kn/m) at Varying Anchor Slopes (α) and (q) (By Author)

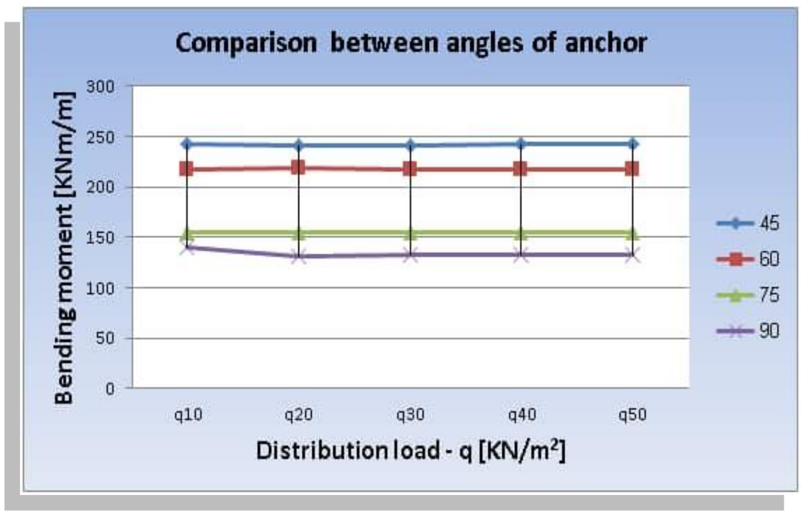


Figure 26 Wall Bending Moment (Kn.m/m) at Varying Anchor Slopes (α) and (q) (By Author)

The following tables summarize the previous data in terms of the maximum and minimum values as shown in Tables (4 to 7).

Table 4: Maximum and Minimum Displacement Values ($*10^{-3}$ m) (By Author)

	E	**Ø**	**EI**	**EA**	**q**
Anchor Angle	Min. 37.57 @75°, E40000 Max. 84.69 @60°, E20000	Min. 35.96 @75°, Ø40 Max. 147.63 @60°, Ø30	Min. 47.22 @75°, EI(10e4) Max. 73.41 @45°, EI (10e4)	Min. 48.79 @75°, EA (20e5) Max. 70.22 @45° EA(2e5)	Min. 49.22 @75°, q(30) Max. 70.23 @45° q(50)

Table 5: Maximum and Minimum Soil Stresses Values (Kn/m^2) (By Author)

	E	Ø	EI	EA	q
Anchor Angle	Min. -298.48 @90°, E20000 Max.-383.13 @45°, E40000	Min. -229.23 @75°, Ø38 Max.-558.0 @45°, Ø30	Min. -298.45 @90°, EI(20e4) Max.-406.0 @45°, E(10e4)	Min.-303.28 @75°, EA(20e5) Max.-393.93 @45°, EA(2e5)	Min. -304.36 @75°, q(30) Max.-393.97 @45°,q(50)

Table 6: Maximum and Minimum Wall Shear Force Values on the Wall (By Author)

	E	Ø	EI	EA	q
Ancho r angle	Min. 104.25 @45°, E40000 Max. 153.67 @75°, E20000	Min. 106.44 @45°, Ø40 Max. 161.73 @75°, Ø30	Min. 110.85 @45°, EI(12e4) Max. 158.56 @75°, EI (30e4)	Min. 110.85 @45°, EA (2e5) Max. 157.76 @75°, EA(20e5)	Min. 110.59 @45°, q(30) Max. 141.37 @75°, q(10)

Table 7: Maximum and Minimum Wall Bending Moment (kn.m/m) (By Author)

	E	Ø	EI	EA	q
Ancho r angle	Min. 112.31 @90°, E40000 Max. 251.51 @60°, E20000	Min. 102.33 @90°, Ø40 Max. 473.42 @45°, Ø30	Min. 119.96 @90°, EI(10e4) Max. 328.89 @45°, EI (30e4)	Min. 131.93 @90°, EA (2e5) Max. 242.52 @45°, EA(2e5)	Min. 131.83 @90°, q(20) Max. 242.52 @45°, q(50)

4. Conclusions

The effect of anchor angles (α) under different wall and anchor properties on the behavior of a typical anchored wall subjected have been studied and presented in this research. The wall behavior was investigated through the wall displacements, wall bending moments, wall shear forces, and soil stresses. A finite element analysis, using PLAXIS software, were utilized to perform the analyses. The overall findings of the study indicate that the soil and anchor & wall properties affect the structural behavior of the wall and should be considered during the design of the walls. The general overview of the results shows a predictable wall behavior with less displacement, shearing and bending moment for the enhanced properties of soil and wall characteristics.

For the purpose of this research which is preparing data base for the sake of future research in this scientific area, mostly all the possible combinations of anchor parameters were taken into account, accordingly, a massive amount of data was obtained for different combinations of parameters. However, some parameters showed a noticeable effect more than others, for example the following results were noticed:

1. Regarding displacement, the best result in terms of displacement was noticed for anchor angle 75°, compared to the other angles taken in this study. In general, the 45° anchor angle showed the worst result with maximum displacement values.
2. The maximum recorded soil stress value was -558 kn/m^2 and it was recorded for Ø30 and anchor angle 45°. Generally the maximum values of soil stress occurred when the anchor angle was 45°, and the best results occurred corresponding to 75°, and 90° cases.
3. Regarding shear force values, the maximum shear value (158.56 kn/m) recorded for the case which combined 75° anchor angle with wall flexural rigidity of (30e4). However, mostly 45° anchor angle combinations showed high values of shear force compared to the other results.
4. Regarding wall bending moment values, lower bending moment results were corresponding to all 90° anchor angle combinations. The higher moment values come with anchor angle 45°. The greatest moment value result (473.42 kn.m/m) occurred corresponding to anchor angle 45° and Ø 30.

The applicability of plaxis2D and its sensitivity to the minor changes in data was proven by this research. A massive amount of data tables were prepared for many different combinations of parameters. These data can be used for retaining wall design purpose with a predicted acceptable degree of accuracy. However, the degree of accuracy can be confirmed only if some field monitoring is performed to accompany this study and confirm some of the findings of this research.

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