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Effect of Soil Behind And Below Anchored Wall on The Behavior of Wall By Using Different Wall & Anchor Properties

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Abstract : *This paper presents a study on the effect of soil behind and below anchored wall on wall behavior by using different wall and anchor properties. Recently the wall depths are considered in the structural design of the wall. So in this paper investigated how soils below and behind the wall with using varying wall and anchor properties affect on the wall behavior such as wall deformations, wall bending moments, axial forces, shear forces, and anchor force. Also the effects of anchor angles on the wall behavior have been investigated. PLAXIS, finite element software package, was used to perform numerical modeling and analyses to evaluate the structural response and behavior of the anchored wall. The results show that the soil conditions below and behind the wall, including the wall properties, anchor properties, and anchor angles may have a significant effect on the wall behavior and should be considered during the design of anchored walls.*

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

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I. Introduction

A retaining 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. The retaining wall can be rigid type, such as masonry wall, simple concrete wall, or reinforced concrete wall. Also, it can be flexible type, such as steel sheet pile wall. Some of the wall types are used with anchors. Relatively high walls may require anchors, while relatively short walls can be cantilever without any anchors. National Cooperative Highway Research 2008 [1] Typically the anchors are installed when the wall height exceeds 6m or the wall supports heavy loads from a structure. Mohamad Gabar & Ömer Bilgin 2016 [2] studied the effect of soil below the wall, sloping bedrock, and different wall height on the wall behavior. Dawkins, William P. 2001 [3]] investigated the effects of wall friction, surcharge loads, and moment reduction curves for anchored sheet-pile walls. Ömer Bilgin 2009 [4] studied the effect of subsurface soil conditions on floodwall behavior. Therefore, this research presented the knowledge and understanding of the behavior of soil under and behind the wall with using different wall properties, different anchor (strut) properties, and anchor angle behaviors on the wall behavior.

1.1 Objective of this Paper

The soils below the anchored wall are not considered in the structural design. Therefore, this paper studies how the soil conditions below and behind the anchored wall with using different wall and anchor properties, and sloping anchor affect the wall behavior such as deformations, moments, stresses, shear forces, strains, and anchor force. Earlier studies showed that the presence of varying soil properties below the wall affects the wall deformations (Gabar & Bilgin, 2016). In addition, the effect of soil below and behind of the wall with using different wall and anchor properties on the wall behavior has also been investigated during this study. The effects of the anchor installation angle on the wall behavior under these varying conditions have also been studied.

1.2 Scope and Parametric Study

The primary focus of this paper is to investigate the structural response of anchored wall using parametric studies for varying conditions. The conditions studied are: (1) Different wall properties (Normal Stiffness EA = $5.5*10^6$ Kn/m to $11*10^6$ Kn/m) as shown in figure (1.1) and Table (1.1); (2) Different anchor properties (Axial Stiffness EA = $01*10^6$ Kn to $07*10^6$ Kn) as shown in Table (1.2); and (3) Different anchor angles (α = 15°, 30°, 45°, & 60°). 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 deformations, wall moments, wall shear forces, wall axial force, strains, and anchor forces.

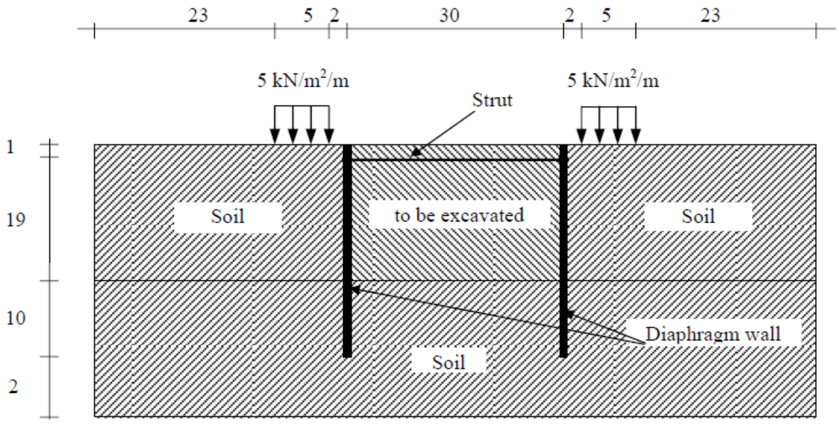

Figure 1.1 Geometry Model of the Situation of A submerged Excavation at Depth 2m

Table 1.1 Material Properties of the Anchored Wall (Plate or wall) (By Author)

Parameter	Name	1	2	3	4	5	6	Unit
Type of behavior	**Material type**	**Elastic $*10^6$**	**Elastic $*10^6$**	**Elastic $*10^6$**	**Elastic $*10^6$**	**Elastic $*10^6$**	**Elastic $*10^6$**	-
Normal stiffness	EA	5.5	6.5	8.5	9.5	10	11	kN/m
Flexural rigidity	EI	1	1	1	1	1	1	kN.m²/m
Weight	W	10	10	10	10	10	10	kN/m/m
Poisson's ratio	ν	0.15	0.15	0.15	0.15	0.15	0.15	-

Table 1.2 Material Properties of the Anchored Wall (Anchor) (By Author)

Parameter	Name	1	2	3	4	5	6	Unit
Type of behavior	**Material type**	**Elastic $*10^6$**	**Elastic $*10^6$**	**Elastic $*10^6$**	**Elastic $*10^6$**	**Elastic $*10^6$**	**Elastic $*10^6$**	-
Axial stiffness	EA	1	3	4	5	6	7	kN
Spacing out of plane	L_s	5	5	5	5	5	5	m

II. 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 depths of the bedrock below the wall, different soil, wall, and anchor properties, and anchor angles on wall behavior. The study was performed using the PLAXIS 2D version 8 finite element program employing 15-noded triangular elements. For all the cases modeled and analyzed, the wall total displacement, wall bending moments, and anchor forces were investigated to understand the effect of various factors on the wall behavior as described above.

2.1 Effect of Wall Properties

The effect of wall properties was investigated by studying different EA- Normal Stiffness with using wall penetration depths (D=5m) and soil property (soil1). The objective was to compare the total displacement, wall bending moment, wall shear forces, wall axial force, total stresses, total strains, and anchor force on the different wall properties. A fixed-end anchor was used to support the walls. The material properties used in PLAXIS for the wall are listed in Table 2.1 and 2.2.

Table 2.1 Material Properties of the Anchored Wall (Plate) (By Author)

Parameter	Name	1	2	3	4	5	6	Unit
Type of behavior	Material type	Elastic $*10^6$	Elastic $*10^6$	Elastic $*10^6$	Elastic $*10^6$	Elastic $*10^6$	Elastic $*10^6$	-
Normal stiffness	EA	5.5	6.5	8.5	9.5	10	11	kN/m
Flexural rigidity	EI	1	1	1	1	1	1	$kN.m^2/m$
Weight	W	10	10	10	10	10	10	kN/m/m
Poisson's ratio	ν	0.15	0.15	0.15	0.15	0.15	0.15	-

Table 2.2 Material Properties for the Soil Types Studied (By Author)

Parameter	Name	Soil 1	Unit
Material model	Model	Mohr-Coulomb	-
Type of material behavior	Type	Drained	-
Soil unit weight above phreatic level	γ_{unsat}	17	KN/m^3
Soil unit weight below phreatic level	γ_{sat}	20	KN/m^3
Permeability in horizontal direction	K_x	1.0	m/day
Permeability in vertical direction	K_y	1.0	m/day
Young's modulus	E	10000	KN/m^2
Poisson's ration	ν	0.3	-
Cohesion	C	1.0	KN/m^2
Friction angle	ϕ	30	°
Dilatancy angle	ψ	2	°
Strength reduction factor interface	R_{inter}	0.67	-

2.2 Effect of Anchor Properties

The effect of anchor properties was investigated by studying different EA- Axial Stiffness with using wall penetration depths (D=5m) and soil property (soil1). The objective was to compare the total displacement, wall bending moment, wall shear forces, wall axial force, total stresses, total strains, and anchor force on the different anchor properties. A fixed-end anchor was used to support the walls. The material properties used in PLAXIS for the wall are listed in Table 2.3.

Table 2.3 Material Properties of the Anchored Wall (Anchor) (By Author)

Parameter	Name	1	2	3	4	5	6	Unit
Type of behavior	Material type	Elastic $*10^6$	Elastic $*10^6$	Elastic $*10^6$	Elastic $*10^6$	Elastic $*10^6$	Elastic $*10^6$	-
Axial stiffness	EA	1	3	4	5	6	7	kN
Spacing out of plane	L_s	5	5	5	5	5	5	m

2.3 Effect of Anchor Angle

The effect of anchor angle on the wall behavior at depth D = 5m under the wall has also been studied. Also, Four anchor angles, 15°, 30° , 45° and 60° were used. The same properties for soil type (soil1), wall property (EA= $7.5*10^6$ Kn/m), anchor property (EA= $1.0*10^6$ Kn), and load (5 Kn/m2/m) on the ground surface were used.

III. Result And Discussion

3.1 Effect of Wall Properties

This modeling and analyses were performed to investigate the effect of wall properties (EA - Normal Stiffness) on the wall behavior under bedrock depth 5m and soil property (E1 & ϕ1) as shown in Table 3.1 through 3.5. Figure 3.1 to 3.5 show that the displacements, strains, and stresses on the wall have the similar behavior under varying wall conditions. Wall bending moments and anchor force along the wall height for varying wall properties are shown in Figures 3.6 to 3.7. As expected, the results show that the wall has higher bending moments values at the anchor level with using different wall properties that cause more effect on the wall. Also the vertical wall displacements are relatively very small and the overall soil movements around the wall affect on the wall displacements and cause the wall to move up or down.

Table 3.1 Maximum Total Wall Displacement for Varying Wall Properties (By Author)

Normal Stiffness EA (Kn/m) * 10^6	Maximum Total Wall Displacement Ut(m)
5.5	0.52068
6.5	0.51459
8.5	0.52014
9.5	0.50723
10	0.52005
11	0.5196

Table 3.2 Maximum Total Strains for Varying Wall Properties (By Author)

Normal Stiffness EA (Kn/m) * 10^6	Maximum Total Strains (%)
5.5	144.55
6.5	37.66
8.5	145.03
9.5	82.69
10	144.84
11	144.84

Table 3.3 Maximum Total Stresses for Varying Wall Properties (By Author)

Normal Stiffness EA (Kn/m) * 10^6	Maximum Total Stresses (Kn/m2)
5.5	-1370
6.5	-1090
8.5	-1370
9.5	-1230
10	-1370
11	-1380

Table 3.4 Wall Anchor Force for Varying Wall Properties (By Author)

Normal Stiffness EA (Kn/m) * 10^6	Wall Anchor Force (Kn/m)
5.5	-640.4
6.5	-613.6
8.5	-640.9
9.5	-636.6
10	-640.2
11	-640

Table 3.5 Wall Bending Moment for Varying Wall Properties (By Author)

Normal Stiffness EA (Kn/m) * 10^6	Wall Bending Moment (Kn.m/m)
5.5	3410
6.5	3400
8.5	3410
9.5	3370
10	3410
11	3410

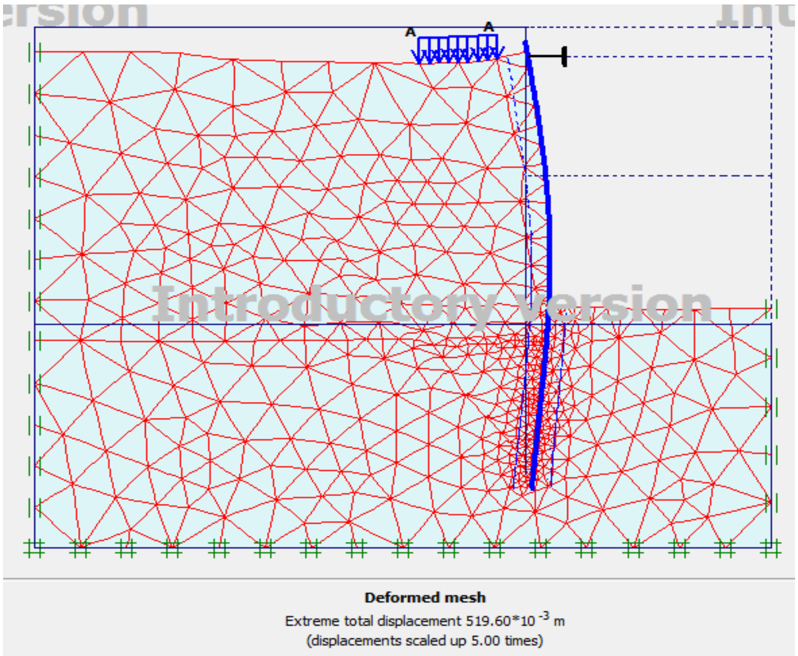

Figure 3.1 Total Displacement Vectors for Depth, D=5 m (EA=11 $*10^6$ Kn/m) (By Author)

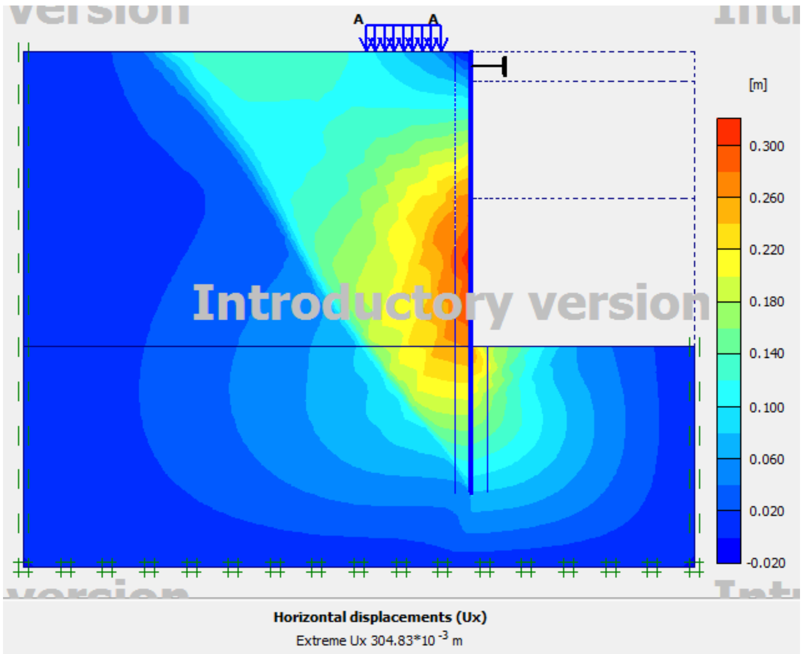

Figure 3.2 Horizontal Displacement Vectors for Depth, D=5 m (EA=11 $*10^6$ Kn/m) (By Author)

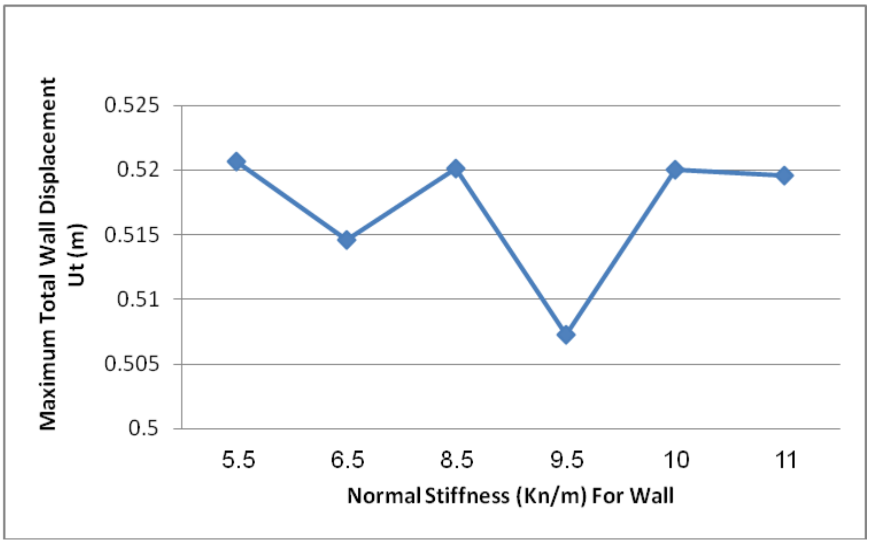

Figure 3.3 Maximum Total Wall Displacement Ut (m) for Varying Wall Properties (By Author)

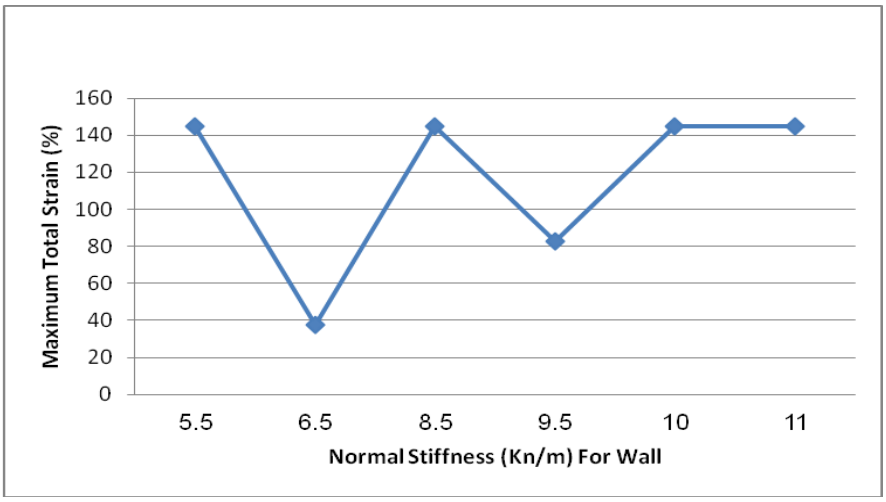

Figure 3.4 Maximum Total Strains (%) for Varying Wall Properties (By Author)

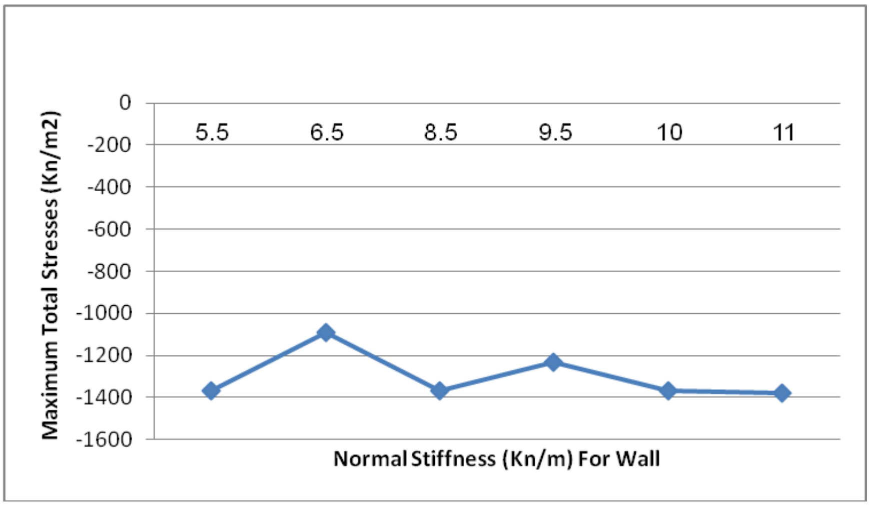

Figure 3.5 Maximum Total Stresses (Kn/m2) for Varying Wall Properties (By Author)

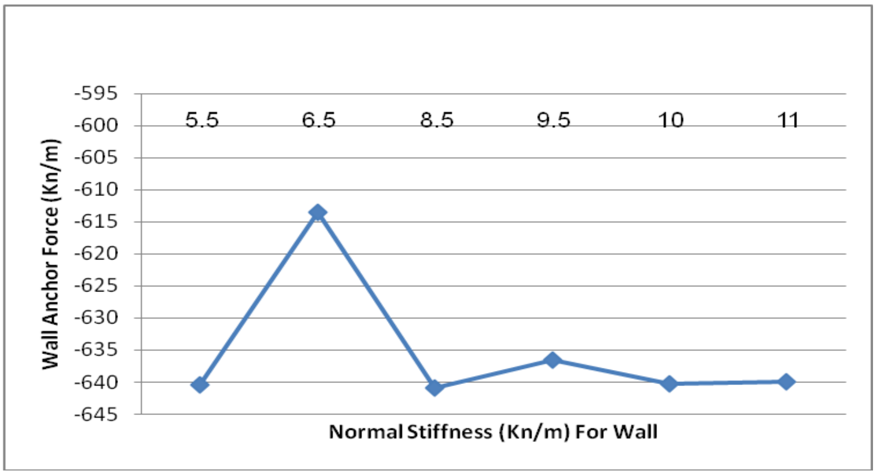

Figure 3.6 Wall Anchor Force (Kn/m) for Varying Wall Properties (By Author)

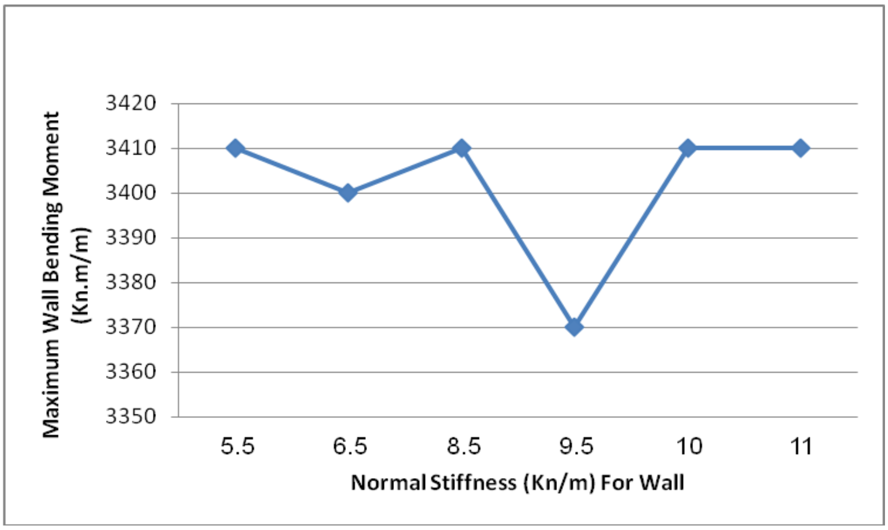

Figure 3.7 Maximum Wall Bending Moment (Kn.m/m) for Varying Wall Properties (By Author)

3.2 Effect of Anchor Properties

This modeling and analyses were performed to investigate the effect of anchor properties (EA - Axial Stiffness) on the wall behavior under bedrock depth 5m and soil property (E1 & ϕ1) as shown in Table 3.6 through 3.10. Figure 3.10 and 3.11 show that the displacements and strains on the wall decrease with increasing anchor properties (EA - Axial Stiffness). Stresses and anchor forces increase with increasing anchor properties but they remain constant when the axial stiffness is more than ($EA = 4*10^6$ Kn) as shown in Figures 3.12 and 3.13. In Figure 3.14 the wall bending moment increase with increasing anchor properties but the bending moment decrease when the axial stiffness is more than $EA = 3*10^6$ Kn. In this case, the anchor properties are very important to prevent the wall from overturning.

Table 3.6 Maximum Total Wall Displacement for Varying Anchor Properties (By Author)

Axial Stiffness EA (Kn) * 10^6	Maximum Total Wall Displacement Ut(m)
1	**0.53144**
3	**0.51876**
4	**0.51344**
5	**0.50981**
6	**0.50981**
7	**0.50789**

Table 3.7 Maximum Total Strains for Varying Anchor Properties (By Author)

Axial Stiffness EA (Kn) * 10^6	Maximum Total Strains (%)
1	143.71
3	143.78
4	141.77
5	140.27
6	140.27
7	139.28

Table 3.8 Maximum Total Stresses for Varying Anchor Properties (By Author)

Axial Stiffness EA (Kn) * 10^6	Maximum Total Stresses (Kn/m2)
1	-1370
3	-1390
4	-1380
5	-1380
6	-1380
7	-1380

Table 3.9 Wall Anchor Force for Varying Anchor Properties (By Author)

Axial Stiffness EA (Kn) * 10^6	Wall Anchor Force (Kn/m)
1	-629
3	-647.1
4	-644.8
5	-645.8
6	-645.8
7	-646.1

Table 3.10 Wall Bending Moment for Varying Anchor Properties (By Author)

Axial Stiffness EA (Kn) * 10^6	Wall Bending Moment (Kn.m/m)
1	3380
3	3430
4	3410
5	3400
6	3400
7	3390

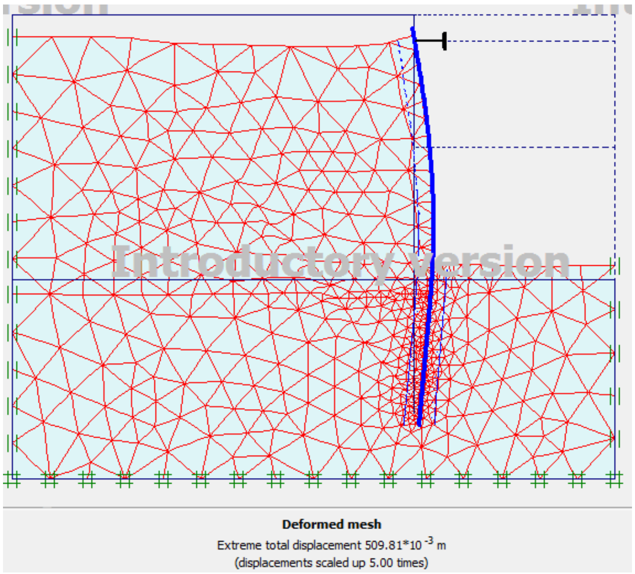

Figure 3.8 Total Displacement Vectors for Depth, D=5 m (EA=6 *10^6 Kn) (By Author)

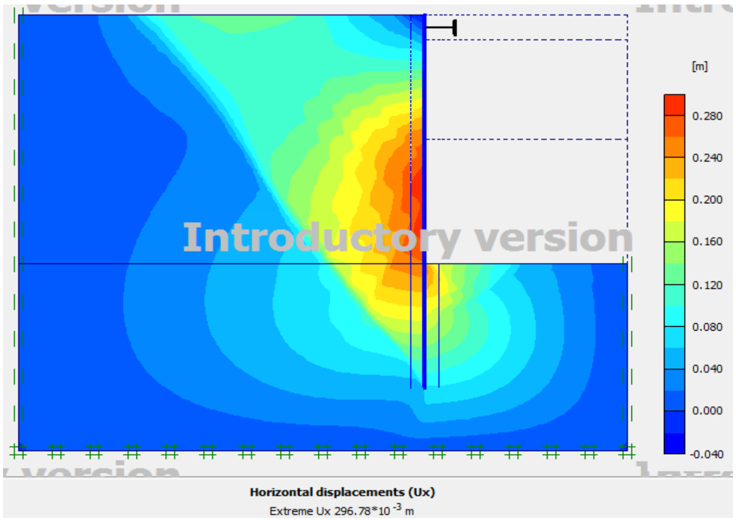

Figure 3.9 Horizontal Displacement Vectors for Depth, D=5 m (EA=6 *10^6 Kn)   (By Author)

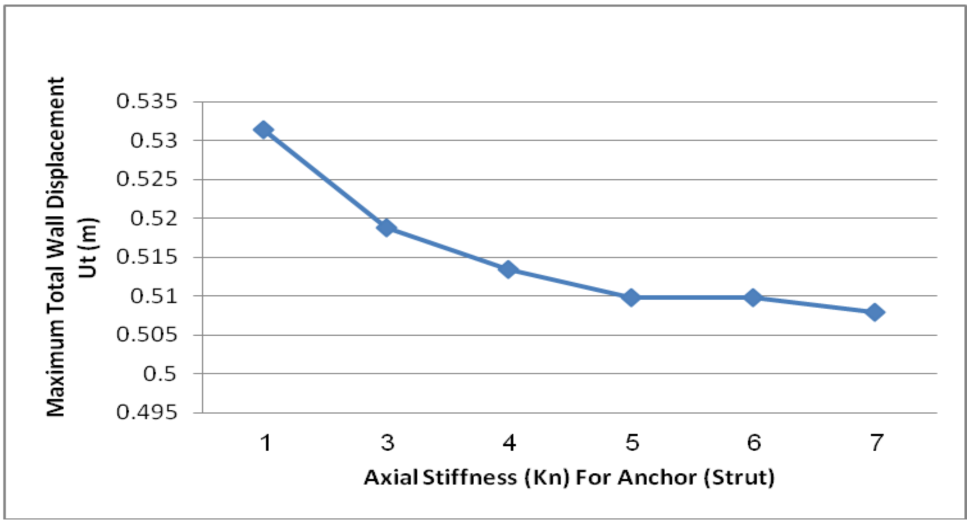

Figure 3.10 Maximum Total Wall Displacement Ut (m) for Varying Anchor Properties (By Author)

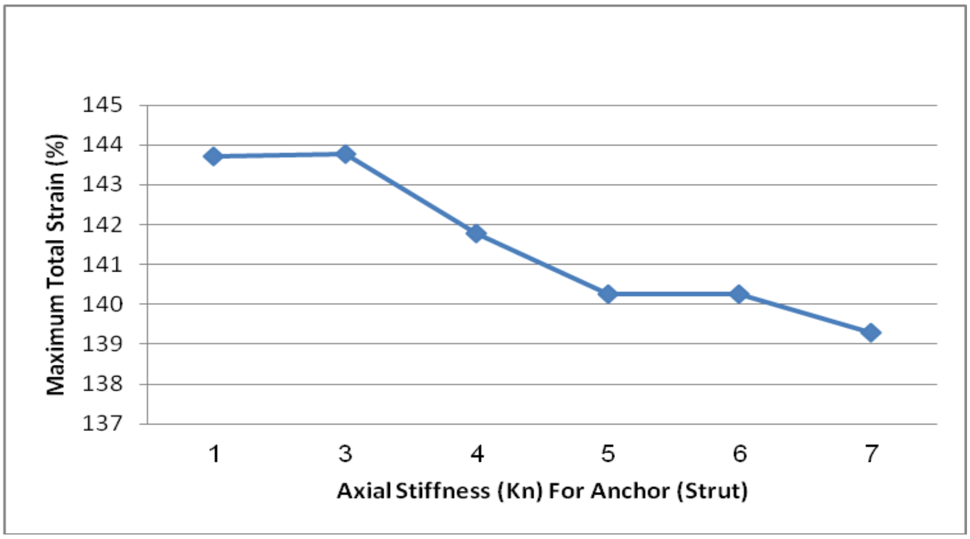

Figure 3.11 Maximum Total Strains (%) for Varying Anchor Properties (By Author)

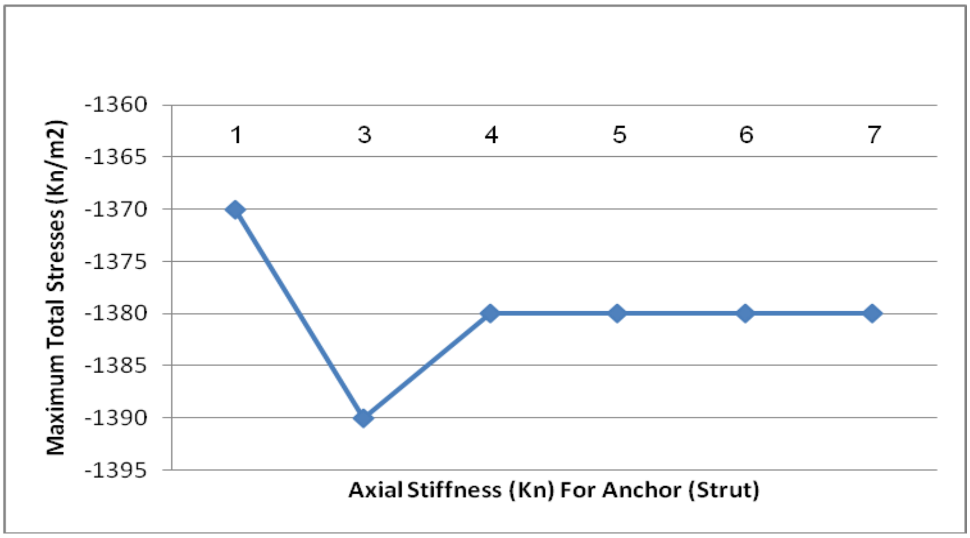

Figure 3.12 Maximum Total Stresses (Kn/m2) for Varying Anchor Properties (By Author)

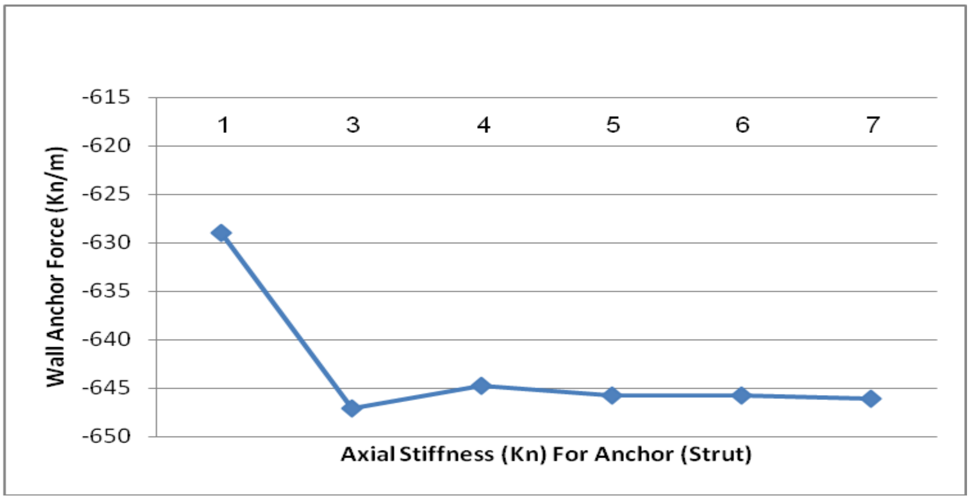

Figure 3.13 Wall Anchor Force (Kn/m) for Varying Anchor Properties (By Author)

Figure 3.14 Maximum Wall Bending Moment (Kn.m/m) for Varying Anchor Properties (By Author)

3.3 Effect of Anchor Angle

This modeling was performed to evaluate the effect of anchor inclination on the wall behavior. All the analyses were performed with anchors installed at 15°, 30° , 45°, and 60° as represented in Tables 3.11 through 3.15 and Figures 3.15 through 3.19 show the results of analyses in terms of bending moment, stresses, strains, anchor force, and displacements for anchor inclination for the case where the bedrock is at 2 m depth.

The results show that anchor inclination has the most effect on maximum vertical and horizontal wall deformations, bending moment, stresses, anchor force, and strains because of the different vertical and horizontal components of the anchor for varying anchor inclination angles that cause more deformation on the wall.

Table 3.11 Maximum Total Wall Displacement for Varying Anchor Angles (By Author)

Anchor Angles	Maximum Total Wall Displacement Ut(m)
15°	0.31381
30°	0.38953
45°	0.25202
60°	0.26836

Table 3.12 Maximum Total Strains for Varying Anchor Angles (By Author)

Anchor Angles	Maximum Total Strains (%)
15°	8.78
30°	12.5
45°	29.71
60°	19.59

Table 3.13 Maximum Total Stresses for Varying Anchor Angles (By Author)

Anchor Angles	Maximum Total Stresses (Kn/m2)
15°	-1350
30°	-1670
45°	-2180
60°	-2060

Table 3.14 Wall Anchor Force for Varying Anchor Angles (By Author)

Anchor Angles	Wall Anchor Force (Kn/m)
15°	-555.8
30°	-612.9
45°	-691.6
60°	-880.4

Table 3.15 Wall Bending Moment for Varying Anchor Angles (By Author)

Anchor Angles	Wall Bending Moment (Kn.m/m)
15°	2410
30°	2420
45°	2420
60°	2500

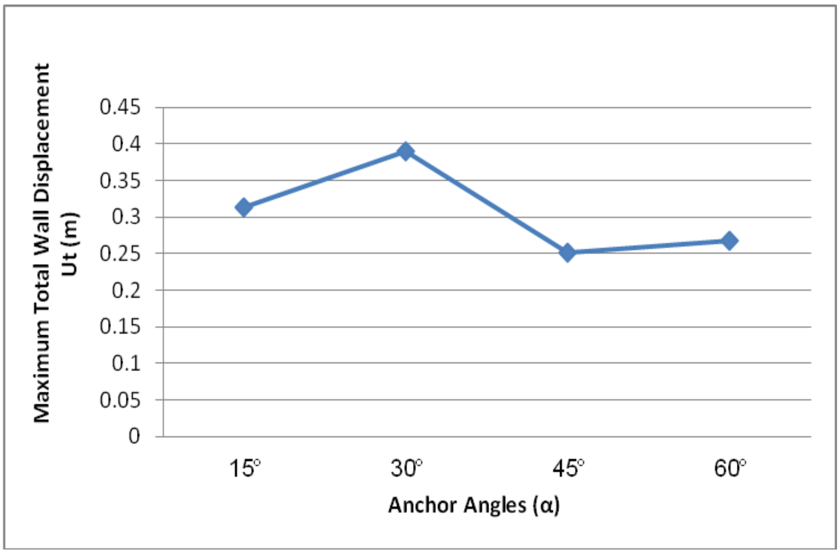

Figure 3.15 Maximum Total Wall Displacement Ut (m) for Varying Anchor Angles (By Author)

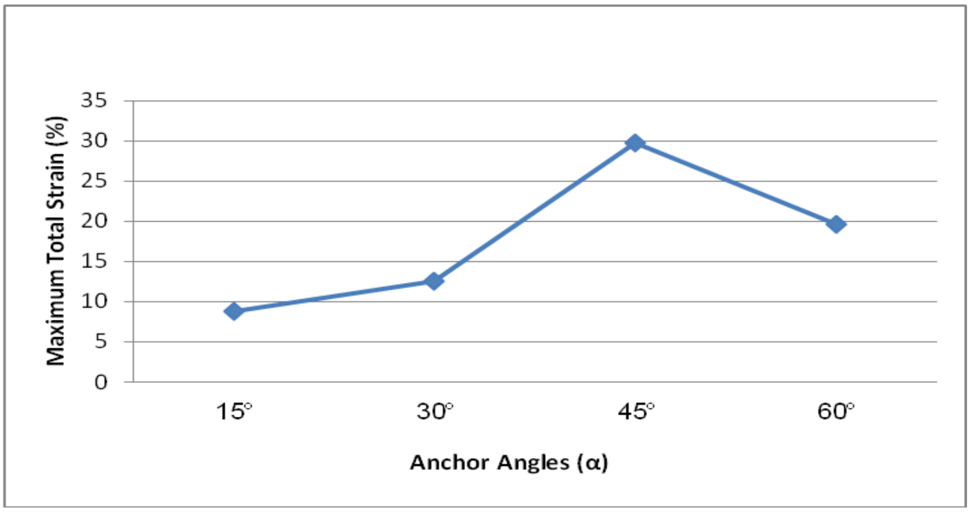

Figure 3.16 Maximum Total Strains (%) for Varying Anchor Angles (By Author)

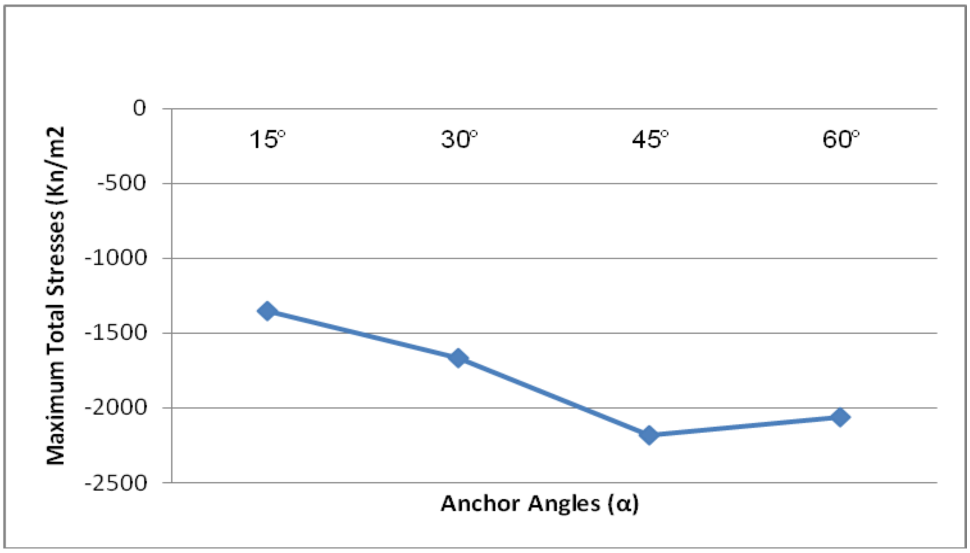

Figure 3.17 Maximum Total Stresses (Kn/m2) for Varying Anchor Angles (By Author)

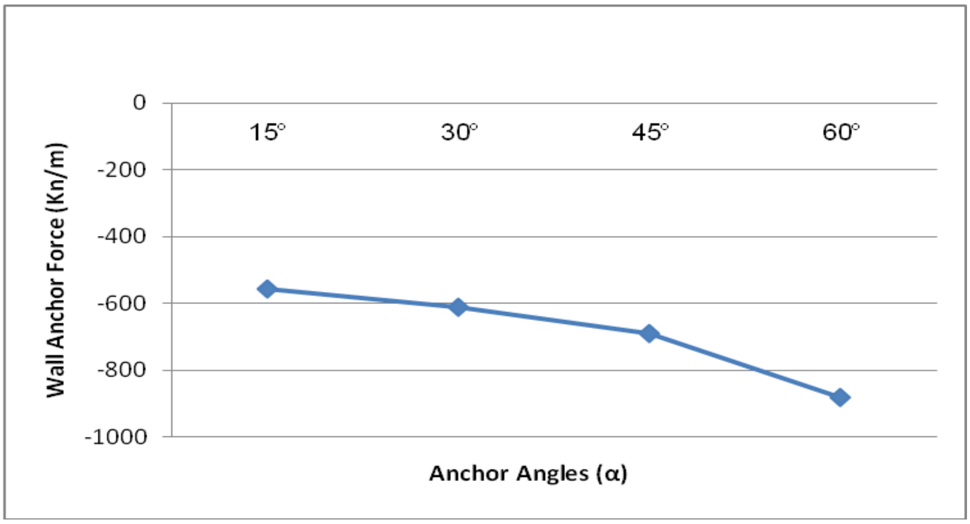

Figure 3.18 Wall Anchor Force (Kn/m) for Varying Anchor Angles (By Author)

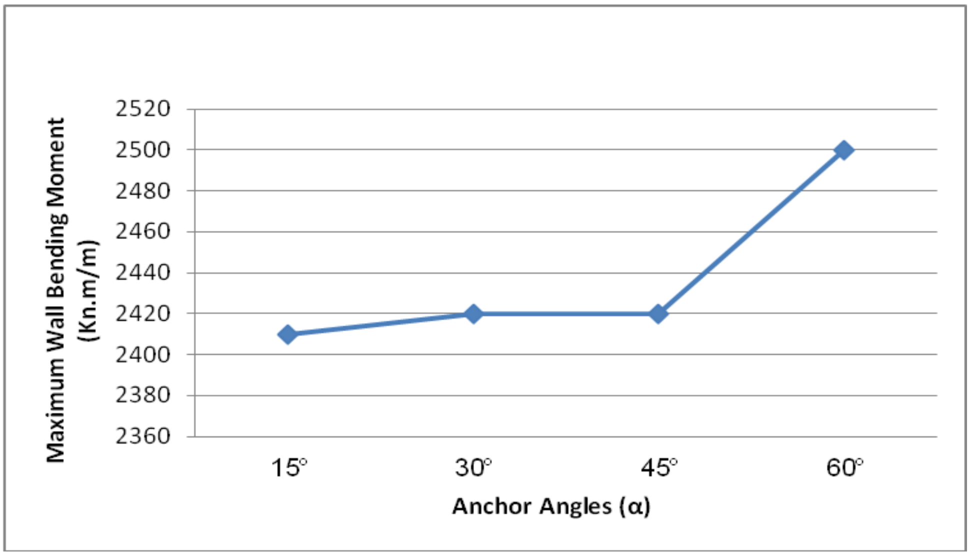

Figure 3.19 Maximum Wall Bending Moment (Kn.m/m) for Varying Anchor Angles (By Author)

Conclusion

The effect of anchor properties, wall properties, and anchor inclination on the behavior of a typical anchored wall subjected have been studied and presented in this paper. The wall behavior was investigated through the wall displacements, bending moments, stresses, strains, and anchor forces. A finite element analysis, using PLAXIS software, were utilized to perform the analyses. The overall findings of the study indicate that the soil conditions below and behind the wall affects the structural behavior of the wall with using parametric study that mentioned in part I and should be considered during the design of the walls. The results of this study will help engineers in designing the anchored retaining walls. For the parameter ranges and the cases studied the following conclusions are reached from this study:

1. Wall properties has a significant effect on the wall behavior. The displacements, strains, and stresses on the wall have the similar behavior under varying wall conditions. The wall has higher bending moments values at the anchor level that cause more effect on the wall. The vertical wall displacements are relatively very small and the overall soil movements around the wall affect the wall displacements and cause the wall to move up or down.
2. This study provides an insight on the effect of the anchor properties structural behavior of anchored walls. Increasing axial stiffness causes more stresses on the anchored wall that lead to soil collapse behind the wall.

3. Anchor inclination has the most effect on maximum vertical and horizontal wall deformations, bending moment, stresses, anchor force, and strains because of the different vertical and horizontal components of the anchor for varying anchor inclination angles.

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.

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