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Effect of Subsurface Conditions on the Behavior of Retaining Walls

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Abstract : *The purpose of this paper is to present the study on the effect of soil and bedrock conditions below retaining walls on the wall behavior. The structural design of the retaining wall considers soils on the back and front of the wall. Soils below the wall and the bedrock conditions are not considered in the structural design of the wall. This paper study investigated how soils below the wall affect the wall behavior such as wall deformations, wall bending moments, and anchor force. The effects of soil strength, depth to bedrock, bedrock slope, wall height, and 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 retaining wall. The results show that the soil conditions below the wall, including the bedrock depth and the bedrock slope angle may have a significant effect on the wall behavior and should be considered during the design of retaining walls.*

Keywords: *Retaining wall, Bedrock conditions, Wall height, Anchor angles, Soil strength.*

I. Introduction

Retaining walls are designed for keeping a level difference of the soil on behind or front of the retaining wall. The retaining wall can be of the rigid type such as Masonry wall, Simple concrete wall, or reinforced concrete. Also, it can be of the flexible type such as Steel wall. In this paper studies anchored wall that are used to provide additional support to the wall. National Cooperative Highway Research [1] investigated that the anchors are installed when the wall height exceeds 20 feet or the wall supports heavy loads from a structure, and the anchors are supported the wall when it exceeds 20 ft. height to protect it from wall overturning, wall displacement, or failure such as cracks on the wall. Those cracks may be by water pressure that caused additional pressure or stresses on the wall or caused by the lateral earth pressures. Ömer Bilgin [2] studied the effect of subsurface soil conditions on floodwall behavior. Marr, W.A., and Christian [3] investigated the permanent displacements due to cyclic wave loading. Peck,R.B [4] studied deep excavations and tunneling behaviors in soft ground. Dawkins, William P. [5] investigated the effects of wall friction, surcharge loads, and moment reduction curves for anchored sheet-pile walls. So in this paper presented the knowledge and understanding of the behavior of soil under the wall, sloping bedrock with different depth under the retaining wall, different wall height, and anchor angle behaviors on the wall.

1.1 Objective of this Paper

Current structural design of a retaining wall considers soils in the back and front of the retaining wall. The soils below the retaining wall are not considered in the structural design. Therefore, this paper studies how the soil and bedrock conditions below the retaining wall affects the wall behavior such as deformations, moments, and anchor force. Earlier studies showed that the presence of soft soil layer and its thickness below the wall affects the wall deformations (Bilgin 2009). In addition, the effect of sloping bedrock with different depths on the wall behavior has also been investigated during this study. Bedrock depths under the retaining wall ranged from 5 m to 50 m. The effects of the wall height and 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 retaining wall using parametric studies for varying conditions. The conditions studied are: (1) Soil strength using dense and loose soils as shown in Table (1); (2) Different bedrock depths (D = 5 m to 50 m) below the wall; (3) Different bedrock slopes (α = 0 to 45◦); (4) Different wall heights (H = 6 m and 9 m) with using properties as shown in Table (2); and (5) Different anchor angles as shown in figure (1.1) with using properties as shown in Table (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 2-D finite element software for geotechnical engineering applications. The structural analysis by PLAXIS involved investigating wall deformations, wall moments, and anchor forces.

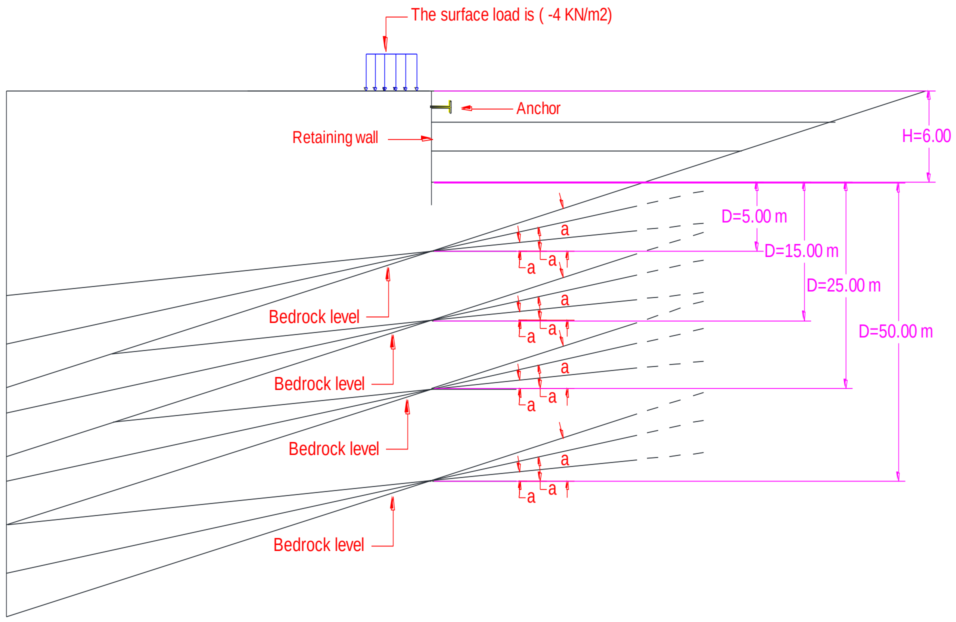

Fig. 1.1 Bedrock Slope (α) – (Upward Slope)

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

Parameter	Name	Loose Sand	Dense Sand	Unit
Material model	**Model**	**Mohr-Coulomb**	**Mohr-Coulomb**	**-**
Type of material behavior	**Type**	**Drained**	**Drained**	**-**
Soil unit weight above phreatic level	γ_{unsat}	17	18	kN/m³
Soil unit weight below phreatic level	γ_{sat}	20	20	kN/m³
Permeability in horizontal direction	K_x	1.0	1.0	m/day
Permeability in vertical direction	K_y	1.0	1.0	m/day
Young's modulus	E	40000	60000	kN/m²
Poisson's ration	N	0.3	0.3	-
Cohesion	C	1.0	1.0	kN/m²
Friction angle	ϕ	32	38	°
Dilatancy angle	Ψ	2	4	°
Soil-wall interface strength	R_{inter}	**0.67**	**0.67**	**-**

Table (2): Material Properties of the Diaphragm Wall (Plate)

Parameter	Name	Value	Unit
Type of behavior	Material type	Elastic	-
Normal stiffness	EA	7.5 * 10^6	kN/m
Flexural rigidity	EI	1.0 * 10^6	kN.m²/m
Equivalent thickness	d	1.265	m
Weight	W	10	kN/m/m
Poisson's ratio	ν	0.15	-

Table (3): Material Properties of the Strut (Anchor)

Parameter	Name	Value	Unit
Type of behavior	Material type	Elastic	-
Normal stiffness	EA	2.6 * 10^6	kN
Spacing out of plane	L_s	5	m
Maximum force	$F_{max,comp}$ $F_{max,tens}$	1.0 * 10^15 1.0 * 10^15	kN kN

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.

2.1 Modeling and Effect of Boundary Conditions

The boundary conditions at the bottom of the soil mass are usually modeled using fixed boundary conditions in PLAXIS. When there is bedrock at the bottom of the model, the boundary also modeled using fixed conditions. In addition, the bottom boundary is generally modeled level, i.e. the bedrock is horizontal at the bottom of the model. However, sloping bedrock conditions have been investigated in this study. Therefore, the first study involved investigating the effect of modeling the boundary conditions at the bottom of the model. Two boundary conditions, one with fixed boundary and one with friction boundary, representing the friction between soil and bedrock, were modeled. Figure (2.1) shows fixed boundary condition for bedrock under the wall and Figure (2.2) shows friction boundary condition for bedrock under the wall. These boundaries were carried out with different bedrock depths and bedrock slopes.

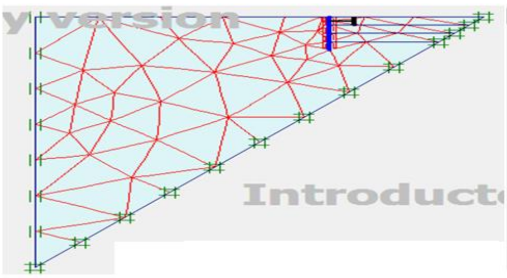

Fig. 2.1 Fixed Boundary Condition for Depth D=15 m

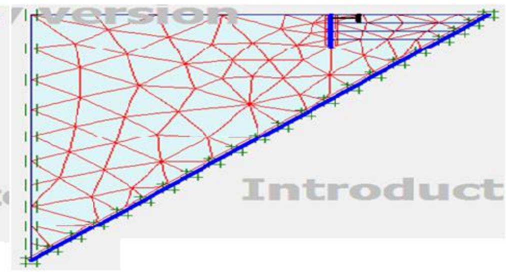

Fig. 2.2 Friction Boundary Conditions for D=15 m

2.2 Effect of Bedrock Depth (D)

This case was established to investigate the effect of bedrock depth (D) below the wall on the wall behavior by using loose sand soil (□=32°). Figures (2.3) and (2.4) show the total displacement vectors for bedrock depths of D=5 m and 25 m under the wall. The horizontal displacement vectors are shown in Figures (2.5) and (2.6). Since there is a larger soil mass present below the wall for the 25 m case, more soils are engaged in overall movements due to the unbalanced pressures behind the wall.

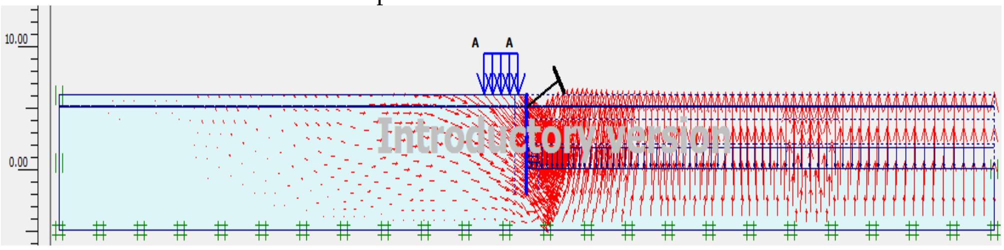

Fig. 2.3 Total Displacement Vectors for Depth, D=5 m (H=6m & □=32°)

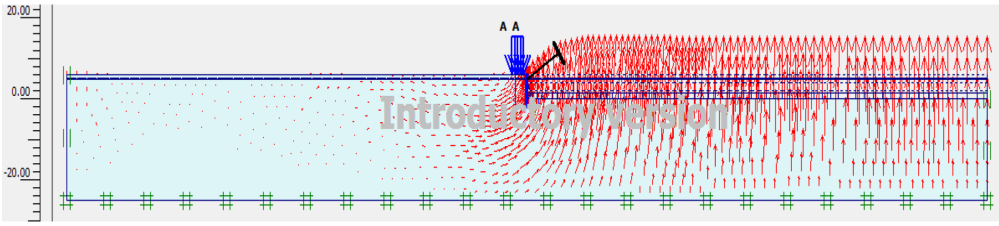

Fig. 2.4 Total Displacement at Depth (D=25m) at (H=6m & □=32°)

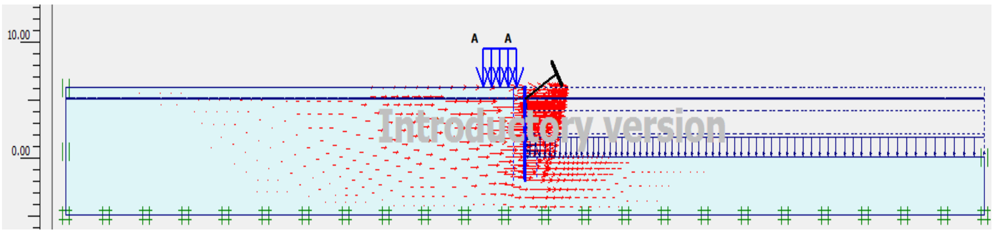

Fig. 2.5 Horizontal Displacement at Depth (D=5m) at (H=6m & □=32°)

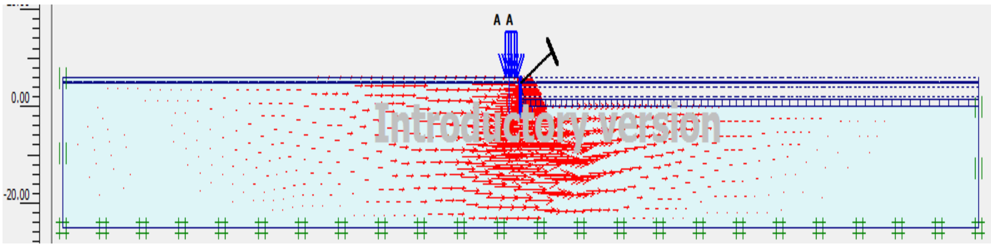

Fig. 2.6 Horizontal displacement at Depth (D=25m) at (H=6m & □=32°)

2.3 Effect of Bedrock Slope (α)

The parametric study results were also studied to investigate the effect of bedrock angle on wall behavior. A parametric study have been performed using bedrock slope ratios of +4:1, +3:1, +2:1, and +1:1 for upward slopes, horizontal, and –4:1, –3:1, –2:1, and –1:1 for downward slopes. For the notations in this thesis "+" and "–" signs indicates upward and downward slopes, respectively. The first and second numbers in the slope ratios represent the lengths in horizontal and vertical directions, respectively, along the slope. For example, "+4:1" indicates upward slope of 4 horizontal to 1 vertical. The bedrock slope angles, α, corresponding to each slope ratio are: 4:1 is 14.0°, 3:1 is 18.4°, 2:1 is 26.6°, and 1:1 is 45° as shown in figure (1.1).

2.4 Effect of Soil Strength

Additional modeling and analysis were performed using relatively stronger soils (dense soil) to investigate the effect of soil strength on the wall behavior and to study if the behavior observed for relatively less stronger soils (loose soil) under varying bedrock depths and slopes.

2.4.1 Effect of Bedrock Depth (D)

A parametric study have been investigated the anchor force for different depths for dense sand soil and loose sand soil under the wall and for different bedrock slopes (ϕ=38° & ϕ=32°).

2.5 Effect of Wall Height (H)

This modeling and analyses were performed to investigate the effect of wall height (H) on the wall behavior under varying depth to bedrock and slope conditions. The parametric study was conducted for 9 m high walls and their behavior was compared the results obtained and presented earlier for 6 m & 9m high walls under varying bedrock slopes.

2.6 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 30° inclination from the horizontal. A new set of analyses were performed by using 0° anchor inclination, i.e. horizontal anchor.

III. Result And Discussion

3.1 Effect of Boundary Conditions

The results of the analysis in term of bending moment, anchor force, and total displacement with different bedrock slopes and different bedrock depths on the wall behavior for fixed and friction boundary conditions are shown in Figures (3.1, 3.2, 3.3, 3.4, and 3.5). The anchor forces in upward and downward bedrock slopes for fixed and friction boundary conditions have similar behavior and the difference in anchor forces for fixed and friction boundary conditions ranged between 1% and 7% Figure (3.5). The wall maximum bending moments in upward and downward bedrock slopes for fixed and friction boundary conditions have also similar behavior and the difference between the fixed and friction boundary conditions is small (1% to 7%) as shown in Figure (3.4). The maximum total, horizontal, and vertical displacements in upward and downward bedrock slopes for fixed and friction boundary conditions have also similar behavior and small difference between them (1% to 4%) as presented in figures (3.1, 3.2, and 3.3). Since there are no big differences between the fixed boundary conditions and the friction boundary conditions on the wall behavior for the cases studied, the fixed boundary conditions were used for the rest of this study.

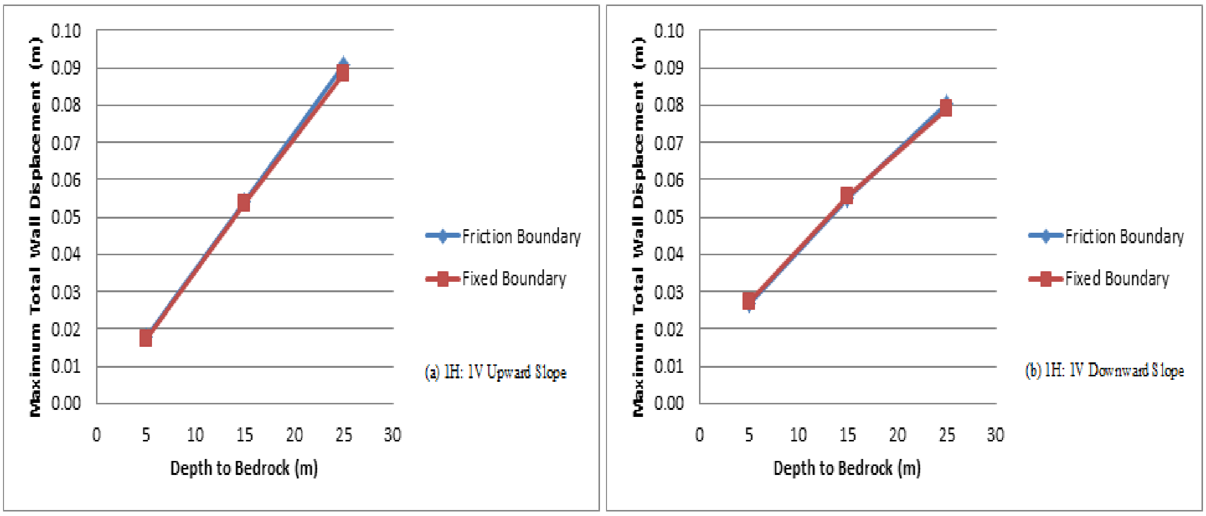

Fig. 3.1 Maximum Total Wall Displacements for Fixed and Friction Boundary Conditions

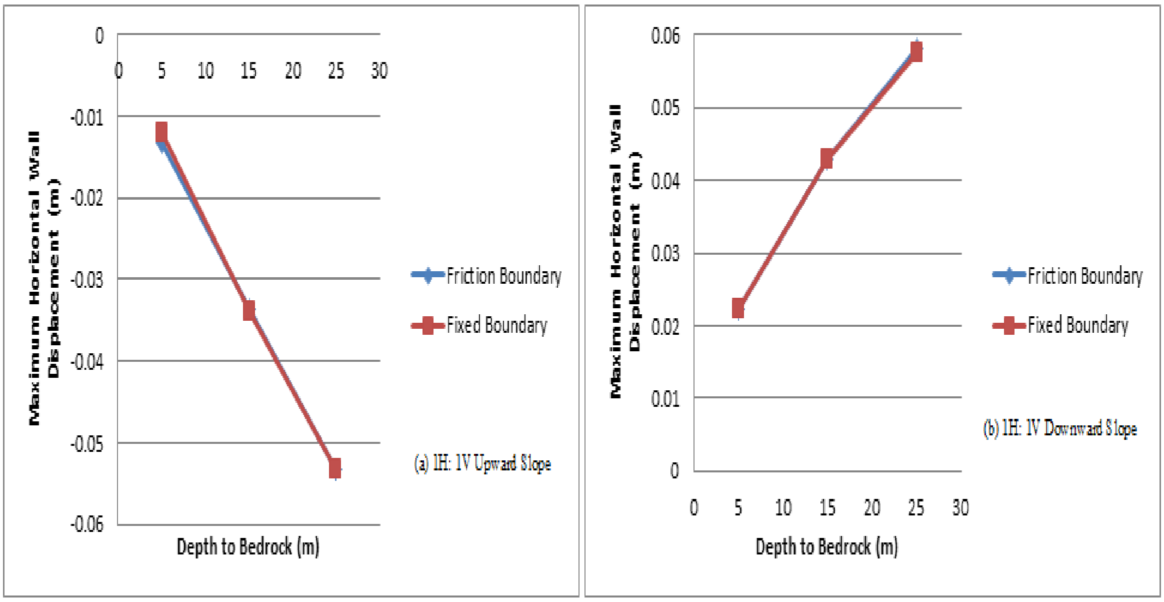

Fig. 3.2 Maximum Horizontal Wall Displacements for Fixed and Friction Boundary Conditions

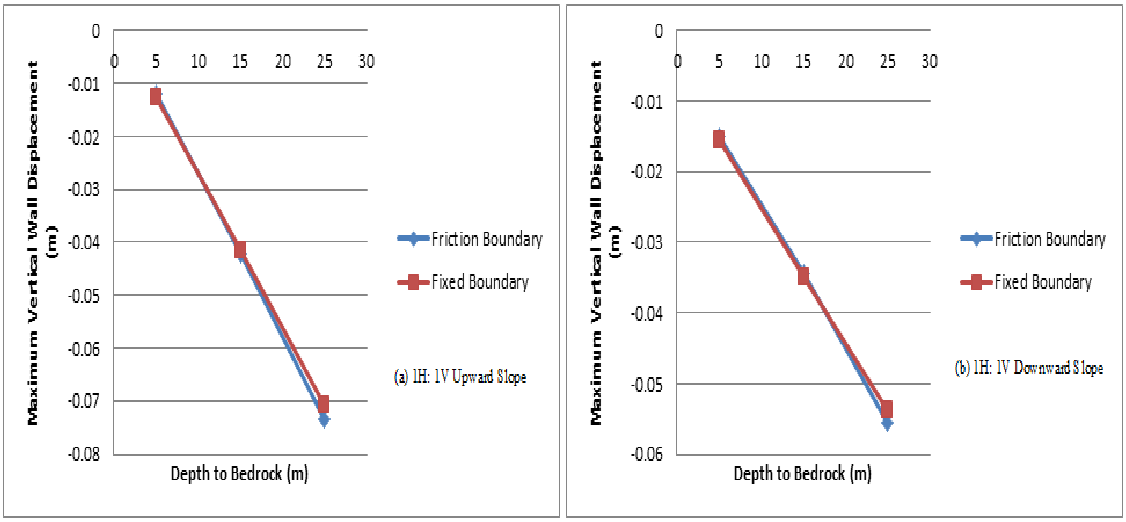

Fig. 3.3 Maximum Vertical Wall Displacements for Fixed and Friction Boundary Conditions

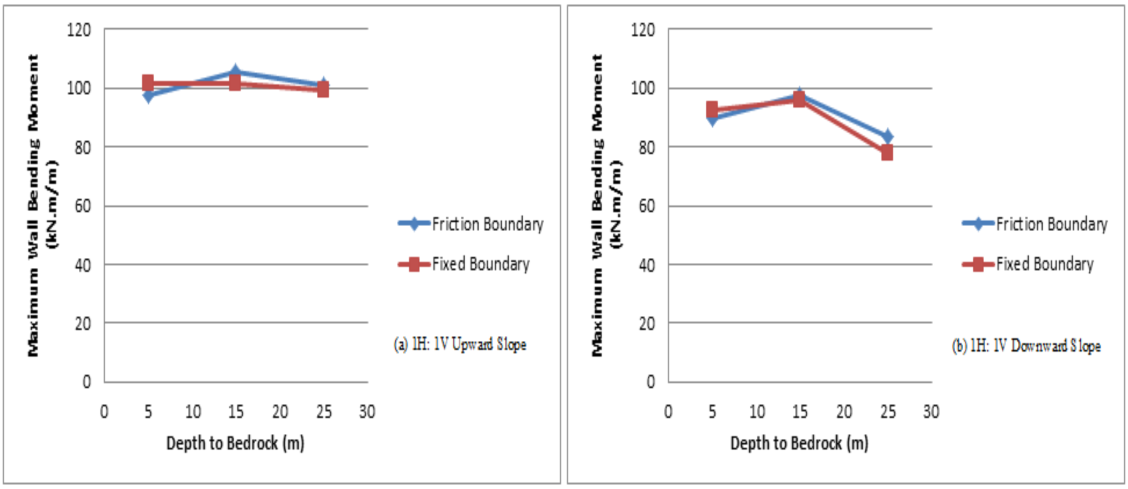

Fig. 3.4 Maximum Wall Bending Moment for Fixed and Friction Boundary Conditions

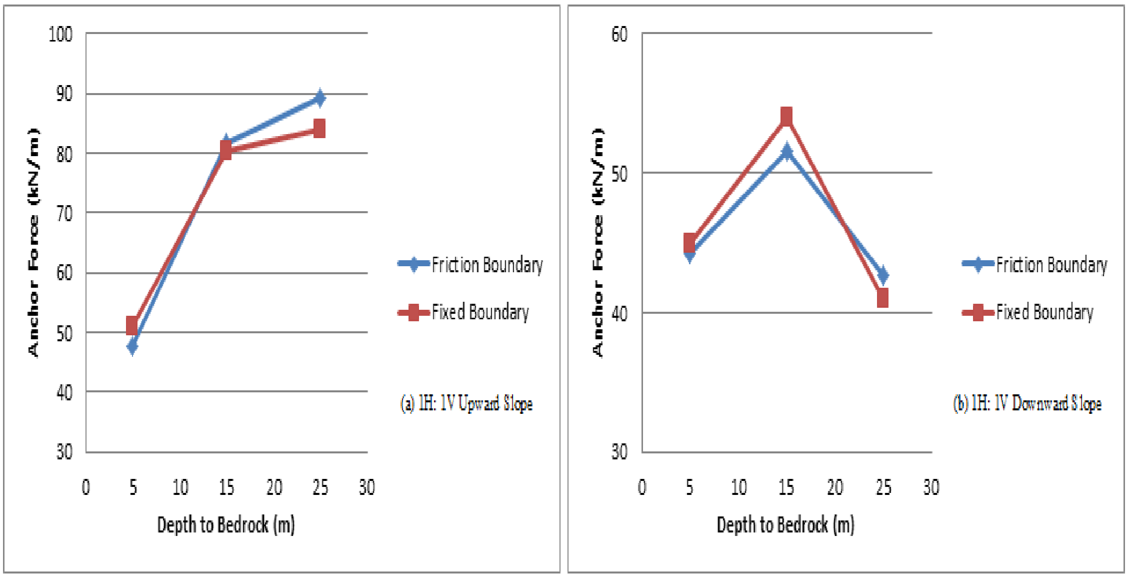

Fig. 3.5 Anchor Force for Fixed and Friction Boundary Conditions

3.2 Effects of Bedrock Depth and slope depth with using soil strength

This case was established to investigate the effect of bedrock depth (D) and slope bedrock (α) below the wall on the wall behavior by using loose sand soil (ϕ =32°) and dense sand soil (ϕ =38°). The results show that the walls in dense and loose soils have the similar behavior under varying bedrock depths conditions.

Wall Displacements: The wall displacements increase with increasing bedrock depths. The maximum vertical displacements of the wall increase as the depth to bedrock increases. This behavior was observed for all bedrock slopes; upward, horizontal, and downward. Similarly, the maximum horizontal displacement of the wall increases as the depth to bedrock increases for all cases. Although there are slight changes in the maximum total wall displacements with changing bedrock slope angles from downward towards upward slopes, the changes are minimal when the bedrock is at relatively shallow depths of 5 m and 15 m. While the bedrock slope angle changes from −1:1 slope to +1:1 slope, the total maximum wall displacements increase 33% and decreases 33% for 25 m and 50 m bedrock depths, respectively. The wall moves downward when the bedrock is 5 m depth for all bedrock slopes and when the bedrock is at 15 m and the bedrock slopes upward. The vertical displacements fluctuate slightly for the downward slopes, however they decrease (or move downward) significantly when the upward slope increases and depth to bedrock is relatively deep.

Bending Moments: The wall maximum bending moments increase with increasing bedrock depths. The effect of bedrock depth is more significant when the bedrock slopes have relatively low angled slopes. As the bedrock slopes increases, the bedrock depth on the wall bending moments has lesser effect. The analysis results show that the bedrock slope angle affects the wall bending moments. Although there is some fluctuations in the maximum wall bending moments within the slope ranges considered there is not an obvious trend observed for the bedrock depths considered, except for 50 m case. For this case, the results show that the bending moments are highest when the bedrock is horizontal and the moments decrease as the bedrock slope increases, either upward or downward. The ±1:1 cases have 22% less moments compared to horizontal bedrock case.

Anchor Force: The results show that depth to bedrock below the wall has a significant effect on anchor forces. The anchor force, independent of bedrock slope, increases with increasing bedrock depths. There is a trend of slight increase in anchor force for almost all cases as the bedrock slope changes from maximum downward slope of −1:1 towards maximum upward slope of +1:1. The only exception to this trend is when the depth to bedrock is deep, i.e. 50 m. As the bedrock slope changes from downward slope of −1:1 to maximum upward slope of +1:1 the anchor force increases significantly and then suddenly drops when there is more than 3:1 upward slope There are two components forces affected on the anchor (vertical and horizontal forces) that increased anchor force with different bedrock slopes in upward slopes. Also the soil strength has an influence on the wall behavior for varying bedrock depths and slopes.

Table (4): Maximum Total Wall Displacement for Varying Depths and Slopes

Depth (m)	Maximum Total Wall Displacement (m) at (ϕ =38°)								
	+(1:1)	**+(2:1)**	**+(3:1)**	**+(4:1)**	**Hori. Slope**	**-(1:4)**	**-(1:3)**	**-(1:2)**	**-(1:1)**
5	0.0039	0.0039	0.0036	0.0036	0.0037	0.0026	0.0027	0.0025	0.0028
15	0.0041	0.0039	0.0034	0.0033	0.0025	0.0018	0.0017	0.0014	0.0013
25	0.0038	0.0048	0.0058	0.0052	0.0044	0.0051	0.0051	0.0051	0.0048
50	0.0104	0.013	0.014	0.014	0.0139	0.0165	0.016	0.0170	0.0167

Table (5): Maximum Horizontal Wall Displacement for Varying Depths and Slopes

Depth (m)	Maximum Horizontal Wall Displacement (m) at (ϕ =38°)								
	+(1:1)	**+(2:1)**	**+(3:1)**	**+(4:1)**	**Hori. Slope**	**-(1:4)**	**-(1:3)**	**-(1:2)**	**-(1:1)**
5	0.0034	0.0035	0.0033	0.0033	0.0033	0.0024	0.0024	0.0023	0.0024
15	0.0038	0.0038	0.0034	0.0033	0.0024	0.0011	0.0008	0.0006	0.0012
25	0.0037	0.0039	0.0040	0.0037	0.0026	-0.0010	-0.0012	-0.0014	-0.0018
50	0.0041	0.0053	0.0053	0.0049	-0.0026	-0.0060	-0.0068	-0.0074	-0.0074

Table (6): Maximum Vertical Wall Displacement for Varying Depths and Slopes

Depth (m)	Maximum Vertical Wall Displacement (m) at (□ =38°)								
	+(1:1)	**+(2:1)**	**+(3:1)**	**+(4:1)**	**Hori. Slope**	**-(1:4)**	**-(1:3)**	**-(1:2)**	**-(1:1)**
5	-0.0018	-0.0012	-0.0014	-0.0013	-0.0017	-0.0010	-0.0010	-0.0011	-0.0013
15	-0.0016	-0.0009	-0.0002	-0.0001	0.00063	0.0010	0.0010	0.0014	0.0005
25	0.0011	0.0028	0.0041	0.0036	0.0036	0.0050	0.0050	0.0050	0.0045
50	0.0096	0.0123	0.0133	0.0137	0.0137	0.0150	0.0150	0.0154	0.0150

Table (7): Maximum Wall Bending Moment for Varying Depths and Slopes

Depth (m)	Maximum Wall Bending Moment (kN.m/m) at (□ =38°)								
	+(1:1)	**+(2:1)**	**+(3:1)**	**+(4:1)**	**Hori. Slope**	**-(1:4)**	**-(1:3)**	**-(1:2)**	**-(1:1)**
5	60.33	58.55	58.95	54.98	58.34	47.25	47.87	47.10	47.52
15	65.31	61.45	57.43	56.32	51.54	52.56	52.99	51.10	49.28
25	60.29	54.30	57.91	61.74	60.48	61.71	59.54	57.47	53.93
50	67.54	76.97	79.55	81.05	80.96	80.08	73.13	68.03	60.57

Table (8): Anchor Force for Varying Depths and Slopes

Depth (m)	Anchor Force (kN/m) at (□ =38°)								
	+(1:1)	**+(2:1)**	**+(3:1)**	**+(4:1)**	**Hori. Slope**	**-(1:4)**	**-(1:3)**	**-(1:2)**	**-(1:1)**
5	34.39	33.50	33.42	33.97	33.86	29.92	29.89	29.59	30.47
15	37.68	37.04	35.65	34.82	30.88	29.97	29.85	29.21	29.50
25	38.88	39.50	42.27	41.29	37.18	33.93	32.66	31.35	30.00
50	51.60	66.51	68.53	67.77	57.84	43.24	39.19	35.19	32.18

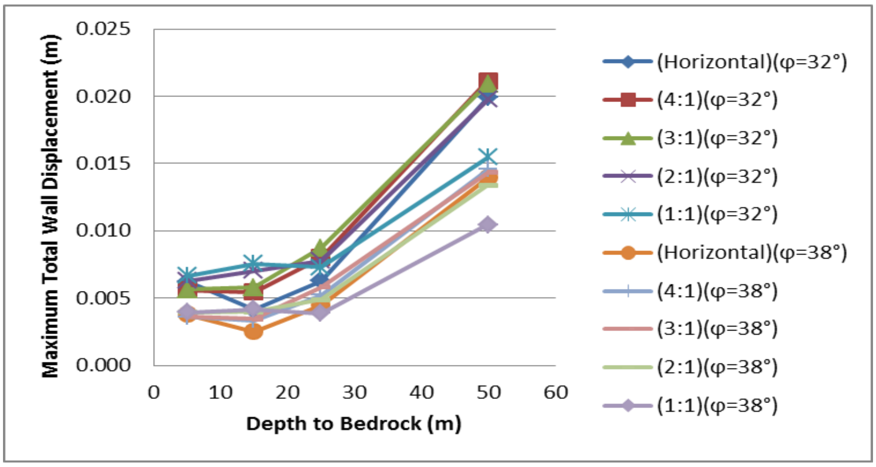

Fig. 3.6 Effect of Soil Strength on Maximum Total Wall Displacements (Upward Slope)

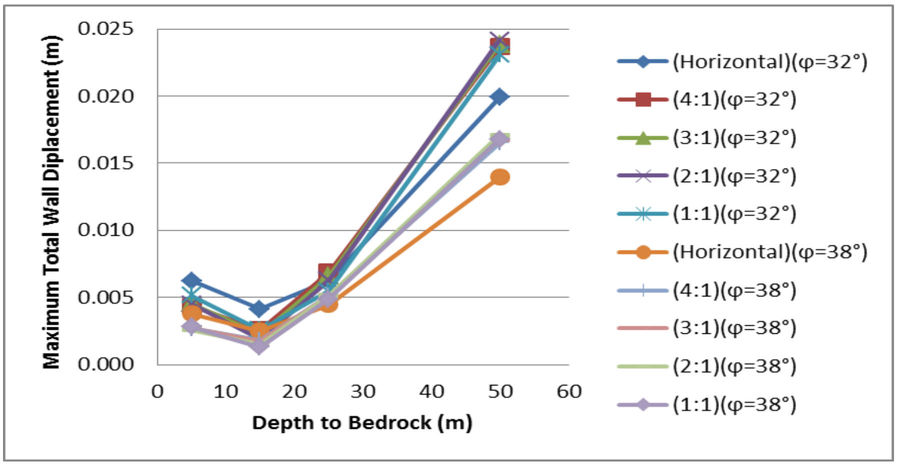

Fig. 3.7 Effect of Soil Strength on Maximum Total Wall Displacements (Downward Slope)

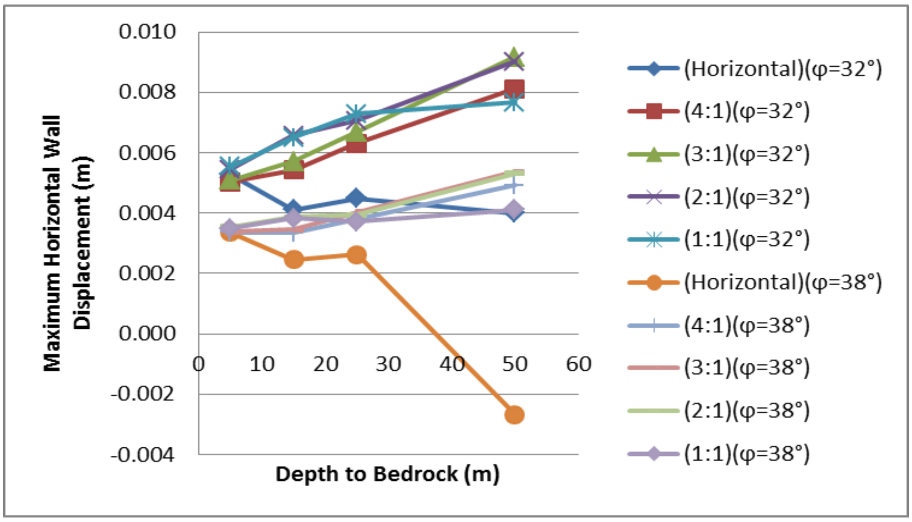

Fig. 3.8 Effect of Soil Strength on Maximum Horizontal Wall Displacements (Upward Slope)

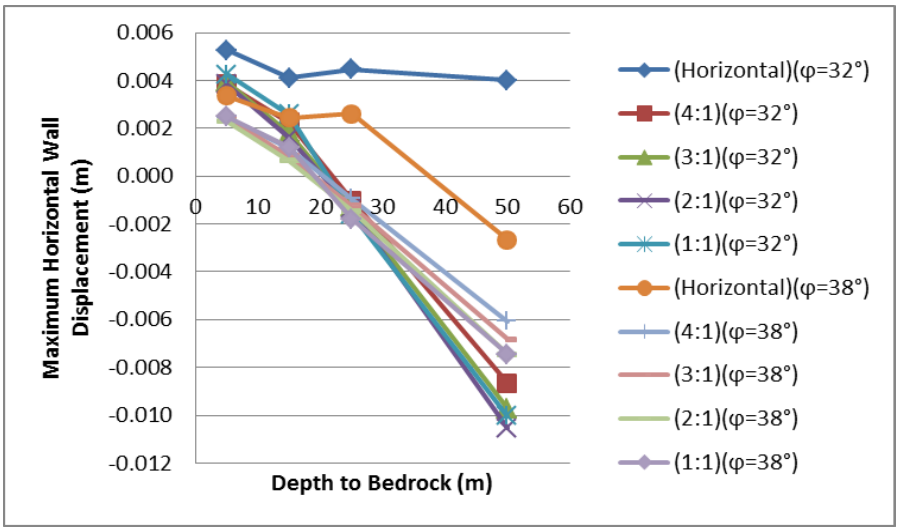

Fig. 3.9 Effect of Soil Strength on Maximum Horizontal Wall Displacements (Downward Slope)

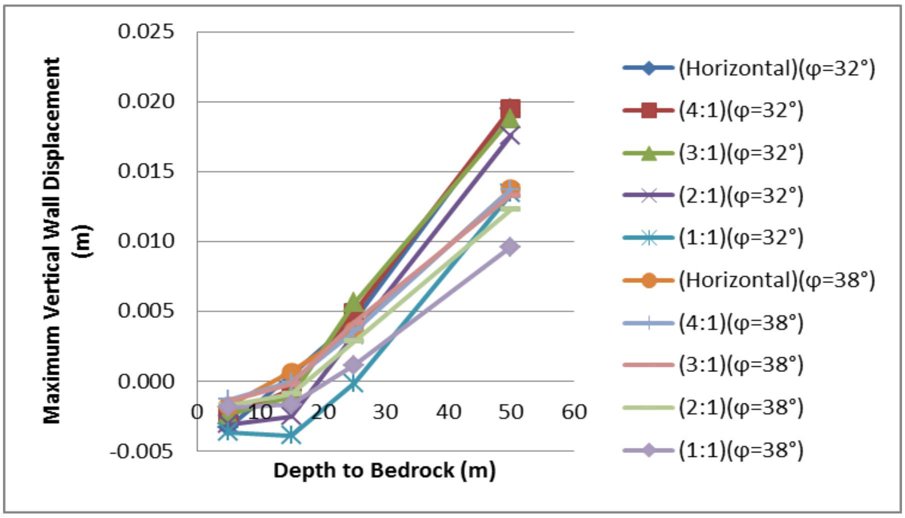

Fig. 3.10 Effect of Soil Strength on Maximum Vertical Wall Displacements (Upward Slope)

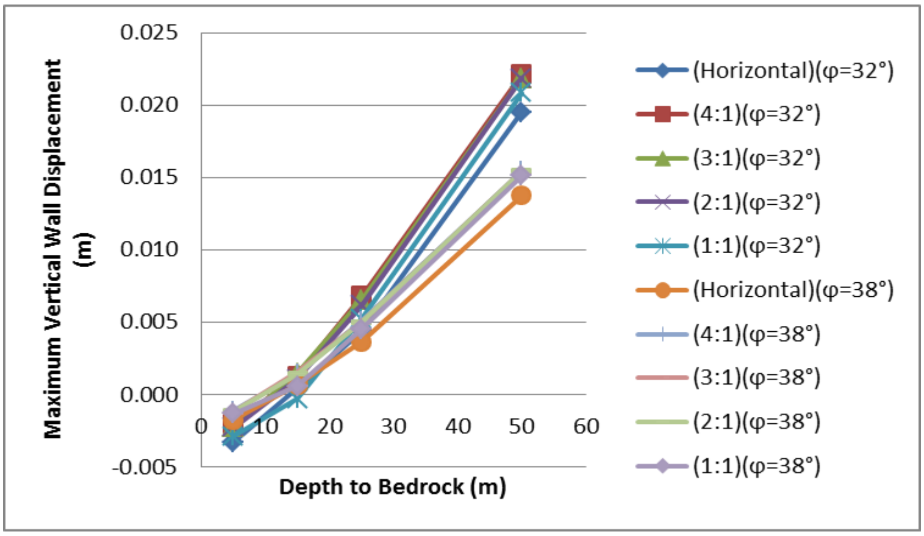

Fig. 3.11 Effect of Soil Strength on Maximum Vertical Wall Displacements (Downward Slope)

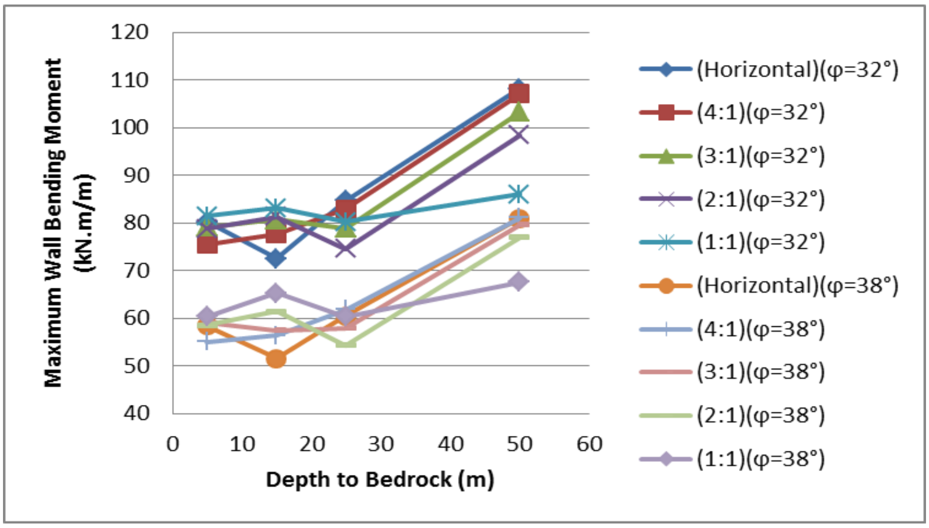

Fig. 3.12 Effect of Soil Strength on Maximum Wall Bending Moment (Upward Slope)

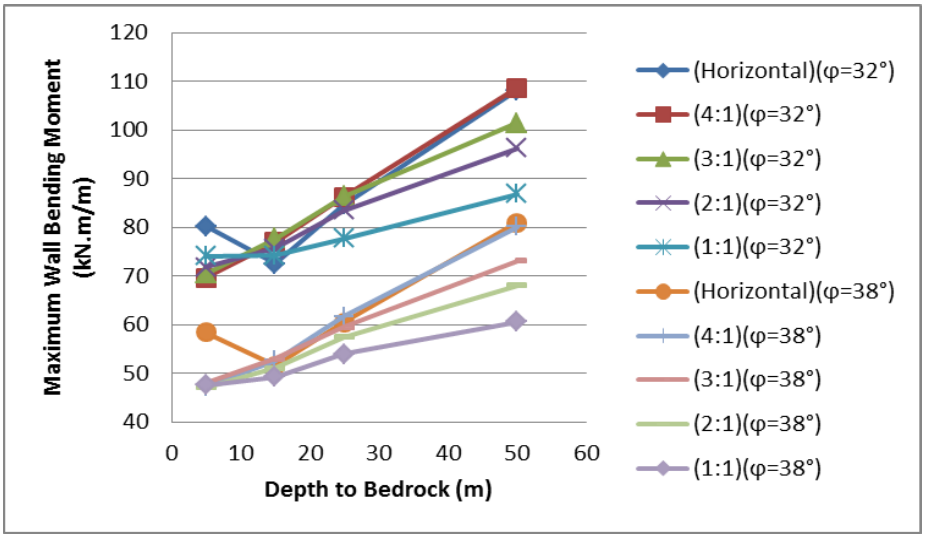

Fig. 3.13 Effect of Soil Strength on Maximum Wall Bending Moment (Downward Slope)

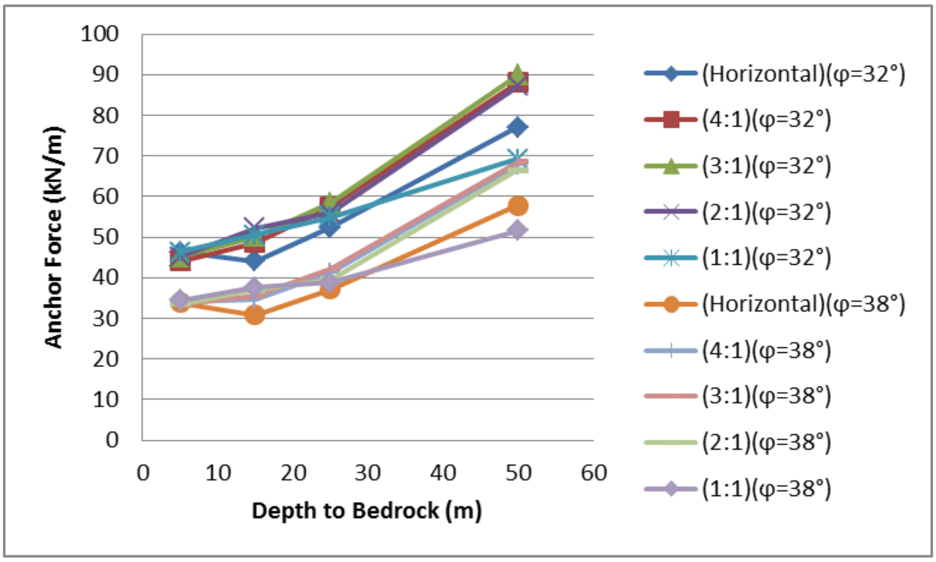

Fig. 3.14 Effect of Soil Strength on Anchor Force (Upward Slope)

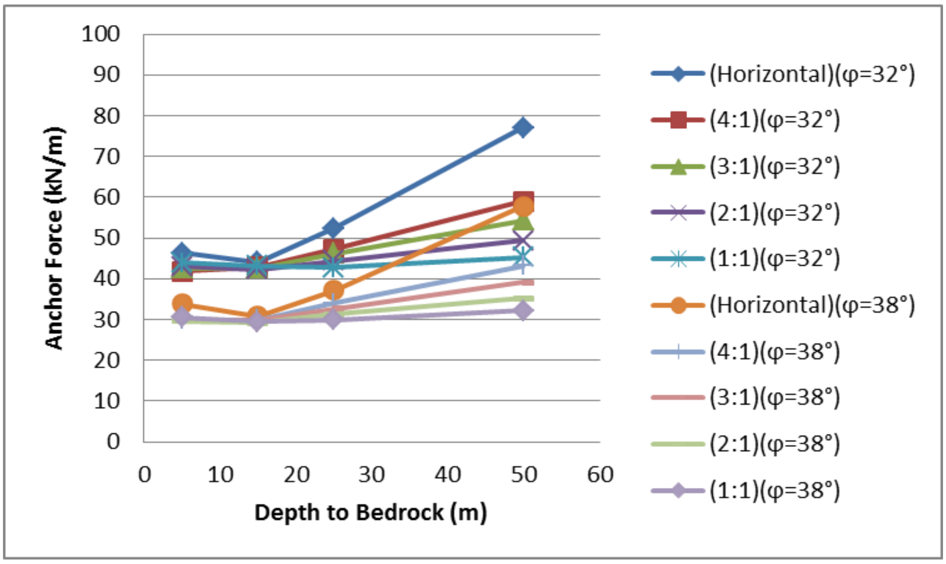

Figure 3.15 Effect of Soil Strength on A nchor Force (Downward Slope)

3.3 EFFECT OF WALL HEIGHT (H)

The parametric study was conducted for 9 m high walls and their behavior was compared the results obtained and presented earlier for 6 m high walls. . The analysis results in terms of bending moment, anchor force, and displacements are analyzed for different bedrock slopes. The results show that the walls in dense and loose soils have the similar behavior under varying bedrock slope conditions. All the results presented for the maximum total wall displacements, for the maximum horizontal wall displacements, for the maximum vertical wall displacements, maximum wall bending moments, and anchor force show that 9 m high walls result in higher displacements, bending moments, and anchor forces compared to 6 m high walls, as expected. However, the effect of bedrock slope angle is pretty similar for both wall heights, indicated by the same trends but with vertical shifts, i.e. increase in values.

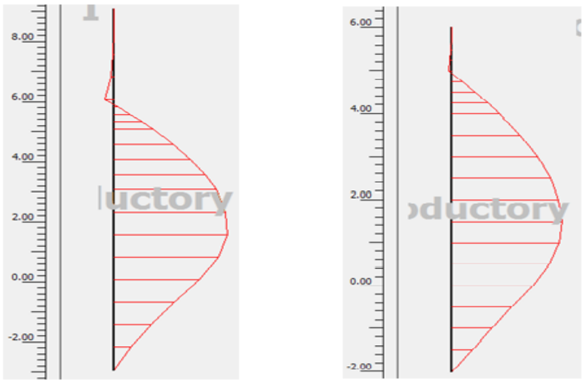

Fig. 3.16 Wall Bending Moments for Upward Bedrock Slope (3:1) at (H=9m & 6 m, □=32°)

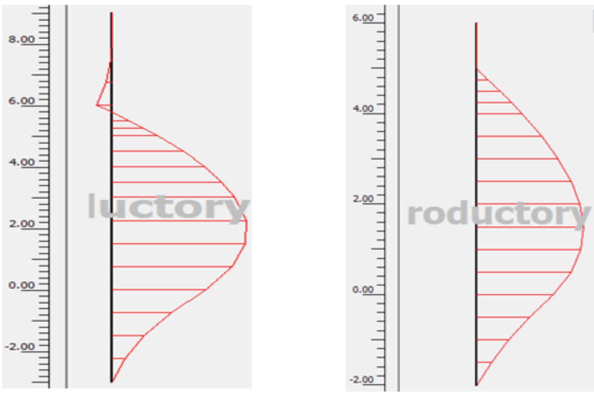

Fig. 3.17 Wall Bending Moments for Downward Bedrock Slope (3:1) at (H=9m & 6 m, □=32°)

Table (9): Maximum Total Wall Displacement for Diff. Wall Heights (H=6m & 9m)

Slope (□)	Maximum Total Wall Displacement (m)			
	Ratio	**Wall Height 9m**	**Wall Height 6m**	**Ratio (Wall Height)**
-45	- (1:1)	0.0122	0.0026	4.69
-27	- (2:1)	0.0099	0.0019	5.21
-18.5	- (3:1)	0.0102	0.0022	4.63
-14	- (4:1)	0.0113	0.0025	4.52
0	0	0.0139	0.0041	3.39
14	(4:1)	0.0178	0.0054	3.29
18.5	(3:1)	0.0203	0.0058	3.50
27	(2:1)	0.0193	0.0070	2.75
45	(1:1)	0.0243	0.0075	3.24

Table (10) : Maximum Hori. Wall Displacement for Diff. Wall Heights (H=6m & 9m)

Slope (α)	Maximum Horizontal Wall Displacement (m)			
	Ratio	**Wall Height 9m**	**Wall Height 6m**	**Ratio (Wall Height)**
-45	- (1:1)	0.0120	0.0025	4.80
-27	- (2:1)	0.0098	0.0016	6.13
-18.5	- (3:1)	0.0102	0.0018	5.67
-14	- (4:1)	0.0114	0.0022	5.18
0	0	0.0135	0.0041	3.29
14	(4:1)	0.0178	0.0054	3.29
18.5	(3:1)	0.0199	0.0057	3.49
27	(2:1)	0.0191	0.0065	2.93
45	(1:1)	0.0227	0.0064	3.54

Table (11): Maximum Vertical Wall Displacement for Diff. Wall Heights (H=6m & 9m)

Slope (α)	Maximum Vertical Wall Displacement (m)			
	Ratio	**Wall Height 9m**	**Wall Height 6m**	**Ratio (Wall Height)**
-45	- (1:1)	-0.0023	-0.0003	7.67
-27	- (2:1)	0.0006	0.0010	1.67
-18.5	- (3:1)	0.0010	0.0014	1.40
-14	- (4:1)	0.0001	0.0013	13.00
0	0	-0.0005	0.0004	1.25
14	(4:1)	-0.0017	-0.0006	2.83
18.5	(3:1)	-0.0041	-0.0010	4.10
27	(2:1)	-0.0029	-0.0025	1.16
45	(1:1)	-0.0087	-0.0039	2.23

Table (12): Maximum Wall Bending Moment for Different Wall Heights (H=6m & 9m)

Slope (□)	**Maximum Wall Bending Moment (kN.m/m)**			
	Ratio	**Wall Height 9m**	**Wall Height 6m**	**Ratio (Wall Height)**
-45	- (1:1)	176.70	74.15	2.38
-27	- (2:1)	162.19	75.62	2.14
-18.5	- (3:1)	158.04	77.63	2.04
-14	- (4:1)	158.28	76.90	2.05
0	0	170.80	72.52	2.36
14	(4:1)	180.28	77.66	2.32
18.5	(3:1)	200.44	80.75	2.48
27	(2:1)	190.08	81.25	2.34
45	(1:1)	198.94	83.07	2.39

Table (13): Anchor Force for Different Wall Heights (H=6m & 9m)

Slope (□)	**Anchor Force (kN/m)**			
	Ratio	**Wall Height 9m**	**Wall Height 6m**	**Ratio (Wall Height)**
-45	- (1:1)	119.70	43.17	2.77
-27	- (2:1)	115.20	42.23	2.73
-18.5	- (3:1)	114.90	42.64	2.69
-14	- (4:1)	115.30	42.87	2.69
0	0	121.40	44.02	2.56
14	(4:1)	123.80	48.65	2.54
18.5	(3:1)	129.60	50.12	2.58
27	(2:1)	128.40	52.19	2.46
45	(1:1)	133.70	50.49	2.65

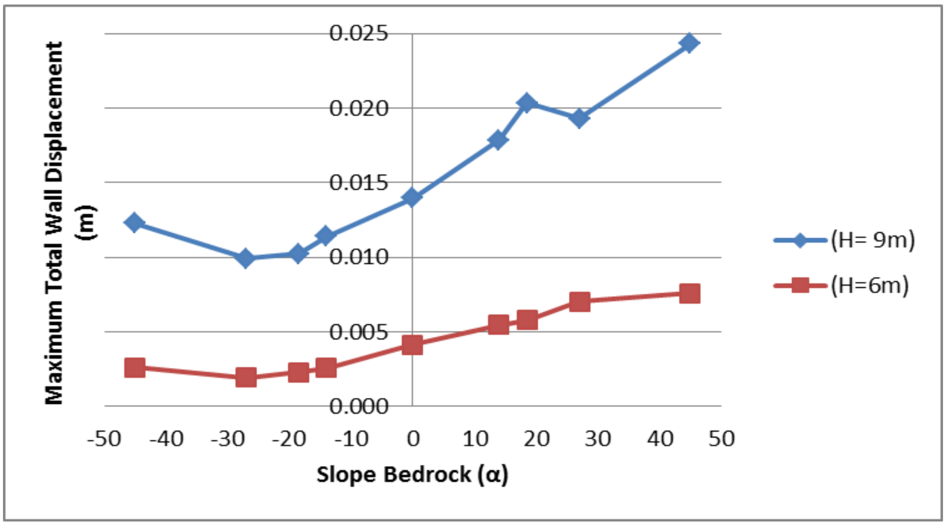

Fig. 3.18 Maximum Total Wall Displacements at Upward and Downward Bedrock Slopes at (H=6 & 9 m, □=32°)

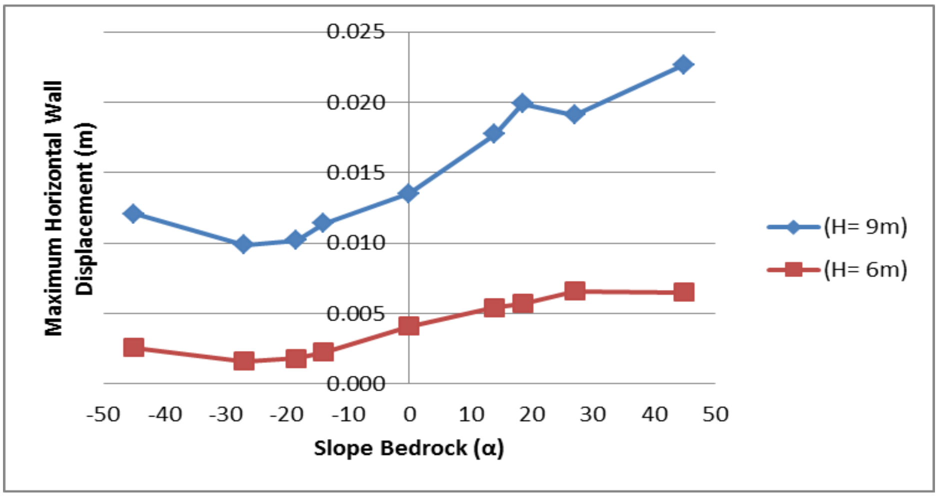

Fig. 3.19 Maximum Horizontal Wall Displacements at Upward and Downward Bedrock Slopes at (H=6 & 9 m, □=32°)

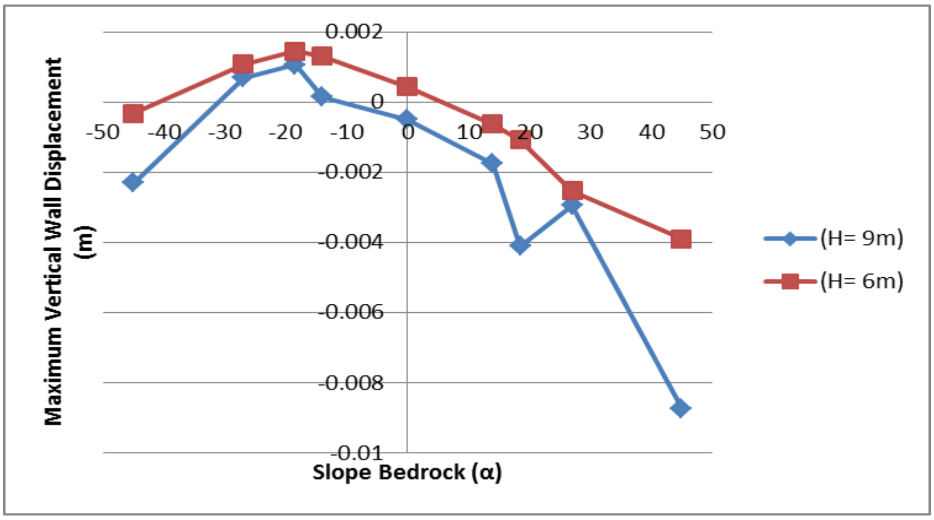

Fig. 3.20 Maximum Vertical Wall Displacements at Upward and Downward Bedrock Slopes at (H=6 & 9 m, □=32°)

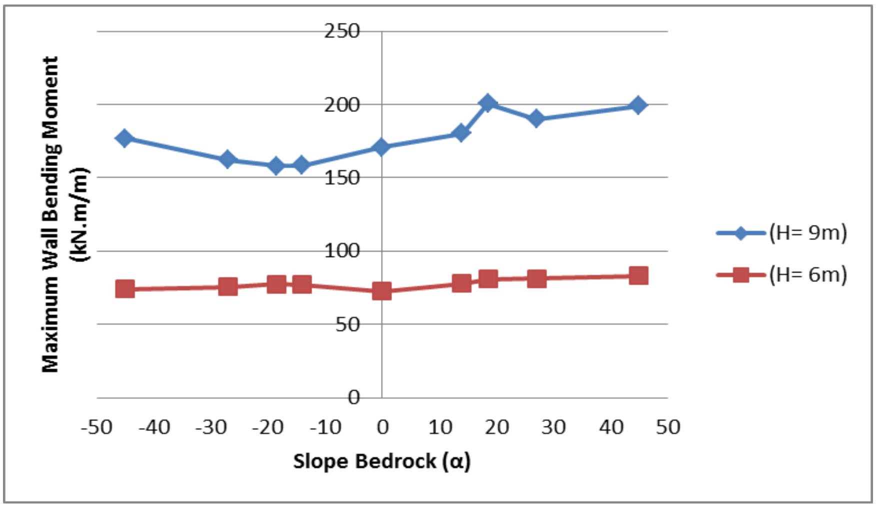

Fig. 3.21 Maximum Wall Bending Moment at Upward and Downward Bedrock Slopes at (H=6 & 9 m, □=32°)

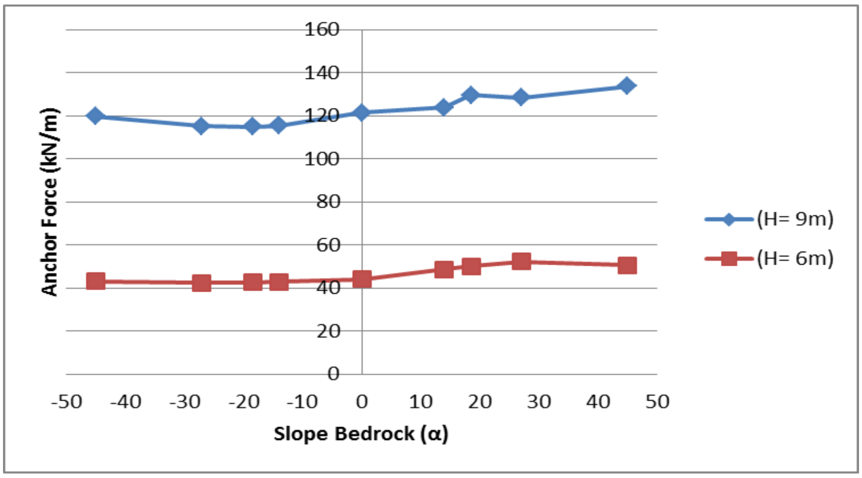

Fig. 3.22 Anchor Force at Upward and Downward Bedrock Slopes at (H=6 & 9 m, □=32°)

3.4 EFFECT OF ANCHOR ANGLE (□)

The results show that the anchor inclination angle of 30° has affected the anchor forces by up to 20%, maximum total wall displacements by up to 48%, maximum wall bending moments by up to 10%, maximum vertical wall deformations by up to 300%, and maximum horizontal wall deformations by up to 160%. As indicated the anchor inclination has the most effect on maximum vertical and horizontal wall deformations because of the different vertical and horizontal components of the anchor for varying anchor inclination angles.

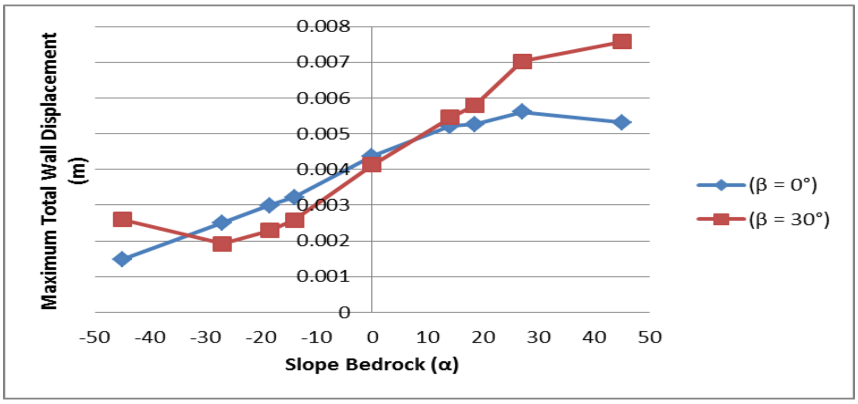

Fig. 3.23 Maximum Total Wall Displacements at Upward and Downward Bedrock Slopes at (H=6m, □=32°)

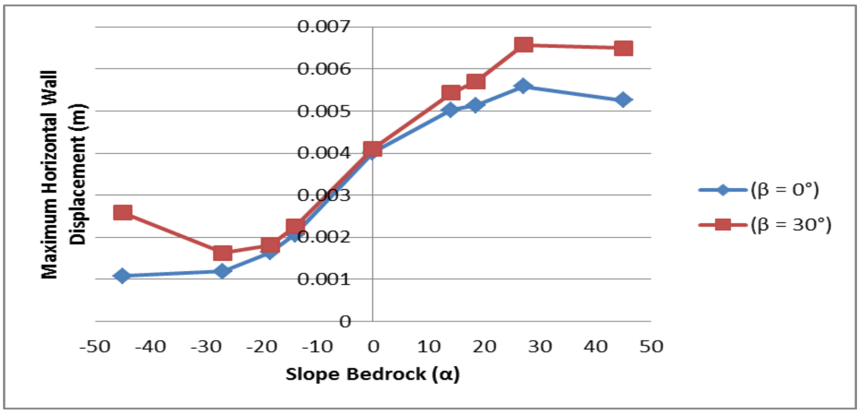

Fig. 3.24 Maximum Horizontal Wall Displacements at Upward and Downward Bedrock Slopes at (H=6m, □=32°)

IV. Conclusion

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. The bedrock depth under the wall has significant effect on the wall behavior. As when the depth increases, the anchor forces, the total displacements, vertical displacements, and bending moments increase for horizontal slope, upward and downward. In addition, the horizontal displacements increase in upward slopes but they decrease in downward slopes.
2. The bedrock slope has significant effects on the wall behavior. As the bedrock slope increases in upward direction, the anchor force, total wall displacements, horizontal wall displacements, and wall bending moments also increase. On the other hand, the vertical wall displacements decrease for increasing upward sloping bedrock conditions. The maximum wall bending moments and vertical displacements in downward slopes increase, but after 25 m moments and vertical displacements decrease. The anchor force for 50 m bedrock depth decreases in upward and downward bedrock slopes. The anchor force, total maximum wall displacements, and maximum horizontal wall displacements also decrease in downward bedrock slopes.
3. Soil strength has an influence on the wall behavior for varying bedrock depths and slopes. Similar wall behavior under varying bedrock depths and slopes were observed for both soil strengths considered.
4. Wall height has a significant effect on the anchor forces, maximum wall bending moments and maximum total wall displacements. However, wall height does not affect the influence of bedrock depth and slope on the wall behavior. Similar wall behavior under varying bedrock depths and slopes were observed for both wall heights considered.
5. The anchor installation angle may have a significant effect on wall deformations. Although similar trends are observed for anchor forces and bending moments for the two anchor angles analyzed and for varying bedrock slopes, for the displacement trends were not similar for the horizontal and inclined anchors.

References

[1] Briaud, Jean Louis, and Kim, Nak-Kyung 1998. "Journal of geotechnical and geoenvironmental engineering." Associate Member, ASCE.
[2] Marr, W.A., and Christian, J.T. 1981 "Permanent displacements due to cyclic wave loading." Journal of the Geotechnical Engineering Division, ASCE 107 (GT8).
[3] Ömer Bilgin 2009. "Effect of subsurface soil conditions on floodwall behavior." IFCEE Conference, Florida.
[4] SEI/ASCE Technical Committee on Performance of Structures During Construction 2000. "Effective analysis of diaphragm walls." Structural Engineering Institute.
[5] Smoltczyk, Ulrich 2003. "Geotechnical engineering handbook." Ernst and Sohn A Wiley Company.
[6] Terzaghi, K. and Peck, R.B 1967. "Soil mechanics in engineering pracice." Wiley, New York.
[7] Tsinker, Gregory P. 2004. "Planning construction, maintenance, and security." Wiley and Sons, Inc.
[8] Waterman, Dennis 2006. "Structural elements in PLAXIS." CG1 Chile.
[9] Woodward, John 2005. "An Introduction to geotechnical processes." Spon Press in the USA and Canada.
[10] Weber, Richard P. 2010. "Earth pressure and retaining wall basics." PDF Course, 2010.
[11] Peck,R.B., 1969, "Deep excavations and tunneling in soft ground." Proc., 7th Int. Conf. Soil Mech. Found. Engrg.
[12] PLAXIS 2D 2002.www.thepiratebay.se/torrent/plaxis-professional8.2, "PLAXIS civil engineering geotechnical CAD." Version 8.
[13] PLAXIS 2D 2011. "Essential for geotechnical professionals." Tutorial Manual.
[14] Sabatini, P.J., Pass, D.G., and Bachus, R.C. 1999. "Geotechnical engineering circular No.4 ground anchors and anchored systems." U.S. Department of Transportation-Federal Highway Administration.
[15] Sarsby, Robert 2000. "Environmental geotechnics." Thomas Telford Publishing, London.

[16] National Cooperative Highway Research 2008. “Seismic analysis and design of retaining walls, buried structures, slopes, and embankments.” Transportation Research Board, Washington, DC.
[17] Hsai, Yang Fang. 2002. “Foundation engineering handbook-Second Edition.” Van Nostand Reinhold.
[18] Geotechnical Engineering Bureau 2007. “Geotechnical design procedure for flexible wall systems.” State of New York Department of Transportation.
[19] Hoe, NG. 2007. “Numerical modeling of diaphragm wall in kuala lumpur limestone formation.” Faculty of Civil Engineering, University Teknology: Malaysia.
[20] Dawkins, William P. 2001. “Investigation of wall friction, surcharge loads, and moment reduction curves for anchored sheet-pile walls.” US Army Corps of Engineering, Engineer Research and Development Center.
[21] Erqgun, M. Ufuk 2008 “Deep excavations; retaining wall; earth pressure.” Department of Civil Engineering, Middle East Technical University, Ankara, Turkey.
[22] Excavation Pits-Sructure solutions 2010. www.bauer.de/en/bst/structure-solutions. BAUER Aktiengesellschaft.
[23] Foundation Piling LTD 2011. www.retaining wall-solution.com/anchored-solutins.html. “Retaining wall solutions.” Technical Office in Thornburg, Bristol.
[24] Bzchy.Soletanche.2012.www.bacsol.co.uk/index.php/techniques/diaphragm-walls. “Diaphragm walls.”
[25] California Dot 2004.www.dot.ca.gov/hq/esc/techpubs/manual. “Retaining walls design.” Bridge Design Specifications.
[26] Bear Creek Dam, Russellville 2012. www.moretrench.com/services-article.php/structural-excavation. “Strut Anchor.” Article Php.