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Behavior of Strut- Deep Excavation in Sandy Ground Considering Adjacent Structures

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ABSTRACT

Deep excavations are required as cities expand due to the increased demand for housing and transportation infrastructures. Supporting deep excavations is necessary to prevent damage to nearby structures, guarantee their safety, and reduce deformations. The braced excavation method is the most popular approach, but it depends on a number of variables, including the construction budget and timeline, the presence of nearby buildings, the availability of construction equipment, and the size of the construction site. In case of existing buildings around the excavation with varying heights, the asymmetric loading should be taken into consideration.
The present study aims to evaluate the change in bending moment and strut loads, deformations of the retaining walls and ground surface settlements, under symmetry and asymmetric surcharge loads. Based on verified case study, PLAXIS 2D – program was used to model strut-supported deep excavation systems in sandy soil with different relative densities. Optimization of strut position was also investigated. It has been demonstrated that, because the retaining walls on the left and right sides of may behave differently, the strut-supported excavation systems should be designed as a whole rather than separately.

Keywords: Plaxis 2-D, Numerical Models. Strut-supported system, Deep excavation geometry Sandy ground, Surcharge load,

1. INTRODUCTION

High-rise structures have become necessary due to the recent population growth, particularly in urban areas. Subways have also proliferated in tandem with the growing demand for public transit. Structures like subway stations and high-rise skyscrapers require deep excavations. Deep excavations must be supported so that they do not damage adjacent structures, ensure their safety and reduce the deformations Akan [1]. An excavation in rock or soil that is deeper than 4.5 meters is generally referred to as a deep excavation (Suliman et. al. [2]. The common deep excavation techniques are: top-down construction, zoned excavation, anchored excavation, braced excavation, island excavation, and full open cut. The braced excavation method is the most popular approach, but it depends on a number of variables, including the construction budget and timeline, the presence and state of nearby buildings Many studies in the literature examined the deformations of the walls and the loads on the struts in the deep excavations, as well as the deformations in the soil surface close to the retaining wall in dry sandy soil Bransby and Milligan [3] Clough and O'Rouke [4]. Fig. 1 shows ground settlement profiles which can be classified into two types: spandrel and concave ~~Hsieh and Ou [5], Clough and O'Rourke [4] showed that~~ excavation in soft clay causes the retaining wall to deflect and results in concave-type settlement under typical construction conditions. In the other hand, Sandy soil will cause less retaining wall deformation, and spandrel-type settlement might result [5 & 4].

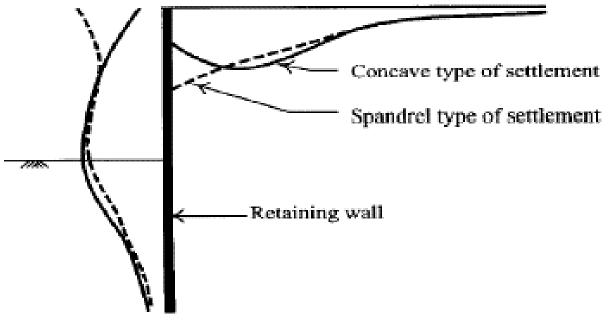


Fig. (1): Types of Ground Surface Settlement [5]

The deep excavations are usually modeled using a half-model, assuming the loads are symmetrical, even though there are buildings and roads nearby, especially in the city center, and it is more likely that the surcharge loads are asymmetrical. However, because each wall reacts differently to asymmetic loading, there may be differences in the strut forces, the behavior of the walls, and the settlements of the soil surface. This could lead to dangerous and unprofitable outcomes. The presence of surcharge loads on both sides of the excavation with varying magnitudes, resulting in different lateral deformations and bending moments for both walls. The asymmetry has a negative impact on the excavation's support system, Xu et al. [6] and Guo et al. [7].
With the advancement of computer technology, many researchers have used the 2D FEM and finite difference approach to conduct parametric studies to examine the change in wall deformations and soil pressure, as well as, the vertical deformations that will occur in sandy soils. Computer-based on Plaxis 2D v20, finite difference, and Abaqus were used to perform the analysis, taking into account characteristics such as sand density, excavation depth and width, wall length and stiffness, and struts stiffness and spacing [8–17].
In the present study, PLAXIS 2D v20 was used to develop a numerical model to verify the results of case study. Then a parametric study was carried to investigate the strut loads, wall deformations, bending moments, ground surface settlements, and heave in strut-supported deep excavations in sandy ground, under symmetrical and asymmetric surcharge loads.

2. CASE STUDY AND VERIFICATION

A case study by Akan [1] was numerically investigated for deep strut-supported excavation system as illustrated in Figure (2). The support system is constructed with five struts, and the embedment depths of the wall and excavation are both estimated to be 16.00 m. The loading type "staged construction" is selected for the analysis. The surcharge load on ground surface ($q_L = q_R$) was taken equal to 60 kN/m Each excavation is made to a depth of 1m below the next bracing level, and the corresponding strut is activated in the next stage. The schematic model of the five-stage bracing system, diaphragm walls and surcharge loads is shown in Figure 2.

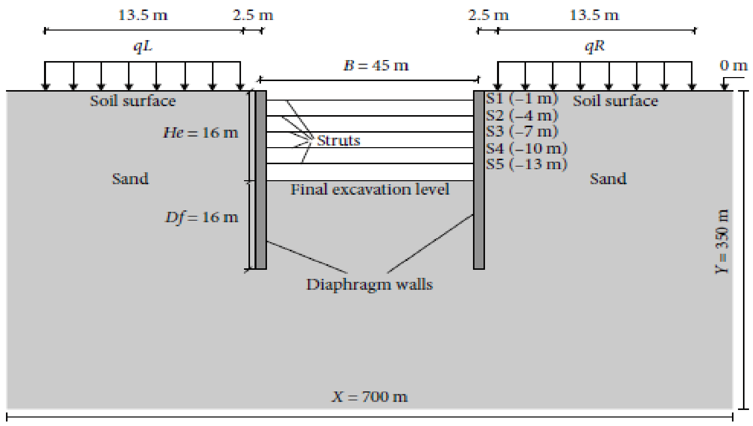


Fig. 2: Scheme of the model for supported excavation system.

The strut-supported deep excavation systems have diaphragm walls in loose (LS) and dense (DS) sandy soils are modeled. The hardening soil model is used, which considers the swelling behavior caused by friction in soil and permits modeling under the conditions of triaxial volume deformation. Table 1 lists the hardening soil, wall and struts parameters used in the study, which were derived from research [18& 19] ~~by Xuan [39] and Brinkgreve et al. [38].~~

Table 1: Soil Parameters for loose sand (LS) and dense sand (DS), wall, and struts

Parameters	DS	LS	Parameters	DS	LS
Yunsat (kN/m^3)	18.2	17	φ(°)	38	30
Ysat (kN/m^3)	20.3	19	Ψ(°)	8	0
Drainage type	Drained	Drained	υ_{ur}	0.35	0.2
$k_x = k_y$ (m/day)	10^{-8}	10^{-8}	p^{ref}(kN/m^2	100	100
$\sum_{50}^{ref}$ (kN/m^2)	48,000	15,000	m	0.45	0.8
$\sum_{oed}^{ref}$ (kN/m^2)	48,000	15,000	K_0^{nc}	0.3843	0.5
$\sum_{ur}^{ref}$ (kN/m^2)	144,000	45,000	R_f	0.9	0.9
c (kN/m^2)	0	0	R_{inter}	0.4, 0.6, 0.8, 1	0.4, 0.6, 0.8, 1

Parameters	Diaphragm walls			Struts
Thickness, d (cm)	40	80	120	–
Material type	Elastic	Elastic	Elastic	Elastic
EA (kN/m)	24×10^6	48×10^6	72×10^6	2×10^6
EI (kNm^2/m)	320×10^3	256×10^4	864×10^4	–
ν	0.15	0.15	0.15	–

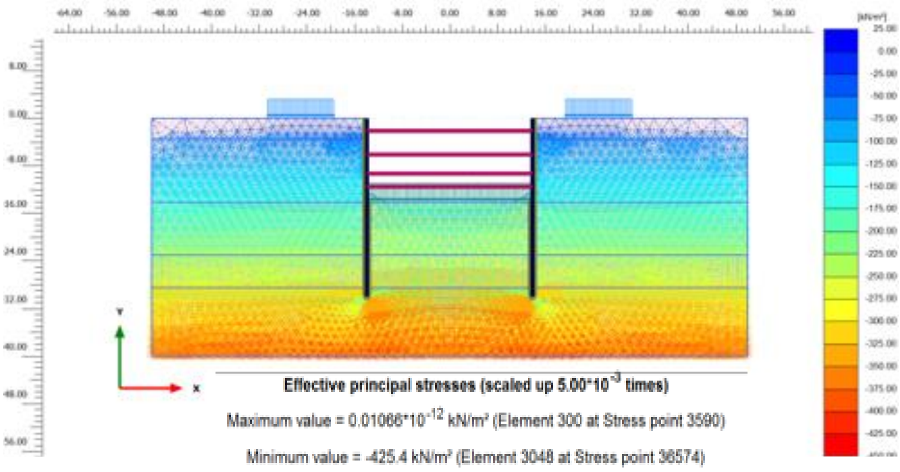


Fig. 3: Effective principal stresses from developed model of Current study for DS

The results of the case study for Ds are compared to the results of the current study as listed in Table (2) for validation of the developed numerical model. The comparison shows that, the results are found to be in fair agreement with slight fluctuation.

Table 2: Comparison between the results of case study and current study

Sand type	Dense Sand (DS)		Loose Sand (LS)	
Parameter	Case Study	Current Study	Case Study	Current Study
Wall M $_{max}$ (kN.m)	193.80	199.40	471.10	460.50
Strut Max. Force (S3)	506.00	537l92	899.46	897.94
Wall max. Deflection (mm)	18.80	22.24	49.53	49.64

3. PARAMETRIC STUDY

3.1 Optimization of One-Strut Deep excavation

The effect of strut position on the strut force (*T*), wall maximum moment (M_{max}.), wall deflection (δ_h), and settlement of ground surface (ΔH) was investigated on strut-support system with 6.00 m excavation depth (H_e). The strut support system in medium sand ground is shown in Fig. (4). The width of the excavation (B) = 20 m, and symmetry surcharge load q_1 =q_2 =100 kN/m^2 at distance of 5.00 m away from the Retaining structure. The boundaries were chosen in the x-direction equal to 200 m, while in the Y-direction to be 100 m. The ground soil used in this study is medium dense sand (MDS), the soil parameters used in this study are listed in Table (3).

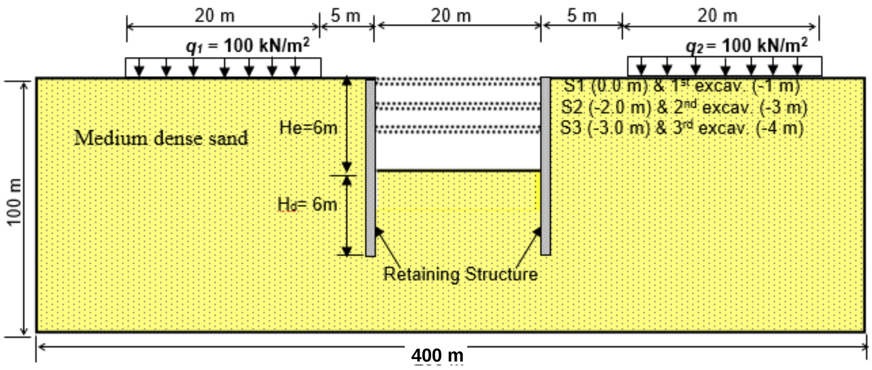


Fig. 4: Sketch of the model for excavation-support system

Table (3) Soil Parameters for MDS

Parameters	MDS
Yunsat (kN/m^3)	17.5
Ysat (kN/m^3)	19.50
Drainage type	Drained
$k_x = k_y$ (m/day)	10^{-8}
$\sum_{50}^{ref}$ (kN/m^2)	31,500
$\sum_{oed}^{ref}$ (kN/m^2)	31,500
$\sum_{ur}^{ref}$ (kN/m^2)	94,500
c (kN/m^2)	0

The deformational behavior of strut-retaining structure was investigated using one trust with five positions: no strut, strut at top of the wall, strut at depth 1.00m or 2.00 m or 3.00 m below the top of the retaining wall. There is no doubt that, the embedded depth has significant effect on the induced straining actions of the supporting system, however, in this part of the study the ratio of the embedded depth to the excavation is taken as 1 as proposed also by Akan [1].

3.1.1 Wall Deflection and Ground Surface Settlement

Deep excavation-support system should be designed taking into consideration the specified limits for wall deflection and the accompanied ground surface settlement, to ensure safety of the work and the adjacent structures (if any). The results of induced wall lateral deflection (δ_h) and settlement of ground surface (δ_v) are plotted in Fig. 4 and 5, and listed in table (4).

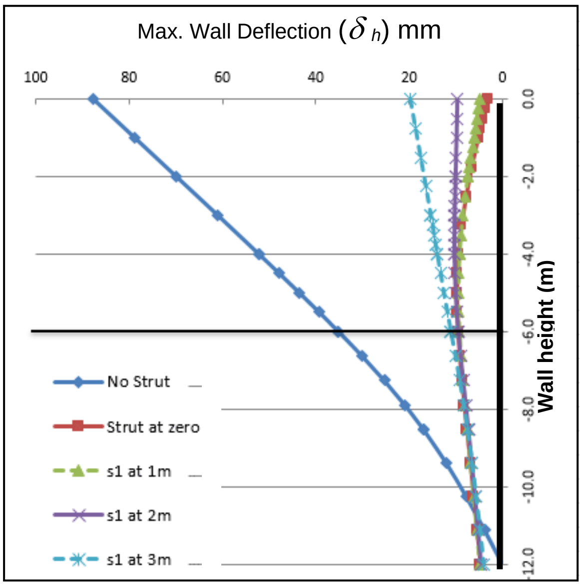


Fig. 4: Wall deflection with strut position

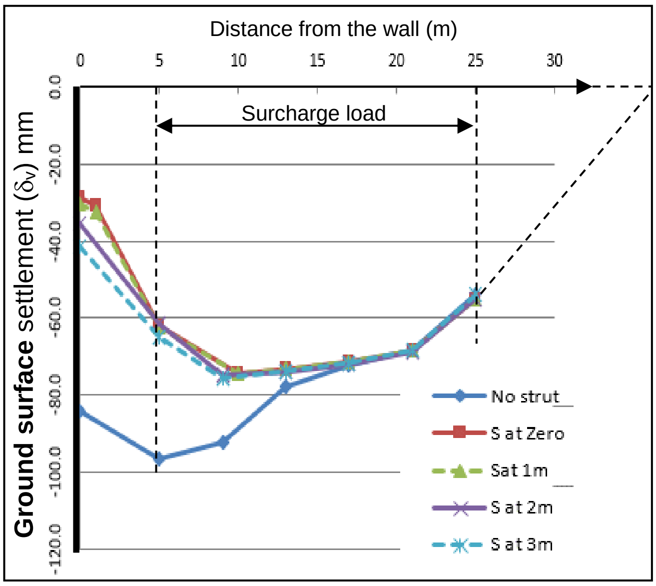


Fig. 5: Ground Settlement surface with strut position

Table (4) Wall deflection (δ_h) and settlement of ground surface (δ_v) with strut position

Strut Position	None	Top of Wall	-1.00 m	-2.00 m	-3.00 m
Max. (δ_h) mm (At depth)	87.85 (0.00 m)	9.71 (-5.00 m)	9.54 (-5.00 m)	10.28 (-3.75 m)	19.71 (0.00 m)
(δ_h /He) ratio	0.015	0.0016	0.0016	0.0017	0.0033
Max./Min.(δv) mm (for distance)	(96.50)/(53.96) (20.00 m)	(73.80)/(53.96) (12.00 m)	(73.80)/(53.96) (12.00 m)	(75.68)/(53.96) (16.00 m)	(75.60)/(53.96) (16.00 m)
Max. Distortion angle ($\Delta\delta v$ /L)	1:470	1:624	1:624	1:736	1:736

BS 8002 recommends the maximum wall deflection to be less than 0.5% (0.005) of wall height for medium dense or firm soils [20], consequently the maximum allowable wall deflection shall be about 30 mm. Therefore, in case of no strut, retaining wall for excavation depth with 6.00 m will be unsafe to act as cantilever wall. Moreover, the associated ground surface settlement will induce angle of distortion ($\Delta\delta v$ /L) less than the safe limit for buildings where cracks is not permissible as (1:500) as recommended by the Egyptian code of Practice (EPC) [21], and the adjacent structure may yield cracks. The ground settlement profile of strut–retaining wall is of concave type, while in cantilever case it seems to of spandrel type. On the other hand, the ground settlement vanishes after about 6 times wall height.

In this stage, all variation of strut position from top of wall to depth of 3.00 m are acceptable for the allowable limits of the wall lateral deflection and the associated ground settlement, and could achieve the safety of the strut- excavation system as well as, the safety of the adjacent structure. Therefore**,** assessment of the induced bending moment and strut force will govern the optimization of the strut position.

3.1.2 Wall Bending Moment and Strut Load

The straining actions induced in the retaining structure such as bending moment along the wall, and load in struts are the main parameters for the design of retaining system. The results of the bending moments and shear force diagrams are presented in Fig. 6 and 7, and the maximum moment (M_{max}) and maximum force in strut (T_{max}) are listed in Table 5.

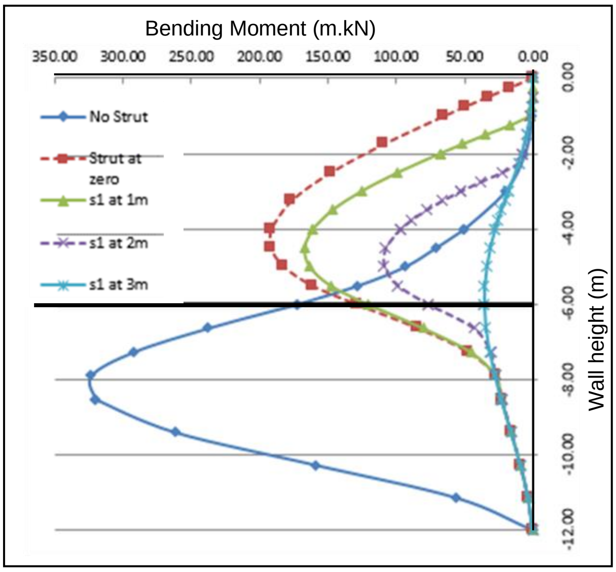


Fig. 6: Bending moment with strut position

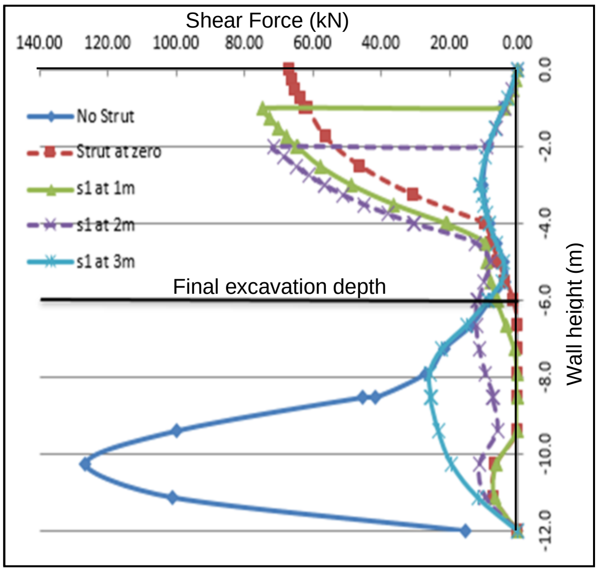


Fig. 7: Shear Force with strut position

Table 5: Maximum moment in the wall and maximum load in the strut

Strut Position	None	Top of Wall	-1.00 m	-2.00 m	-3.00 m
Wall M_{max} (kN.m) (At depth)	322.30 (-8.00 m)	192.30 (-4.00 m)	167.20 (-4.50 m)	109.00 (-5.00 m)	35.84 (- 6.00 m)
M_{max} reduction	-------	40.30%	48.03%	66.18%	89.00%.
Strut T_{max} (kN/m')	-------	199.82	238.70	258.09	244.11
Increase %	-------	-------	+19.46%	+16.00%	+22.17%

From the results and analysis of Table 5 the following observations could be drawn:

(a) - The minimum wall M_{max} is for strut with position at depth of 3.00 m, while the increase of load in strut was only by about 22%.

(b)- Therefore, for excavation with depth of 6.00 m, placing the strut at depth of 3.00 m represents the optimization model for safe and economic design of strut-retaining structure in medium dense sandy ground.

(c)- For all struts the induced wall maximum moment is observed to be at depth of about 3.00 m below the strut position.

For relatively shallow deep excavation such as in the case of 6.00 m, in some projects with retaining walls of tangent piles in sandy ground, the designer may practically prefer to place the strut at the top of the retaining structure (at the R.C. tie beam), the cost of the retaining structure may increase by 150% or more compared to that for strut at 3.00 m.

3.2 Multi-Strut Deep Excavation

In this part the effect of embedded depth, variation of surcharge distance from the wall, density of the sandy ground (Loose and dense), and asymmetric of surcharge loads will be investigated for multi-strut deep excavation with depth of 12 m. The used soil parameters are as previously listed in Table 3 for medium dens sand (MDS).

3.2.1 Effect of Embedded Depth

For multi-struts deep excavation with depth of 12.00 as shown in Fig. 8, the wall deflection, ground settlement, wall bending moment, and load in strut were investigated with embedded depth of 3.00, 6.00, 9.00 and 12.00 m, and under surcharge load of 120 kN/m^2.

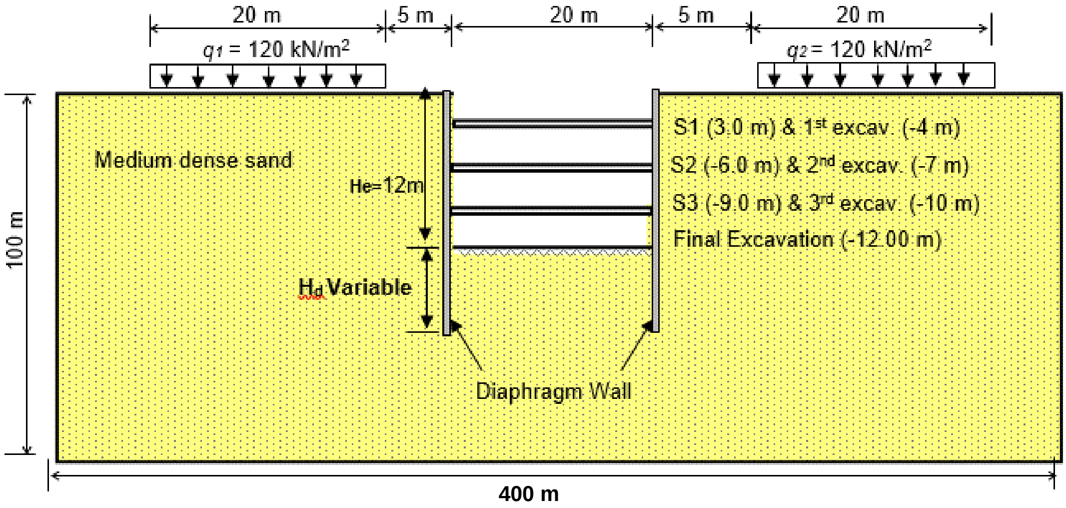


Fig. 8: Sketch of the model for multi- strut excavation system for variable embedded depth

The results of the wall deflection, ground surface settlement, bending moments and shear force, diagrams with the variation of wall embedded depth are presented in Fig. 9 to Fig. 12, and the maximum values are listed in Table 6.

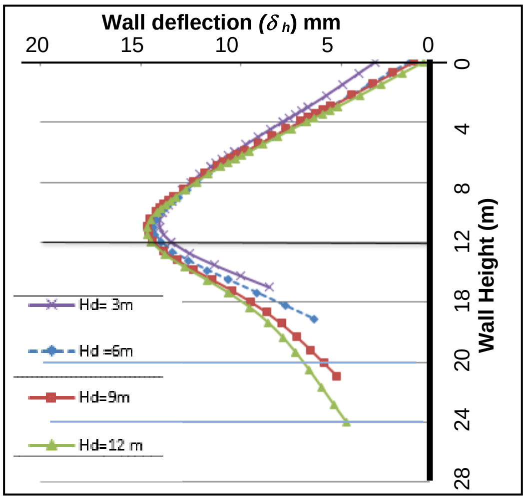


Fig. 9: Wall deflection - embedded depth

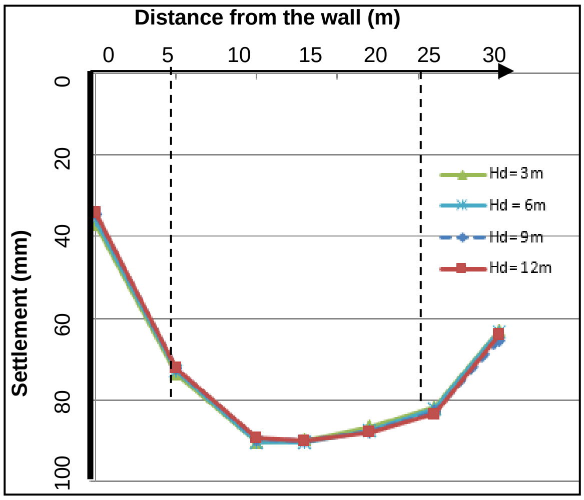
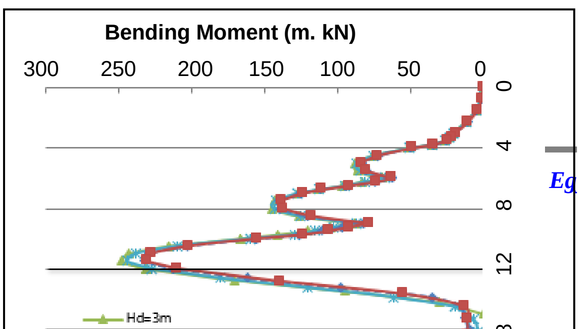


Fig. 10: Ground Settlement – embedded depth



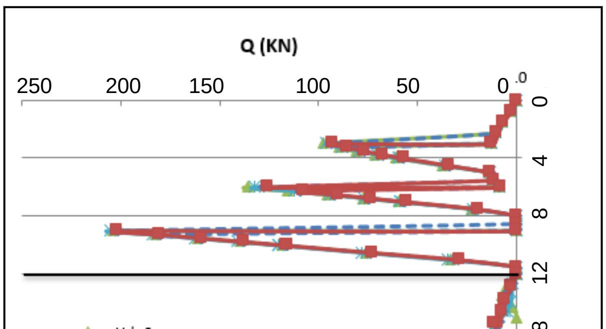


Fig. 11: Bending moment – embedded depth

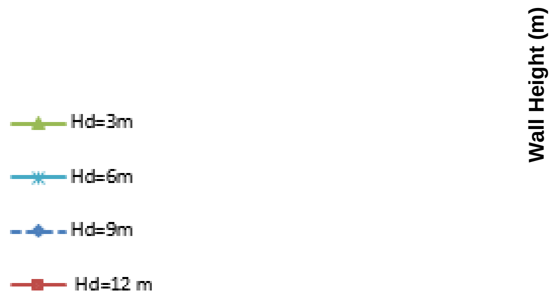


Fig. 12: Shear Force - embedded depth

Table 6: Effect of embedded depth on wall deflection, ground settlement, bending moment and load in strut

Embedded Depth	3.00 m	6.00 m	9.00 m	12.00 m
Embedded/excavated depth (H_d/H_e)	0.25	0.50	0.75	1.00
Wall Deflection Max. (δ_h) mm	14.10	14.30	14.62	14.68
Rate of increase (%)	-----	1.42%	3.68%	4.11%
Ground Settlement Max.(δv) mm	92.30	91.61	91.21	90.87
Rate of decrease (%)	-----	0.75%	1.18 %	1.55%
Wall Max. Moment (M_{max}) kN.m	248.10	243.70	232.10	230.20
Decrease (%)	----	1.78%	6.45%	7.21%
Load In Strut 1st (S1) at depth 3.00 m T_{max} (kN/m')	449.81	398.62	364.31	370.17
Decrease (-) / Increase (+) (%)	----	-11.38%	-19.01%	-17.71%
2nd (S2) at depth 6.00 m T_{max} (kN/m')	695.47	683.26	661.06	653.27
Decrease (-) / Increase (+) (%)	----	-1.76%	-4.95%	-6.07%
3rd (S3) at depth 9.00 m T_{max} (kN/m')	956.38	966.62	951.59	950.34
Decrease (-) / Increase (+) (%)	----	+1.07%	-0.50%	-0.63%

From the results of Table 6 with increase the embedded depth from 3.00 to 6.00 m, the following findings can be observed:

(a)- The values of wall deflection and ground surface settlement are nearly close, with slight average differences of +3.00% and -1% respectively.

(b)- The induced wall bending moment decreased with only average value of about 5%,

(c)- The load in struts decreased with an average value in the range of 1% to 4%, with the higher value for the upper strut.

(d)-The ratio of embedded depth to excavation depth (H_d/H_e) of 0.25 seems to be the most economical and practical ratio, for multi-struts deep excavation with depth of 12.00 m.

A numerically study for the effect of embedded depth [1] had shown that, increasing the ratio of embedded depth to the excavation depth (H_d/H_e) from 0.50 to 2.00, had decreased the induced wall bending moment by only about 8%, while the load in strut decreased by less than 5.00%.

3.2.2 Effect Position of Surcharge Load

The position of surcharge load was investigated for distances of 0.00, 5.00 m and 10.00 m away from the edge of the retaining wall (Fig. 13), under surcharge load of 120 kN/m^{2}m and with embedded depth of 3.00 m. The results of wall deflection, ground settlement, and induced wall bending moment, and load in struts are plotted in Fig. (13) to Fig. (16). The maximum values of the straining actions are summarized in Tables 7& 8.

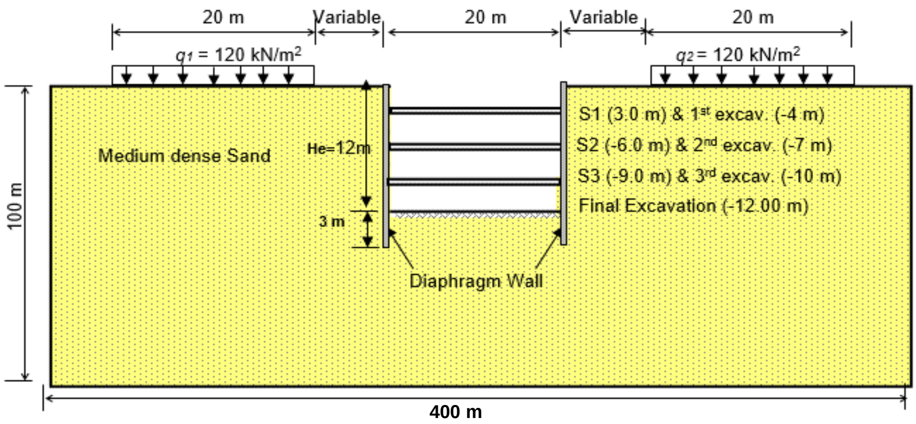
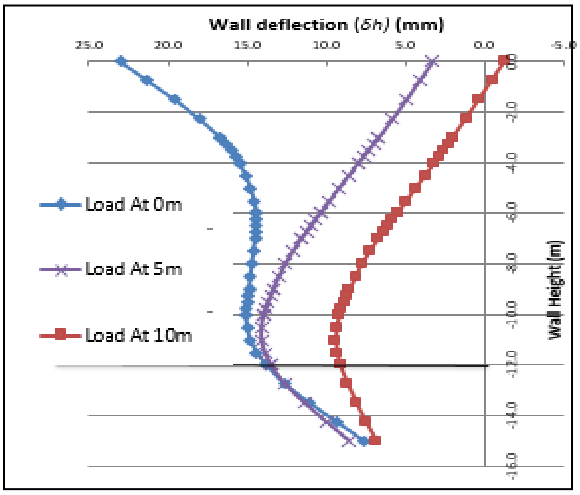


Fig. 13: Sketch of the model for 12 m strut excavation with variable surcharge positions



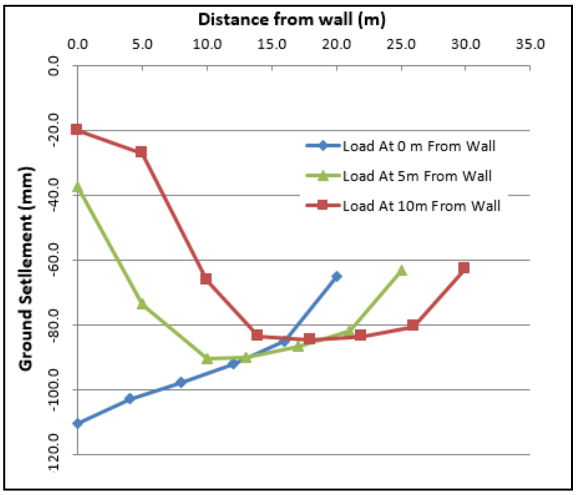


Fig. 14: Wall deflection - embedded depth

Fig. 15: Ground Settlement – embedded depth

Table 7: Wall deflection (δ_h) and settlement of ground surface (δ_v) with variation of surcharge position

Surcharge load Position Relative to the edge of wall	At Zero distance 0.00 m	At distance of 5 .00 m	At distance of 10.00 m
Max. (δ_h) mm (At depth)	23.00 mm (0.00 m)	14.10 mm (-11.00 m)	9.40 (-11.00 m)
(δ_h /He) ratio	0.0019	0.0011	0.0008
Max./Min.(δv) mm (for distance)	(110.07)/(65.00) (25.00 m)	(90.16)/(62.97) (15.00 m)	(84.47)/(62.61) (18.00 m)
Max. Distortion angle ($\Delta\delta v$ /L)	1:554	1:551	1:548

From the results and analysis of Table 7 the following observations could be drawn:

(a)- For all surcharge load positions, the wall deflections are within the limit recommended by British standard as 0.5% of wall height for retaining wall in medium to firm sandy ground.

(b)- The maximum wall deflection is for the surcharge position close to the wall edge, moving the surcharge load for distances of 5.00 and 10.00 m away from the wall, the wall deflection decreases by 40% and 60% respectively.

(c)- The ground surface settlement is significantly affected by wall deformation. Therefore, as the wall deflection decreases with the movement of surcharge load away from the wall, the maximum surface ground settlement was observed to decrease by about 18% and 23% with moving distance of 5.00 m and 10.00 m respectively.

(d)- The angle of distortion of the ground surface settlement due to the maximum differential settlement is in the allowable limit as 1:500, as recommended by the ECP for buildings where the cracks are not permissible.

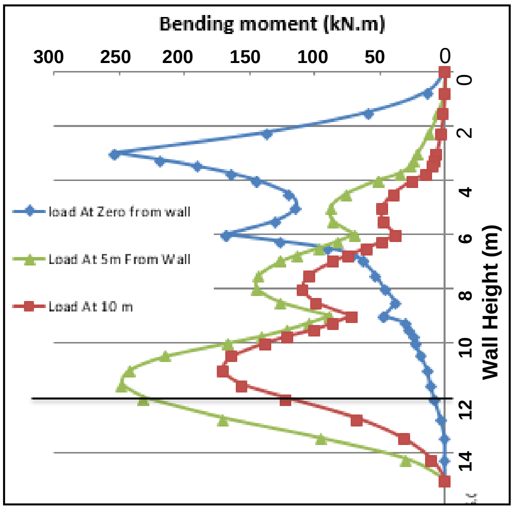


Fig. 16: Bending moment and position of surcharge load

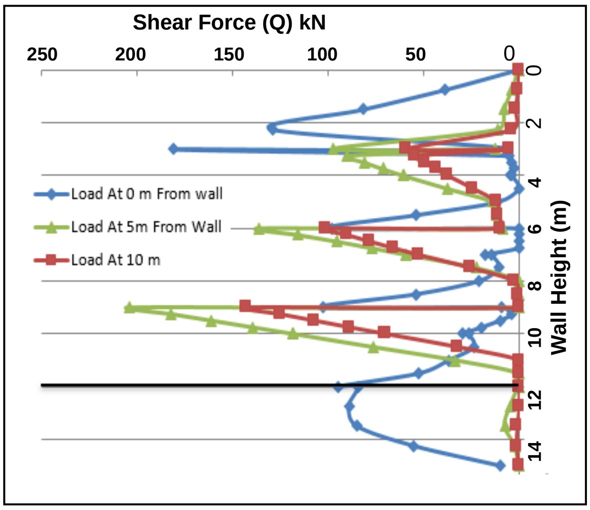


Fig. 17: Shear Force and position of surcharge load

Table 8: Effect of embedded depth on wall deflection, ground settlement, bending moment and load in strut

Surcharge load distance from the wall	0.00 m	5.00 m	10.00 m
Wall Max. Moment (M_{max}) kN.m (At depth)	253.4 (3.00 m)	248.10 (11.50 m)	170.10 (11.00 m)
Rate of decrease (%)	----	2.00 %	33.00 %
Load In Strut 1st (S1) at depth 3.00 m T_{max} (kN/m')	982.00	449.81	237.29
Reduction (-) or increase (+) in strut load	----	- 54.19	-75.84
2nd (S2) at depth 6.00 m T_{max} (kN/m')	832.47	695.47	467.91
Reduction (-) or increase (+) in strut load	----	-16.45	- 43.79
3rd (S3) at depth 9.00 m T_{max} (kN/m')	996.98	956.38	653.90
Reduction (-) or increase (+) in strut load	----	-4.07	-34.41

From the results of Table (8) it can be observed that:

(a)-. The wall induced maximum bending moment decreased by about 33% for surcharge load at distance 10.00 m away from compared to that at the wall edge. While moving the surcharge load to distance of 5.00 m reduced the maximum bending moment by only 2%.

(b)- The load in struts decreased by an average value of 65%,30% and 19% for the upper, middle and lower struts respectively.

(c)- The effect of surcharge load may be vanishing at distance of 20.00 m, i.e. after approximately 1.50 times the excavation depth. It is miss-leading to roughly estimate the effect of surcharge load at distance 10.00 m on the wall using the approximate 2:1 method.

3.2.3 Effect Density of Sandy Ground

The effect of type of sandy ground as loose (LS), medium dense (MDS) and dense sand (DS) was investigated for the current multi-strut retaining structure (fig.18) The used soil properties are as previously listed in Tables 1 & 3.

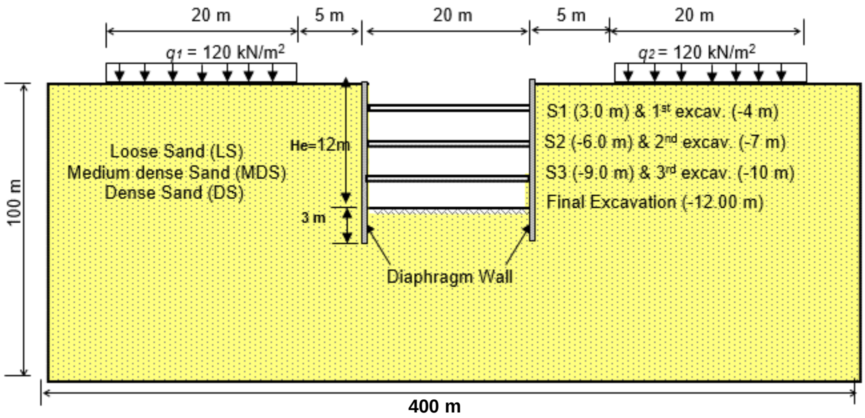


Fig. 18: Sketch of the model for 12 m strut excavation with variable density of sandy ground

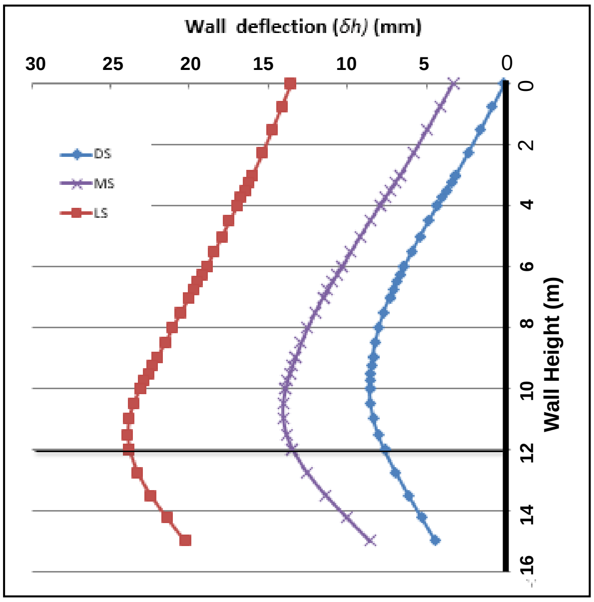


Fig. 19: Wall deflection for LS, MDS & Ds

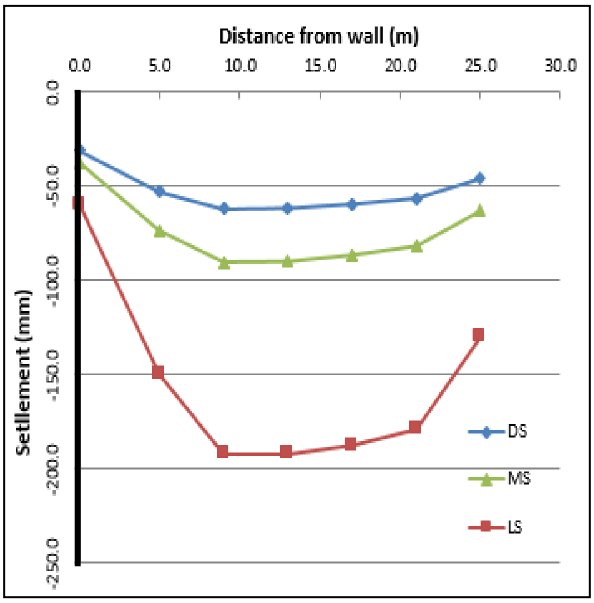


Fig. 20: Ground Settlement for LS, MDS & Ds

Table (9) Wall deflection (δ_h) and settlement of ground surface (δ_v) for LS, MDS & DS

Soil Type	Loose Sand (LS)	Medium Dense Sand (MDS)	Dense Sand (DS)
Max. (δ_h) mm (At depth)	23.90 mm (-11.50 m)	14.10 mm (-11.00 m)	8.60 (-10.00 m)
(δ_h /He) ratio	0.0020	0.0012	0.0007
Reduction (%)	----	41.00%	64.00%
Max./Min.(δv) mm (for distance)	(192.97)/(129.76) (12.00 m)	(90.16)/(62.97) (15.00 m)	(62.50)/(45.70) (12.00 m)
Max. Distortion angle ($\Delta\delta v$ /L)	1:190	1:551	1:741
Reduction in max . (δv)	----	53.00%	67.61%

From the results and analysis of Table (9) the following observations could be noticed:

(a)- The wall maximum deflection (δ_h) in case of medium dense and dense sandy ground is less than that of loose sand by about 41% and 64% respectively.

(b)- The Egyptian code of practice (EPC) [22] mentioned that, the approximate lateral deflection to mobilize the active earth pressure is in the order of $5x10^{-4}$ and 2x 10-3 of wall height for dense and loose sandy soil respectively. For excavation depth (He) = 12.00 m, the wall approximate lateral deformation required to mobilize the active are in the order of 6.00 and 24.00 mm for dense and loose sandy ground, the recommended values are the top of wall for cantilever retaining wall without surface surcharge load. Therefore, straining actions of the sandy backfill ground of the multi-strut retaining wall system is nearly at rest state rather than active state.

(c)- In case of loose sand (LS), the maximum angle of distortion due the maximum differential settlement of ground surface under the surcharge load is higher than the value recommended as 1:500 for buildings where cracks are not permissible.

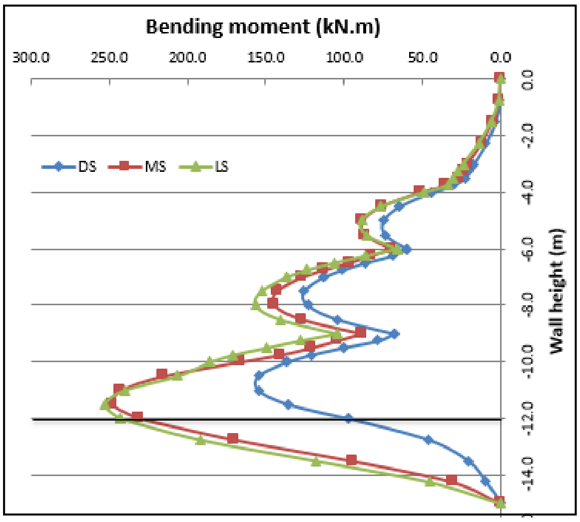


Fig. 21: Bending moment for LS, MDS & DS

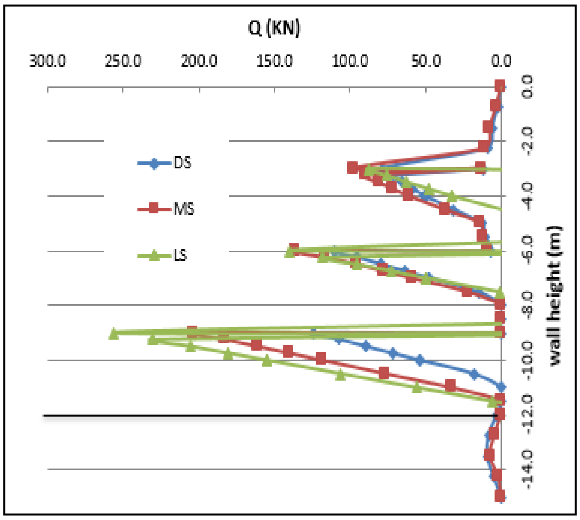


Fig. 22: Shear Force for LS, MDS & DS

Table 10: Effect of soil type on wall maximum bending moment and load in strut

Soil Type	Loose Sand (LS)	Medium Dense Sand (MDS)	Dense Sand (DS)
Wall Max. Moment (M_{max}) kN.m (At depth)	253.40 (-11.50 m)	248.10 (-11.50 m)	154.40 (10.50 m)
Reduction (%)	----	2.10 %	39.00 %
Load In Strut 1st (S1) at depth 3.00 m T_{max} (kN/m')	470.05	449.81	355.52
Reduction %	----	4.30%	24.36%
2nd (S2) at depth 6.00 m T_{max} (kN/m')	778.00	695.47	526.49
Reduction %	----	10.61%	32,33%
3rd (S3) at depth 9.00 m T_{max} (kN/m')	1208.46	956.38	626.08
Reduction %	----	20.86%	48.20%

From the results of Table 10 the following findings can be observed:

(a)- Increasing the density of the sandy soil from loose to dense had decreased the wall maximum bending moment by about 30%.

(b)- In general, for all types of sandy soil the force in struts decrease with the increase of soil density. The reduction in strut load is with an average value of 14%, 21% and 34%, with higher reduction for the lowest strut position.

3.2.4 Asymmetrically Loaded Strut-Supported Excavation System

The effect of surcharge load in symmetric and asymmetric surcharge (q_L on left wall, and q_R on right wall) cases was investigated using the current multi-strut retaining model (Fig. 19), with excavation depth of 12.00 m and three strut levels.. The ground is medium dense sandy soil, with embedded depth of 3.00 m, and the surcharge load was kept at distance of 5.00 m away from the wall.

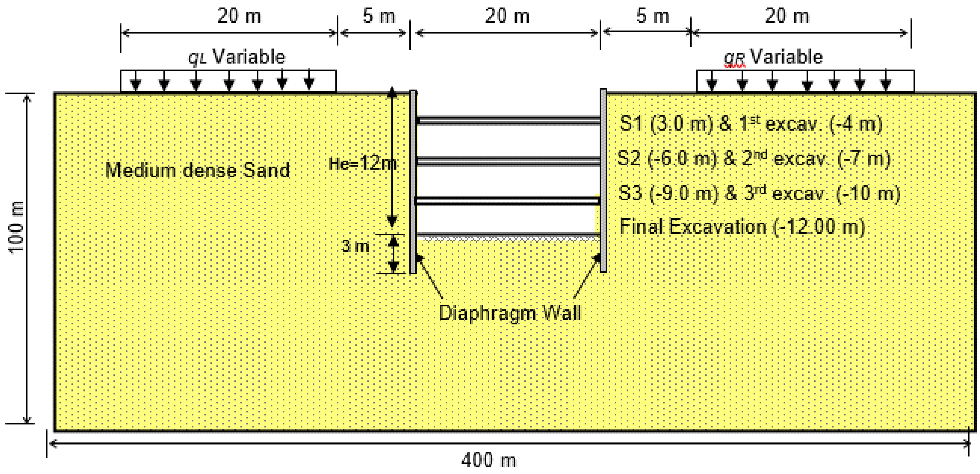


Fig. 19: Sketch of the model for 12 m strut excavation with variable of surcharge load

The results of asymmetry surcharge loads on the induced maximum bending moment and surcharge load are listed in Table 11

Table 11: Comparison between left and right wall max. bending moment and ground settlement

Case No.	Surcharge Load (kN/m²)			M max. (m.kN)			Max. Strut Load (T_{max}) kN		
	q_L	q_R	q_L/q_R	M_L	M_R	Reduction in M_R (%)	S1 (3 m)	S2 (6 m)	S3 (9 m)
1	0	0	1.00	125.3	125.3	0.00	221.61	375.79	506.83
2	40	0	------	148.40	117.10	21%	261.52	411.94	536.64
3	80	40	2.00	179.70	147.30	18%	315.98	504.66	659.81
4	90	30	3.00	186.30	139.80	25%	327.59	511.09	551.87
5-a	120	30	4.00	205.10	138,80	32%	374.30	560.48	700.81
5-b	120	120	1.00	248.10	248.10	0.00	695.47	956.38	248.10
Reduction				17%	44 %	----	17%	19 %	27%

From the results and analysis of Table (11) it can be observed that:

(a) - Increase the asymmetrical surcharge load ratio from 1.0 to 4.0, had increased the reduction in the maximum bending moment induced in retaining wall with lower surcharge load by about 32%. The maximum load in strut increases with increasing surcharge load for both asymmetric and symmetric loading

(b)- Comparison of cases (5-a & 5-b) show that, taking the asymmetry loading into consideration, and not to analysis the lift wall only with the higher surcharge load as the worst case had led to reduction in the maximum bending moment in the left and side walls by 17% and 44% respectively. On the other hand, the loads in struts reduced by 17%, 19% and 27% for the upper, middle and lower struts respectively.

(c)- The reduction in maximum bending moment and loads in struts reflects the interaction of both walls in braced systems and the importance of evaluating them together.

4. CONCLUSIONS

From the present numerical study for deep excavation-strut retaining structure concerning the adjacent structures, the following findings could be drawn:

1- Retaining wall with depth more than 4.5 m may not act as stable cantilever wall. For one-strut deep excavation with depth of 6.00 m, moving the strut to depth of 3.00 m below the wall top represents the optimism position. On the other hand, sometimes for practical application the strut may be placed at the top of the wall, that may increase the wall bending moment by more than 400%, which means higher economical cost.

2- Investigation the effect of embedded depth with range of 3.00 to 12.00 m, for multi-strut deep excavation with depth of 12 m and 20 m width, in medium dense sandy ground and under surcharge load of 120 kN/m^2 had shown that, the ratio of embedded depth to excavation depth (H_d/H_e) of 0.25 seems to be the most economical and practical ratio.

3- Moving the position of the building surcharge load to a distance of 10.00 m away from the wall edge, had decreased the wall maximum bending moment by about 33% compared to that at the wall edge. The effect of surcharge load may be vanished after a distance of about 1.50 times the excavation depth. It is miss-leading to roughly estimate the effect of surcharge load at distance 10.00 m on the wall using the approximate 2:1 method.

4- Increasing the density of the sandy soil from loose to dense had decreased the wall maximum bending moment by about 30%. The wall maximum deflection (δ_h) in case of medium dense and dense sandy ground is observed to be less than that of loose sand by about 41% and 64% respectively.

5. The strut-supported excavation systems should be built as a whole rather than separately since the behavior of the retaining walls on the left and right sides is impacted by one another.

6. Taking the asymmetry loading into consideration, and not to analysis the left wall only with the higher surcharge load as the worst case had led to reduction in the maximum bending moment in the left and side walls by 17% and 44% respectively. On the other hand, the loads in struts reduced by 17%, 19% and 27% for the upper, middle and lower struts respectively. The reduction in maximum bending moment and loads in struts reflects the interaction of both walls in braced wall systems and the importance of evaluating them together.

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