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Studying the behavior of different parameters on inclined anchors

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Abstract— Sheet pile wall system is considered one of the oldest common earth retention systems used in civil engineering projects. The common methods used in the design of sheet pile walls were based on the limit equilibrium approach using active and passive earth pressures. These methods - based on force and moment equilibrium- don't consider wall deformations, which are very important for achieving serviceability. An extensive parametric study was made through the finite element program, PLAXIS version 8.6 to investigate the behavior of inclined anchored sheet pile walls, studying the effect of changing wall penetration depth, and inclination of ground surface for different sand soil types, effect of ground water table and number of anchors on wall. to show the effect on horizontal wall displacements, anchor force and maximum wall bending moments for all cases. The minimum set of values of the wall penetration depth, unbonded length and bonded length satisfied the requirements of the instructions of (FHWA). Analyses were performed using the finite element method. The analysis results show that for penetration depth it was found that the maximum bending moment decreases significantly with the increase of penetration depth. And the anchor force decreases with the increase of wall penetration depth. Also, the horizontal displacement decreases slightly with the increase of penetration depth. On adding two rows of anchor, a significant reduction in maximum wall bending moment is noticed with a percent more than 55%, 45% and 38% for dense, medium and loose sand respectively. For ground surface inclination it was found that the maximum horizontal displacement, maximum bending moment and anchor force increase with the increase in ground surface inclination. On adding another row, the maximum bending moment is reduced by 48%, 43% and 37% for dense sand, medium sand and loose sand respectively. On taking ground water table in consideration for both sides, the maximum bending moments are reduced by 29%, 30% and 39% for dense sand, medium sand and loose sand respectively. Also, anchor forces are reduced by 24%, 25% and 34% for dense sand, medium sand and loose sand respectively.

Index Terms— sheet pile wall, pentraton depth, ground wather table, tie inclination, soil type, wall height, unbonded length, bonded length

1 Introduction

Many authors in the literature have attempted to predict and analyze load carrying capacity of different retaining walls types. Some authors take into account the ability of sheet piles to deform considering the wall to be a flexible structure (Sahajda and Rymsza, 2008; McNab, 2002; Cherubini, 2000; Endley et al., 2000; and Valsangkar Schriver and, 1996).

Others used the finite element technique in their analysis to investigate the behavior and failure mechanisms of the structure (Bilgin (2009), Warrington and Don, 2007; Krabbenhoft et al., 2005; Damkilde and Krabbenhoft, 2003; Sloan and Lyamin, 2002 and Lim and Briaud, 1999).

Sheet pile walls are used for many different purposes; such as excavation support system, slope stabilization, cofferdams, and cut-off walls under dams, waterfront structures, and floodwalls. Although there are several other materials (such as reinforced concrete, timber, and plastics) used for sheet piles, steel sheet piles are the most common in retaining walls.

The sheet pile walls can be either cantilever or anchored depending on the wall height. While relatively shorter sheet pile walls can be cantilever while higher walls require anchors. The selection of wall type, either cantilever or anchored, is based on the function of wall, the characteristics of foundation soils, and the proximity of wall to existing structures, Bilgin (2009)

The objective of this study was to investigate the maximum horizontal wall displacement, maximum wall bending moment and anchor force for two main cases, the first parameter studies the change in wall penetration depth for [loose sand (LS), medium dense sand(MS) and dense sand(DS)] for wall heights 8m. additional analysis were performed by adding two rows of anchors for the same types of soil used before. And then comparing these results to that of one row of anchor.

Additional modeling and analysis were performed to investigate the effect of adding water table to the same types of soil at the anchor level on both sides. The second parameter studies the change of inclination of ground surface for the same previous cases

2 NUMERICAL MODELING AND ANALYSES

2.1 Geometry and Material Properties

A parametric study was made to investigate the effect of wall penetration depth on wall behavior for different soil conditions. Anchored sheet pile wall was studied for this parametric study. Each model has one soil layer for the entire model. Also, the groundwater table level was assumed to be at the lower line for PLAXIS MODEL in order to use dry soils that means that no excess pore water pressures are generated for all anchored sheet pile wall cases, the anchor location was assumed to be at the anchor level at 2.0 m from ground surface. The inclination of anchor is set to 20 degrees from the horizontal line for all cases known that the unbonded length is 8m and the bonded length is 7 m. in case of adding another row of anchor, the second row is 2 m below the 1st row. The soil properties used for the analyses are listed in Table 1. Three different soil types considered were dense sand (DS), medium dense sand (MS), loose sand (LS). The cases were identified with a number followed by a two-letter code. The number refers to the wall height and two-letter code indicates the soil type as given in the parentheses above. The interface elements were introduced for the considered soils to simulate the soil-structure interaction behavior so as to predict the wall behavior more accurately. Drained soil conditions were analyzed for sand soils. The material data used for sheet pile, anchors, grouted body are listed in tables 2, 3 and 4

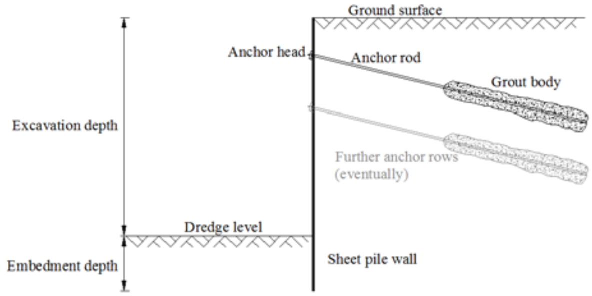

Figure. 1. Typical soil and wall profile used in parametric study

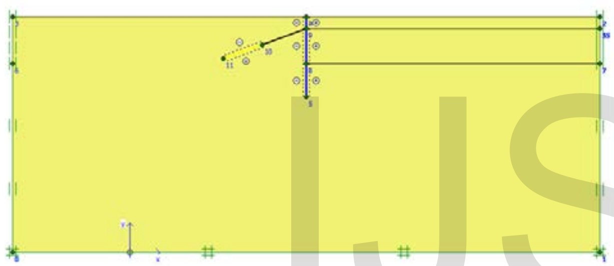

Figure 2 Schematic of Anchored Sheet Pile Wall and Penetration Depths Analyzed

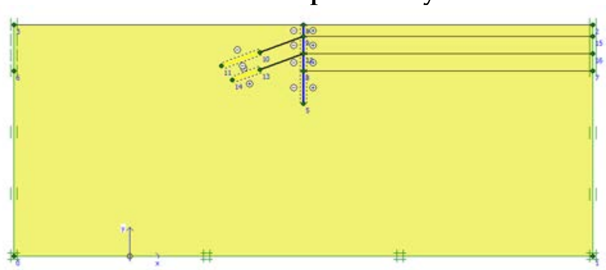

Figure 3 Schematic of Anchored Sheet Pile Wall and Penetration Depths Analyzed for add two anchors

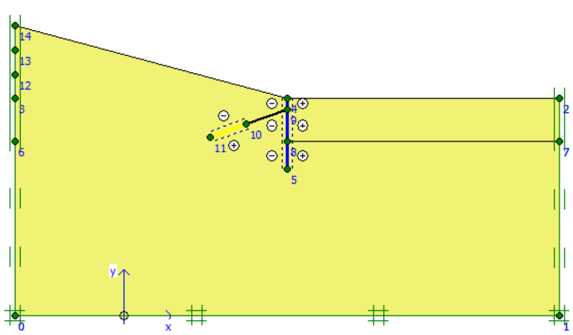

Figure 4 Schematic of Anchored Sheet Pile Wall and inclination of ground surface (ψ) Analyzed

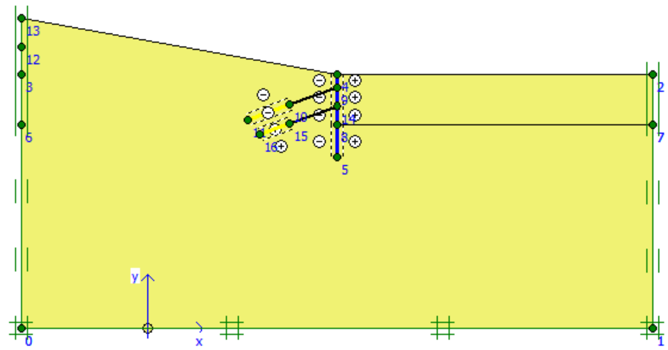

Figure 5 Schematic of Anchored Sheet Pile Wall and inclination of ground surface (ψ) Analyzed for add two anchors

TABLE 1. Material Properties for the Soil Types Studied

Parameter	Name	Loose Sand (LS)	Medium Dense Sand (MS)	Dense Sand (DS)	Unit
Material model	Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	
Type of material behavior	Type	Drained	Drained	Drained	
Soil saturated unit weight	γ_{sat}	16	19	20	kN/m^3
Soil unsaturated unit weight	γ_{unsat}	16	17	18	kN/m^3
Young's modulus	E	2.50E+04	7.50E+04	1.30E+05	kN/m^2
Friction angle	ϕ	30	36	40	°
Cohesion	C	1	1	1	kN/m^2
Soil-wall interface	R_{int}	0.67	0.65	0.63	

Table 2 Material Properties of Sheet Pile Wall (Plate) – Using PZ-40

Parameter	Name	Value	Unit
Type of behavior	Material type	Elastic	-
Normal stiffness	EA	4.98E+06	kN/m
Equivalent thickness	d	0.5682	m
Weight	W	2	kN/m/m
Poisson's	ν	0.15	-

Table 3 Properties of Grouted body (geotextile)

Parameter	Name	Value	Unit
Type of behavior	Material type	Elastic	-
Normal stiffness	EA	3.00E+06	kN/m

Table 4 Properties of the anchor rod (node-to-node anchors)

Parameter	Name	Value	Unit
Type of behav-	Material	Elastic	-
Normal stiffness	EA	4.30E+05	kN/m
Spacing out of plane	L	1.5	m

By using the (FHWA) instructions, the anchored sheet pile walls were designed for the wall height and three types of soil combinations. The pile section selected and the depth of wall penetration calculated were used in numerical modeling during the parametric study. The calculated anchor forces were used to determine the anchor stiffness. The anchor force was calculated using the (FHWA) instructions and Plaxis 8.6 The design anchor stiffnesses, EA, used in the numerical analyses were obtained by multiplying the anchor area by the elastic modulus of steel. The variables and their ranges considered in the parametric study are given in TABLE 5.

2.2 finite Element Software and Constitutive Model

Finite element analyses were performed using Plaxis 8.6 finite element. The finite element modeling comprised two-dimensional plane strain analysis. The soil layers and the sheet pile walls were modeled using 15-node triangular elements. A finer mesh was used around the wall and the grout minimize the stress concentration around them. The excavation was simulated by removing soil in lifts. The complete excavation was performed on two steps, the anchor was installed when excavation reached the anchor level. Due to the cohesionless of the soils, the analyses were performed considering drained conditions.

2.3 Variables and Ranges Used in Parametric Study

Variable	Range Considered
penetration depth	0.3H,0.4H,0.5H,0.6H,0.7H
Ground surface inclination	0,5,10,15,20 (in degrees)
Number of anchor	1 and 2
Soil type	Dense sand, medium dense sand and loose sand

TABLE 5. Variables and Ranges Used in Parametric Study

3. RESULTS AND ANALYSIS:

3.1 Effect of increasing wall penetration depth.

The Parametric study was performed to investigate the effect of increasing wall penetration depth (D) on anchored sheet pile wall behavior by using dense sand soil (ϕ = 40°) with the height (H=8.0 m). The minimum set values of the wall penetration depth satisfy the design requirements for anchored sheet pile wall cases; However, the upper range of the wall penetration depths were determined by increasing the design depths until a small or no influence will be observed in the wall behavior in terms of wall displacement and bending moments. These ranges of wall penetration depth (D) are obtained by analyzing the results given by PLAXIS, and equation from (FHWA) and then plotting these results to see the change in wall behavior. Figures 6, 7, 8 and 9 show horizontal wall displacements and bending moments for lower and upper ranges of the wall penetration depth analyzed for anchored sheet pile wall respectively, considered in this parametric study.

The analysis results in terms of maximum horizontal wall displacements, maximum wall bending moments, and anchor forces with increasing wall penetration depth, for the 8.0 m anchored sheet pile wall in dense sand soil, are given in, shown in figures 10 through 12 and discussed below.

3.1.1 Wall Displacement:

The results show that as the wall penetration depth increases the horizontal displacements decrease slightly from 0.3 H to 0.5 H, then increase at 0.6 H and 0.7 H as shown in figure 10. The change in wall displacement for all cases studied is minimum because the anchored wall is tied at anchor position and is restricted at the bottom of the wall. Although the wall can bend between these positions, the overall wall displacements will be relatively little with increasing the penetration depth.

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3.1.2 Bending Moments:

The maximum wall bending moments for anchored sheet pile walls decrease significantly with the increase in the wall penetration depth as shown in figure 11. The results in this figure show that by increasing the wall penetration depth in dense sand soils, about 18.5 percent reduction in maximum wall bending moments was observed. The change in wall bending moments for all cases studied is relatively large due to the flexibility of anchored sheet pile walls and the effect of lateral earth pressures. By increasing the wall penetration depth, the passive stress below dredge line is increased and then wall bending moments decrease.

3.1.3 Anchor Forces:

The anchor force for anchored sheet pile walls decreases with increasing the wall penetration depth as shown in Figure 12. the results in this figure show that by increasing the wall penetration depth in dense sand soils for anchored sheet pile wall with height 8.0 m, about 15 percent reduction in anchor force values was observed.

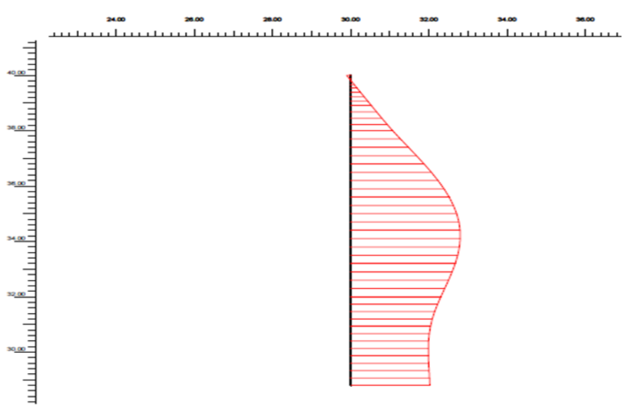
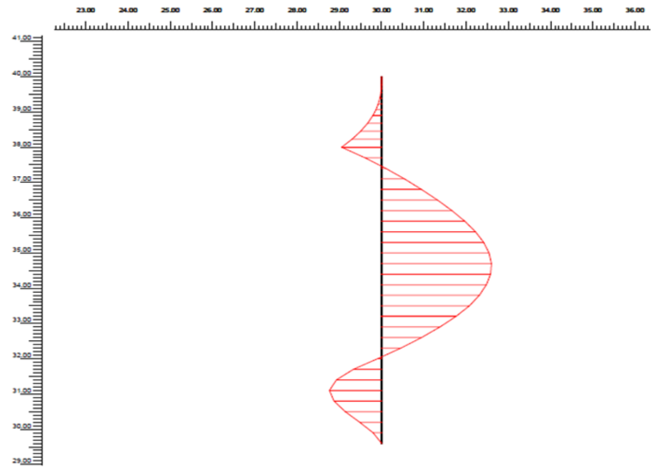
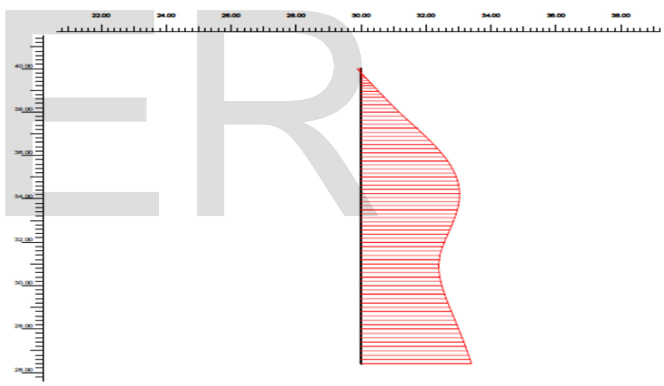


Figure 6 Horizontal Displacements for Anchored Wall Penetration Depth at (8.0DS).



(b) D=0.7H

Figure 7 Bending Moments for Anchored Wall Penetration Depth at (8.0DS)



(a) D=0.3H

(b) Figure 8 Horizontal Displacements for Anchored Wall Penetration Depth at (8.0DS).

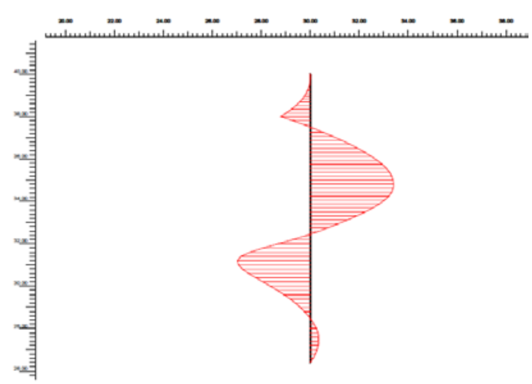


Figure 9 Bending Moments for Anchored Wall Penetration Depth at (8.0DS).

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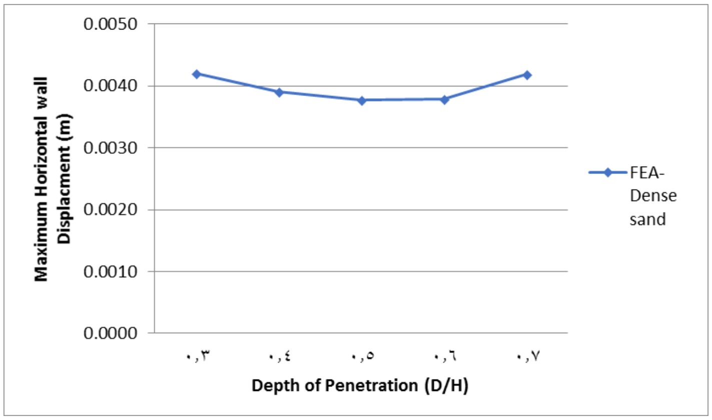

Figure 10 Effect of Increasing Wall Penetration Depth on Maximum Horizontal Wall Displacements (8.0DS).

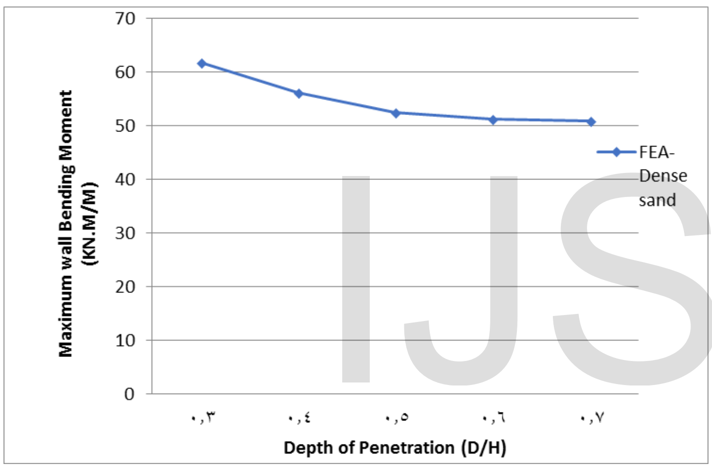

Figure 11 Effect of Increasing Wall Penetration Depth on Maximum Wall Bending Moment (8.0DS).

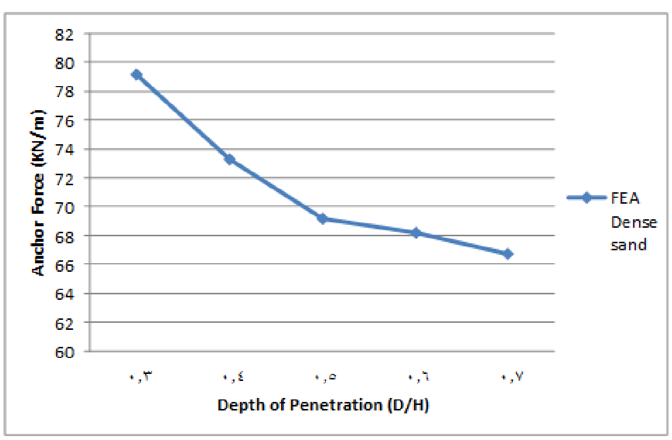

Figure 12 Effect of increasing Wall Penetration Depth on Anchor Force (8.0DS).

3.2 Effect of Soil Strength:

Additional modeling and analysis were performed using medium dense sand and loose sand soil to investigate the effect of soil strength on the wall behavior with increasing wall penetration depth. and also, to study whether the wall behavior observed for dense sand with increasing the wall penetration depth- as shown above- are similar to the walls behavior in medium dense sand or loose sand soils. Soil properties used for this parametric study were provided in (table1).

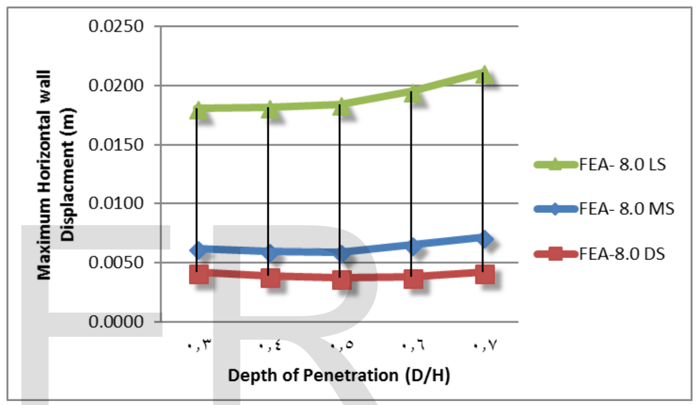

Figure 13 Effect of Soil strength with Increasing Wall Penetration Depth on Maximum Horizontal Wall Displacements (Granular Soils-H=8.0).

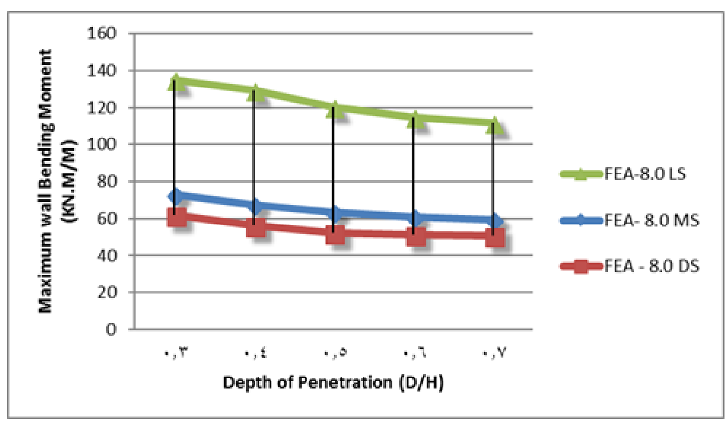

Figure 14 Effect of Soil strength with Increasing Wall Penetration Depth on Maximum wall Bending Moments (Granular Soils-H=8.0).

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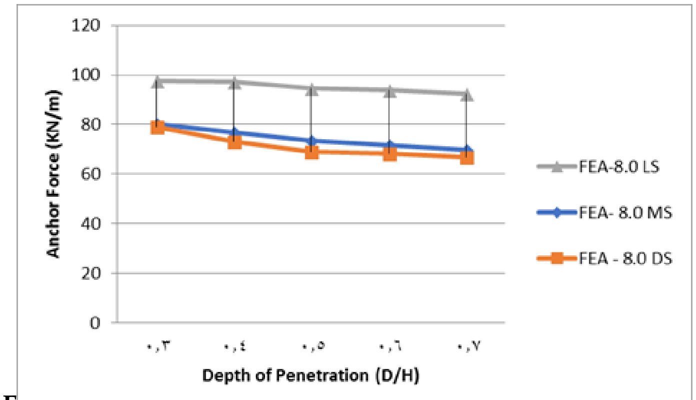

F[illegible]e-tration Depth on Anchor forces (Granular Soils-H=8.0).

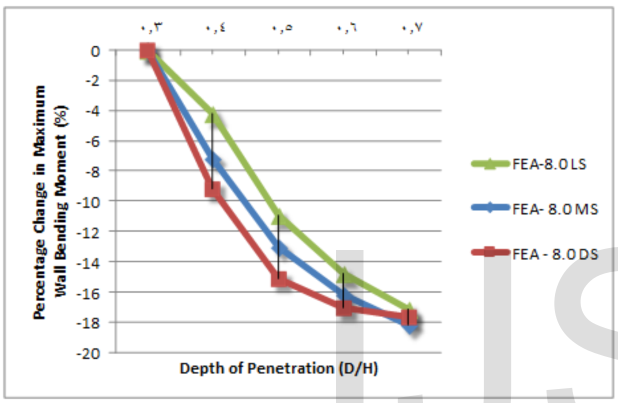

Figure 16 Reduction in Maximum Wall Bending Moments with Increasing Wall Penetration Depth (Granular Soils-H=8.0).

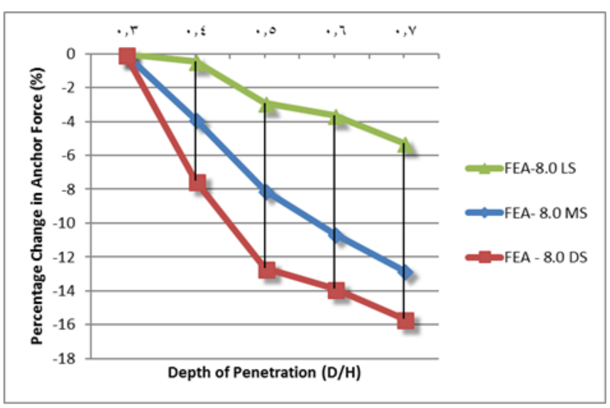

Figure 17 Reduction in Anchor forces with Increasing Wall Penetration Depth (Granular Soils-H=8.0).

Figures 16,17 show the percentage of reductions in maximum wall bending moments and anchor forces in all types of sand soils. The results in figure 16 show that by increasing the wall penetration depth in medium dense sand and loose sand soils, more than 18 percent and 17 percent reduction in maximum wall bending moments were observed.

And also, the results in figure 17 show that by increasing the wall penetration depth in medium dense sand and loose sand soils, more than 12 percent and 5 percent reduction in anchor forces were observed. However, more than 15 percent reduction in anchor forces was observed in dense sand soils. This means that the dense sand soil has the highest reduction in anchor force with increasing the penetration depth for anchored sheet pile

3.3 Effect of Adding Two Rows of anchors

Additional modeling and analysis were performed using dense sand, medium dense sand and loose sand soils to investigate the effect wall behavior for Adding Two rows of anchors for different soil conditions with increasing wall penetration depth, and also to compare results to one-row-anchor model. Soil properties used for this parametric study were provided in (table 1).

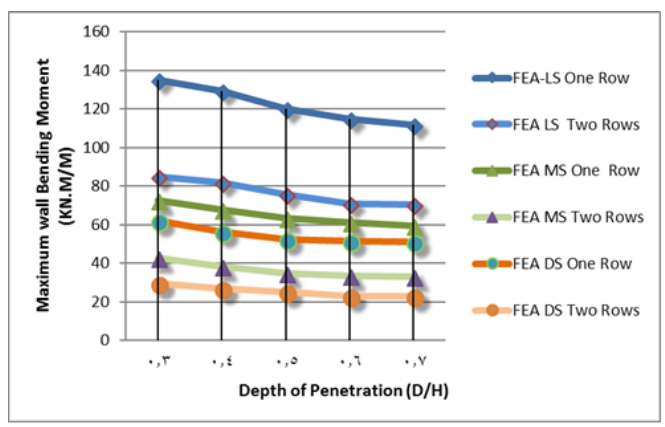

Figure 18 Effect of adding two rows of anchors with Increasing Wall Penetration Depth on Maximum wall Bending Moments (DS-MS-LS-H=8.0).

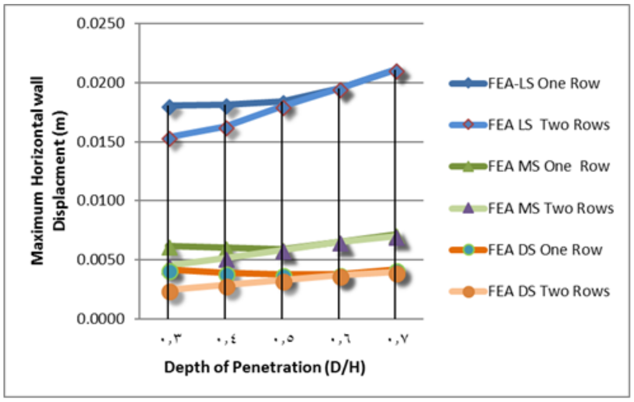

Figure 19 Effect of adding two rows of anchors with Increasing Wall Penetration Depth on Maximum Horizontal Wall Displacements (DS-MS-LS-H=8.0).

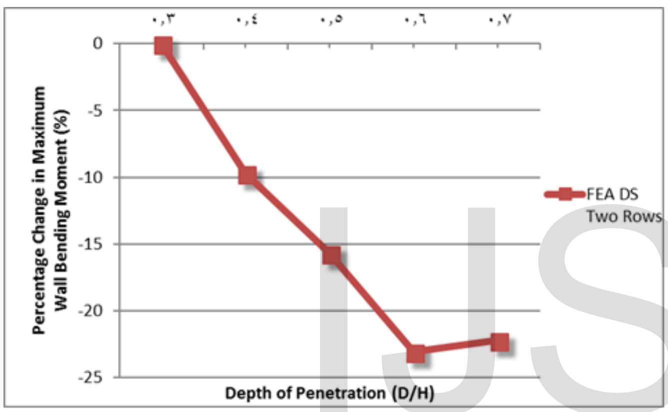

Figure 20 Reduction in Maximum Wall Bending Moments with Increasing Wall Penetration Depths (DS-H=8.0).

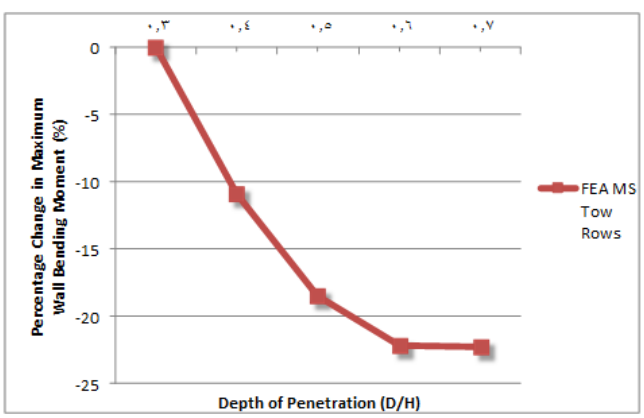

Figure 21 Reduction in Maximum Wall Bending Moments with Increasing Wall Penetration Depths (MS-H=8.0).

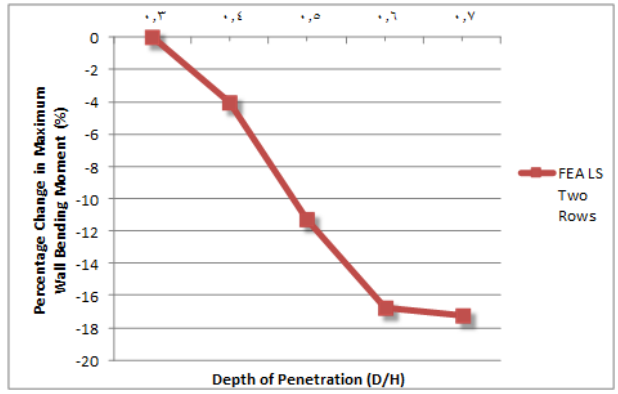

Figure 22 Reduction in Maximum Wall Bending Moments with Increasing Wall Penetration Depths (LS-H=8.0).

The results of analysis for dense, medium dense and loose sand for two rows of anchors are given in figure 18, through 22 For comparative purposes. The results show that the anchored sheet pile walls in dense sand, medium dense sand and loose sand soils have the identical behavior observed for adding the second level of anchors and reduce the wall deformations and maximum bending moments -as expected-. The results show that by increasing the wall penetration depth in dense sand, medium dense sand and loose sand soils, more than 23 percent, 22 percent, and 17 percent respectively, reduction in maximum wall bending moments were observed.

On Comparing the effect of two rows of anchors to one row of anchors on sheet pile wall behavior Maximum wall bending moments, it was noticed that the reduction is more than 55 percent, 45 percent, and 38 percent when the second level of anchor is installed for dense sand, medium dense sand and loose sand soils respectively. This mean that the dense sand soil has the highest reduction in Maximum wall bending moments with increasing the penetration depth for anchored sheet pile wall.

3.4 Effect of Ground Water table

Additional modeling and analysis were performed using dense sand, medium dense sand and loose sand soils to investigate the effect of adjusting the water level at the anchor level on both sides for different soil conditions on wall behavior with increasing wall penetration depth, and also to compare the results to that of dry condition.

The analysis results, in terms of maximum horizontal wall displacements, maximum wall bending moments, and anchor forces with increasing wall penetration depth, for the 8.0 m anchored sheet pile wall in dense sand (ϕ = 40°), medium dense sand soil (ϕ = 36°), loose sand soil (ϕ = 30°) are given.

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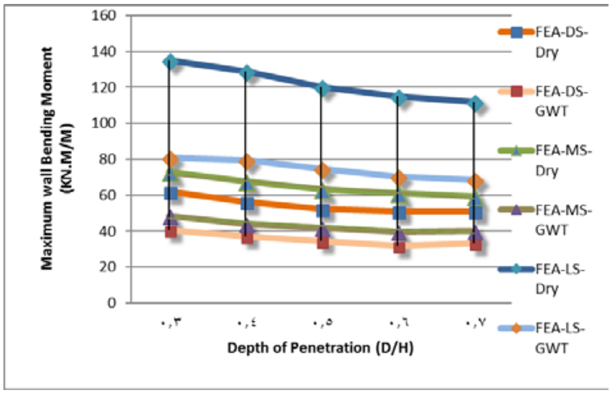

Figure 23 Effect of adding water level table at anchor level with Increasing Wall Penetration Depth on Maximum wall Bending Moments (DS-MS-LS-H=8.0).

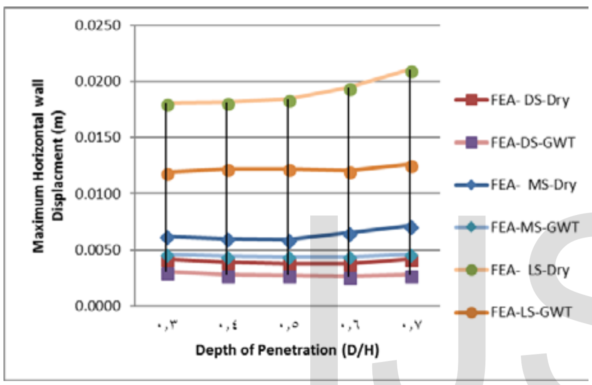

Figure 24 Effect of adding water level table at anchor level with Increasing Wall Penetration Depth on Maximum Horizontal Wall Displacements (DS-MS-LS-H=8.0).

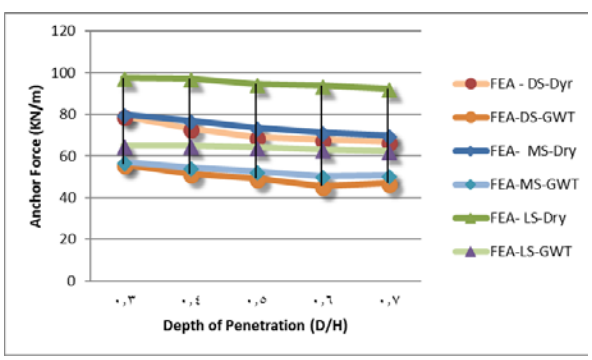

Figure 25 Effect of adding water level table at anchor level with Increasing Wall Penetration Depth on Anchor forces (DS-MS-LS-H=8.0).

The results in figures 23 through 25 shows that by increasing the wall penetration depth in dense sand, medium dense, and loose sand soils, more than 18 percent, 11 percent, and 4 percent respectively, reduction in anchor forces were observed. This means that the dense sand soil has the highest reduction in anchor forces with increasing the penetration depth for anchored sheet pile wall.

4. Effect of Inclination of Ground Surface.

The Parametric study was performed to investigate the effect of inclination of ground surface (ψ) on anchored sheet pile wall behavior by using dense sand soil (ϕ = 40°) with the height (H=8.0 m). The minimum values of the wall penetration depth we set to satisfy the design requirements for anchored sheet pile wall cases. However, the upper range of inclination of ground surface (ψ) were determined by the design until a small or no change was observed in the wall behavior in terms of wall displacement and bending moments. These ranges of inclination of ground surface (ψ) were obtained by analyzing the results given by PLAXIS, and then plotting these results to see the change in wall behavior.

The analysis studied the results in terms of maximum horizontal wall displacements, maximum wall bending moments, and anchor forces with increasing of inclination ground surface (ψ), for the 8.0 m anchored sheet pile wall in dense sand soil.

4.1 Wall displacement:

The results show that as the inclination of ground surface (ψ) increases the horizontal displacements increases as shown in figure 26. The change in wall displacement for all cases studied are minimum because the anchored wall is tied at the anchor position and restricted at the bottom of the wall. However, the wall can bend between these positions, the overall wall displacements will be relatively little with increasing the inclination of ground surface (ψ).

4.2 Bending Moments:

The maximum wall bending moments for anchored sheet pile walls increase with the increase in inclination of ground surface (ψ) as shown in figure 27. the results in this figure show that by increasing inclination of ground surface (ψ) in dense sand soils, about 51 percent change in maximum wall bending moments was observed. The increase in wall bending moments for all cases studied is relatively large due to the flexibility of anchored sheet pile walls and the effect of lateral earth pressures.

4.3 Anchor Forces:

The anchor force for anchored sheet pile walls increases with the increase in the inclination of ground surface (ψ) as shown in Figure 28. the results in this figure show that by increasing inclination ground surface (ψ) in dense sand soils for anchored sheet pile wall with height 8.0 m, about 84 percent increasing significant in anchor force values was observed.

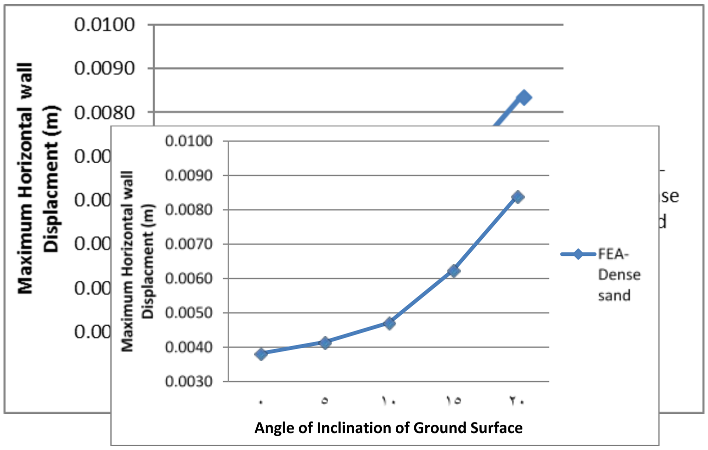

Figure 26 Effect of Increasing Inclination of ground surface on Maximum Horizontal Wall Displacements (8.0DS).

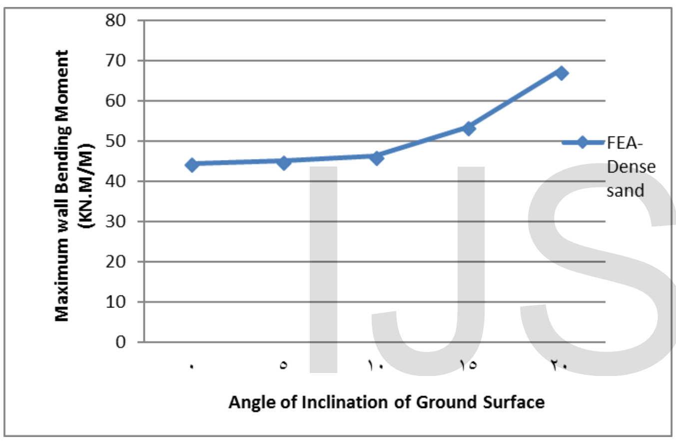

Figure 27 Effect of Increasing Inclination of ground surface on Maximum Wall Bending Moments (8.0DS).

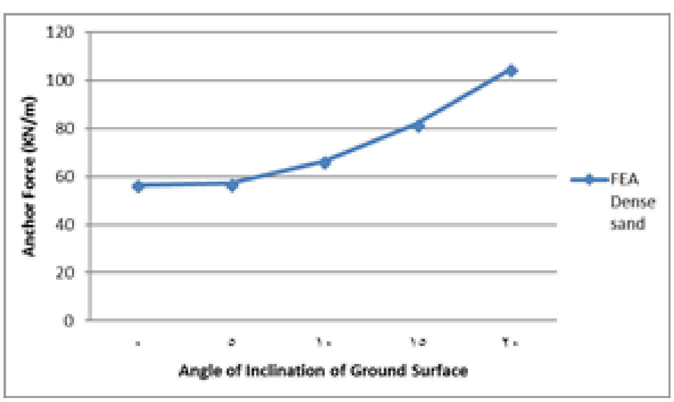

Figure 28 Effect of Increasing Inclination of ground surface on Anchor force (8.0DS).

4.2 Effect of Soil Strength

Additional modeling and analysis were performed using medium dense sand, and loose sand soil to investigate the effect of soil strength on the wall behavior with increasing inclination ground surface (ψ). and also, to study whether the wall behavior observed for dense sand with increasing inclination ground surface (ψ) -as shown above- are similar to the walls behavior in medium dense sand or loose sand soils. Soil properties used for this parametric study were provided in (table 1). The analysis results show that the anchored sheet pile walls in medium dense sand and loose sand soils have an identical behavior observed to those walls in dense sand soils. All the results presented for maximum horizontal wall displacement in figure 29, for maximum wall bending moments in figure 30, and anchor forces in figure 31displays that the anchored sheet pile walls in loose sand soil, have more deformations, more bending moments, and more anchor forces with increasing inclination ground surface (ψ).

Figures 32, 33 shows the percentages change in maximum wall bending moments and anchor forces in all types of sand soils. The results in figure 32 show that by increasing the inclination of ground surface (ψ)in medium dense sand and loose sand soils, more than 66 percent and 105 percent increase in maximum wall bending moments were observed.

And also, the results in figure 33 show that by increasing the inclination of ground surface (ψ) in medium dense sand and loose sand soils, more than 120 percent and 173 percent change in anchor forces were observed. However, more than 84 percent change in anchor forces was observed in dense sand soils. This means that the dense sand soil has the lowest change in anchor force with increasing inclination ground surface (ψ) for anchored sheet pile wall.

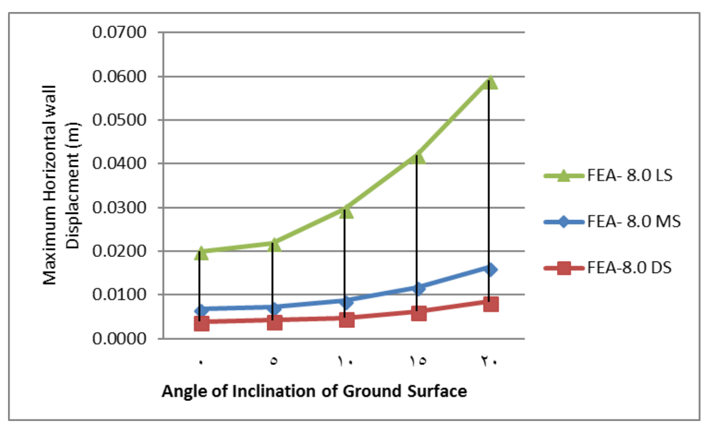

Figure 29 Effect of Soil strength With Increasing inclination of ground surface (ψ) on Maximum Horizontal Wall Displacements (Granular Soils-H=8.0).

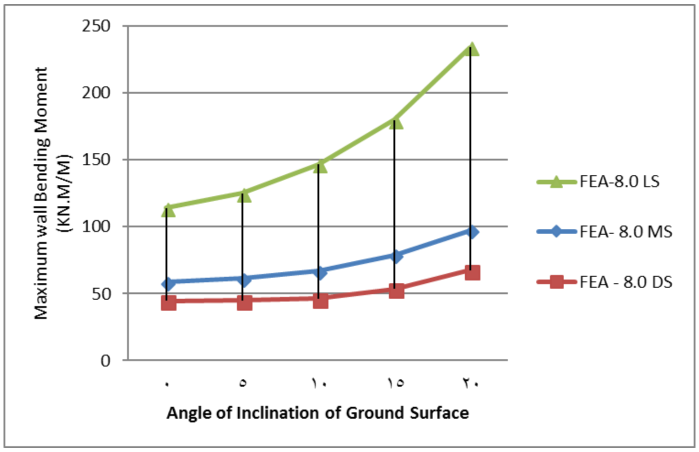

Figure 30 Effect of Soil strength with Increasing inclination of ground surface (ψ) on Maximum wall Bending Moments (Granular Soils-H=8.0).

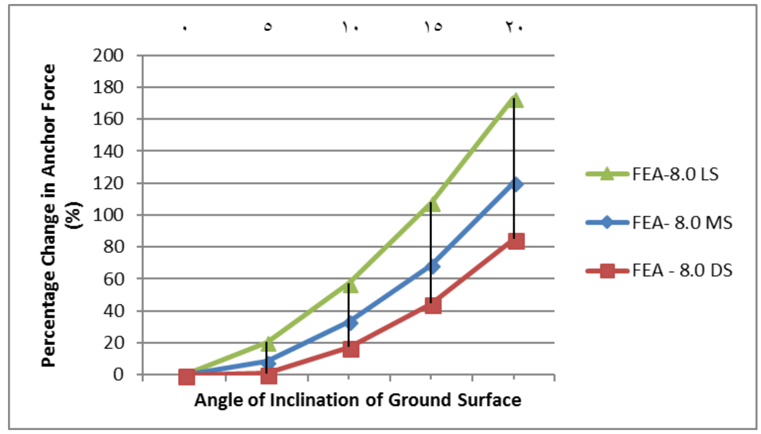

Figure 33 Change in Anchor forces with Increasing inclination of ground surface (ψ) (Granular Soils-H=8.0).

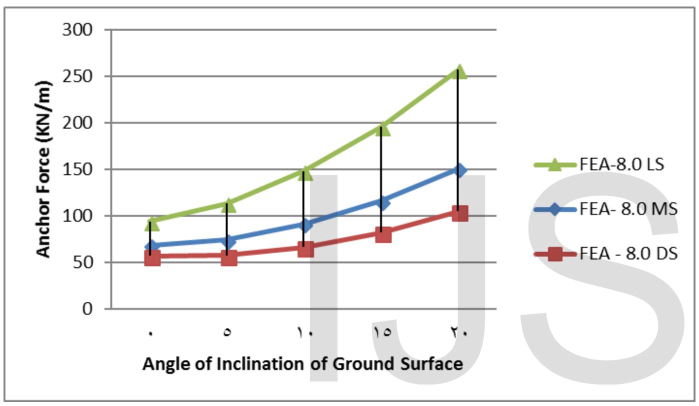

Figure 31 Effect of Soil strength with Increasing inclination of ground surface (ψ) on Anchor forces (Granular Soils-H=8.0).

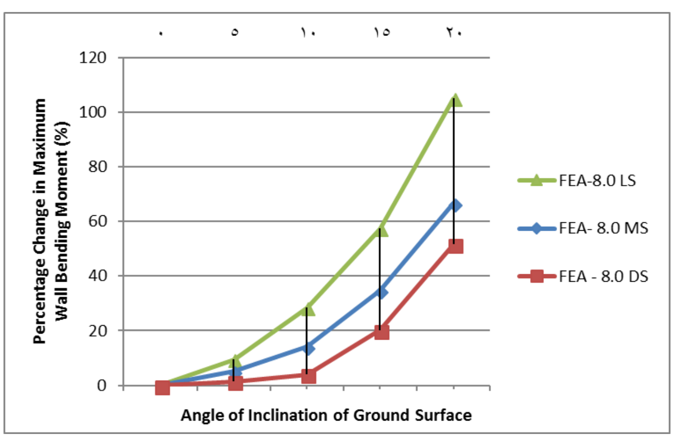

Figure 32 Change in Maximum Wall Bending Moments with Increasing inclination of ground surface (ψ) (Granular Soils-H=8.0).

4.3 Effect of Add Two Rows of anchors

Additional modeling and analysis were performed using dense sand, medium dense sand and loose sand soils to investigate the effect wall behavior on adding two rows of anchors for different soil conditions with increasing inclination of ground surface (ψ), and also to compare the results to that of one row anchor. Soil properties used for this parametric study were provided in (table 1).

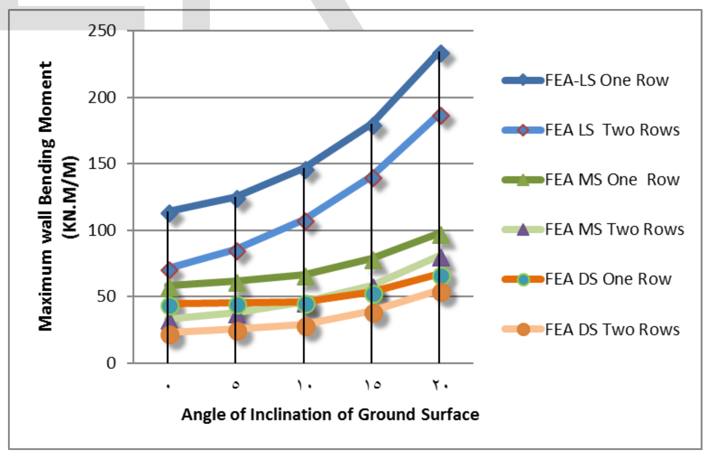

Figure 34 Effect of add two rows of anchors with increasing inclination of ground surface (ψ) on Maximum wall Bending Moments (DS-MS-LS-H=8.0).

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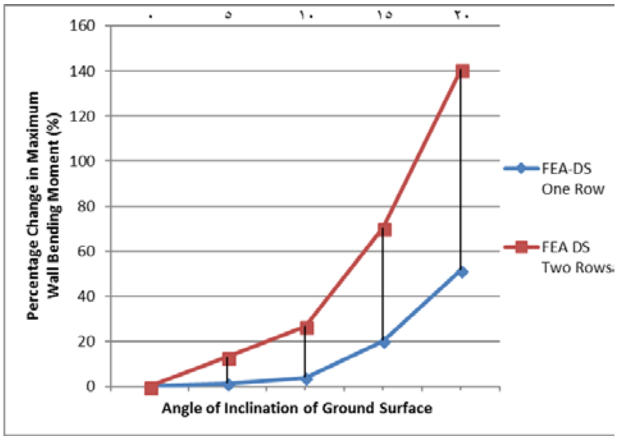

Figure 35 Effect of add two rows of anchors with increasing inclination of ground surface (ψ) on Maximum Horizontal Wall Displacements (DS-MS-LS-H=8.0).

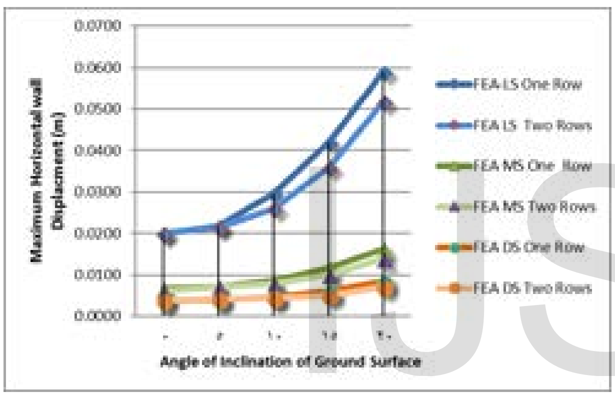

Figure 36 Change in Maximum Wall Bending Moments with increasing inclination of ground surface (ψ) (DS-H=8.0).

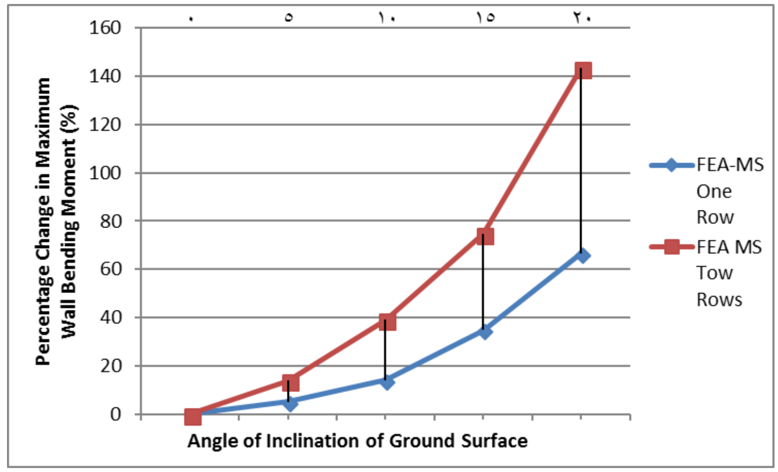

Figure 37 Change in Maximum Wall Bending Moments with increasing inclination of ground surface (ψ) (MS-H=

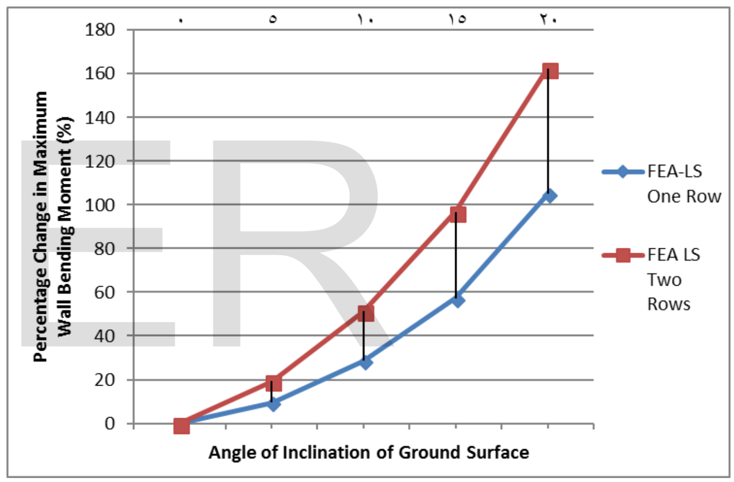

Figure 38 Change in Maximum Wall Bending Moments With increasing inclination of ground surface (ψ) (LS-H=8.0).

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4.4 The analysis results,

The results of analysis for dense, medium dense and loose sand for two rows of anchors, are given in figure 32, through 37. For comparative purposes. The results show that the anchored sheet pile walls in dense sand, medium dense sand and loose sand soils have the identical behavior observed for adding the second level of anchors, and reduce the wall deformations and maximum bending moments, as expected. The results show that by increasing inclination of ground surface (ψ) in dense sand, medium dense sand and loose sand soils, more than 140 percent, 143 percent, and 162 percent respectively, change in maximum wall bending moments were observed.

Comparison between adding two rows of anchored and one row of anchored on sheet pile wall behavior is made, Maximum wall bending moments are reduced more than 48.0 percent, 43 percent, and 37 percent when the second level of anchor is installed for dense sand, medium dense sand and loose sand soils. This means that the dense sand soil has the highest reduction in Maximum wall bending moments with increasing inclination of ground surface (ψ)for anchored sheet pile wall.

4.5. Effect of Ground Water table with inclination

Additional modeling and analysis were performed using dense sand: medium dense sand and loose sand soils to investigate the effect of adjusting the water level to be at the anchor level on both sides for different soil conditions on wall behavior with increasing inclination ground surface (ψ). and also, to compare it to dry condition. Soil properties used for this parametric study were provided (table 1).

5. The analysis results

. the results show that the anchored sheet pile walls in dense sand, medium dense sand and loose sand soils have the identical behavior observed for adding water table at anchor level and reduce the wall deformations and maximum bending moments, and anchor forces as expected. The results show that by increasing inclination ground surface (ψ), in dense sand, medium dense, and loose sand soils, more than 97 percent, 101 percent, and 198 percent respectively, change in maximum wall bending moments were observed.

The results show that by increasing inclination ground surface (ψ), depth in dense sand, medium dense, and loose sand soils, more than 117 percent, 161 percent, and 274 percent respectively, change in anchor forces were observed. This means that the dense sand soil has the lowest increase in anchor forces and bending moments with increasing inclination ground surface (ψ), for anchored sheet pile wall.

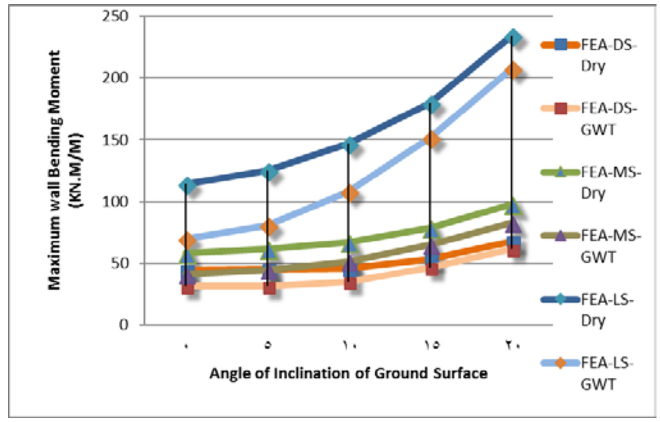

Figure 38 Effect of add water level table at anchor level with increasing inclination ground surface (ψ), on Maximum wall Bending Moments (DS-MS-LS-H=8.0).

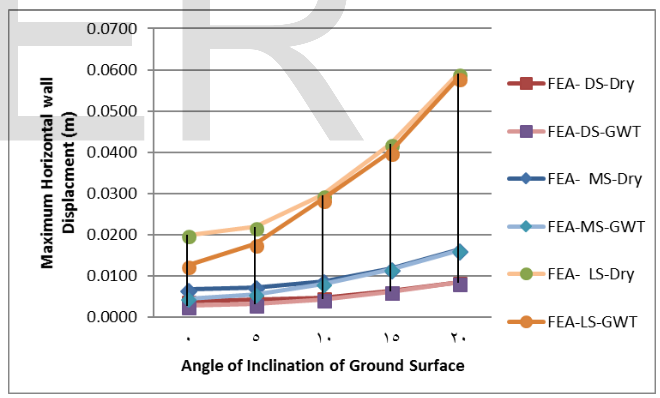

Figure 39 Effect of add water level table at anchor level with increasing inclination ground surface (ψ), on Maximum Horizontal Wall Displacements (DS-MS-LS-H=8.0).

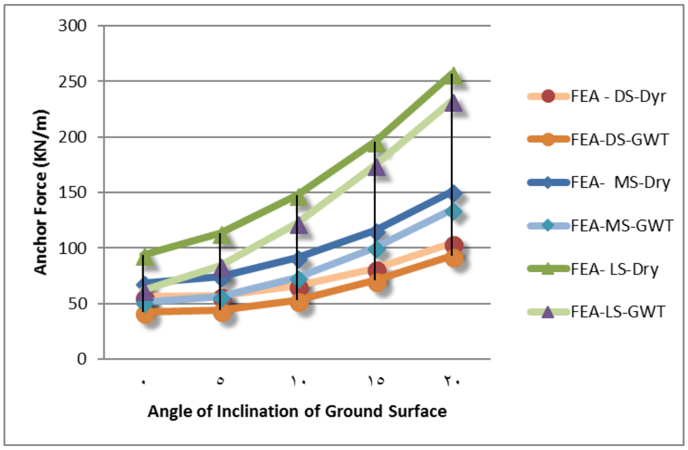

Figure 40 Effect of add water level table at anchor level with increasing inclination ground surface (ψ), on Anchor forces (DS-MS-LS-H=8.0).

Comparison between adding water table at anchor leve and dry soil on sheet pile wall behavior is made. Maximum wall bending moments are reduced more than 29 percent, 30 percent, and 39 percent when adding water table at level of anchor for dense sand, medium dense sand and loose sand soils. Also anchor forces are reduced more than 24 percent, 25 percent, and 34 percent for dense sand, medium dense sand and loose sand soils

6. Conclusion:

From the previous studies of the change in penetration depth of sheet pile wall and change in ground surface inclination taking the effect of change in different parameters in consideration for both cases such as the effect of ground water table, adding of another row of anchor. Analyses were performed using the finite element method. The analysis results show that:

for penetration depth it was found that the maximum bending moment decreases significantly with the increase of penetration depth. And the anchor force decreases with the increase of wall penetration depth. Also, the horizontal displacement decreases slightly with the increase of penetration depth. On adding two rows of anchor, a significant reduction in maximum wall bending moment is noticed with a percent more than 55%, 45% and 38% for dense, medium and loose sand respectively. For ground surface inclination it was found that the maximum horizontal displacement, maximum bending moment and anchor force increase with the increase in ground surface inclination. On adding another row, the maximum bending moment is reduced by 48%, 43% and 37% for dense sand, medium sand and loose sand respectively. It is preferred that the inclination of ground surface doesn't exceed 10 degrees. When taking ground water table in consideration for both sides, the maximum bending moments are reduced by 29%, 30% and 39% for dense sand, medium sand and loose sand respectively. Also, anchor forces are reduced by 24%, 25% and 34% for dense sand, medium sand and loose sand respectively

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