EFFECT OF STRUTTED EXCAVATION CORNERS ON GROUND DEFORMATIONS IN CLAY

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ABSTRACT

In the last decades, Deep excavations in populated urban areas had been become a traditional practice. One of the essential for such excavations is to prevent damage to the nearby existing buildings. In order to guarantee the security for the existing buildings and excavation site, it is needed to predict possible problems. In order to evaluate the wall deformation and soil displacements, numerical analyses and empirical methods shall be taken into consideration. In numerical analysis the use of 2D modelling computer programs considered that modelled section is continues infinitely with the same geometry through the perpendicular axis to the section. However, any variation the supporting conditions and stiffness of pit corner in this perpendicular axis effects the behaviour of the deformation. Therefore 3D modelling computer programs provide more realistic solution considering any effect of 3D behavior. In this paper, A 3D analysis computer modeling program PLAXIS 3D is used to study the corner effect on the behavior of the ground deformation around the braced excavation pit. It was found that the deformation decreased when go far from the center of excavation. The corner stiffness has a significant effect on the wall deformation.

Keywords: deep Excavation, Numerical Analysis, PLAXIS 3D, and Corner effect

1- INTRODUCTION

Most of the urban areas have deltaic soils creating by rivers and oceans; they comprise sediments such as silts, clay and sands under shallow groundwater table. Such deltaic soils are often encounterred in the most densely populated areas, like Egypt.

Due to space limitations in such urban areas, underground construction has become a communal practice. Basement construction or underground utilities are proposed to be developed nearby old and historical buildings or infrastructures. Deep excavations may generate ground movements (Lateral deformation and vertical settlement) that can lead to significant distortion and cracks in the adjacent structures.

The magnitude and shape of ground deformations that are induced by a deep excavation depend on many factors, such as the soil and groundwater conditions, geometry of excavation, existence of adjacent structures, stiffness and penetration of the retaining wall, and spacing and stiffness of the struts. Furthermore, in certain excavations, the magnitude and shape of the ground deformations are also affected by the distance from the interested location to the corner of the excavation. The effect of the section’s location on the deformation is known as the three-dimensional or the corner effect.

Majority of braced excavation analyses assume a plane strain condition, ie. The length of the excavation wall is assumed to be infinitely long, and thus analyses are performed 2D. However this two dimensional analysis may be incorrectly

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represent the actual soil movements, especially for the excavation in which the wall length is considered short (i.e., the ratio of length to width of excavation is small). In this kind of excavation, plane strain analysis neglects the corner stiffening effect which may lead to smaller ground movements near the corners, and larger ground movements towards the middle of the excavation wall (Finno et al., 2007).

With the advancements of the technology more capable computers are provided which enable three dimensional modelling and new computer programs are released for this purpose. Previous case studies have showed that wall deflections near the corner generated by 2D plane strain analysis are generally overestimated as the restraint effect of the corner is not considered.

2- A GENERAL BACKGROUND FOR THREE DIMENSIONAL MODELLING IS GIVEN BELOW

In 1975 St. John studied a square shaped unsupported excavation in stiff London Clay. Both 2D plain strain, 2D axisymmetric and 3D models are analyzed. According to the results good agreement was obtained between 2D axisymmetric and 3D models however 2D plain strain analysis significantly over predicted horizontal movements.

In 1979 Burland et al. also recommended axial symmetry instead of plain strain in square excavations, further if the excavation supported with diaphragm walls large compressive hoop stresses are arisen along diaphragm walls which does not represent a realistic consequence(Lee et al., 1998)

In 1995 Lee et al. reported that in soft soils corner effect is getting stronger and this showed that 2D models to be much more sensitive to soil parameters than the 3D models.

In 1995 Liu reported that in deep excavations which are strutted densely corner effects are suppressed above the excavation level but under the excavation level it is again possible to see the corner effect preventing high wall deflection.

In 1998 Lee et al. stated a comparison between field data and 2D, 3D analysis. The results of the 3D analysis are mostly in agreement with field data, some differences are also obtained due to the construction delay and over-excavation.

In 2000 Ou et al. published a case study about Taipei National Enterprise Centre Project and it is reported that plain strain condition could be occurred 34.4 m away from the corner, excavation depth was 19.7 m and construction method was topdown.

In 2002 Beadman and Cheng utilized results of four case studies to calibrate an empirical method for calculation of displacements around corners which was developed by Arup Geotechnics in London. Then in 2010 Fuentes and Devriendt developed a new empirical method for calculation of displacements around corners.

3 - FINITE ELEMENT MODEL AND PROCEDURES

The next section will study the corner effect of strutted deep excavation on the hypothetical case of strutted deep excavation. It was assumed that one layer of medium stiff clay extended around the excavation plan and depth. Also, the anchors are replaced by levels of steel struts. The commercially available PLAXIS 3D, three-dimensional and plane strain geotechnical finite element software package, was employed to conduct the effect of corner stiffness on the ground deformation.

4- DESCRIPTION OF EXCAVATION SITE CONDITION

The excavation was 40m long and 24m wide. The construction was carried out using the bottom-up method in 5 excavation stages with 3-levels steel struts, and the maximum excavation depth was 12.0 m in the final excavation stage. The excavated pit was retained by a 0.9-m-thick and 18-m-deep secant pile wall. Fig. (1) shows the layout plan and the cross section and. Also, figure (2 and 3) show the structural elements of the strutted side support system and excavation process using PLAXIS 3D program. Hardening soil model is used for soil modeling in PLAXIS 3D and the input parameters for medium clay soil are as per table (1).

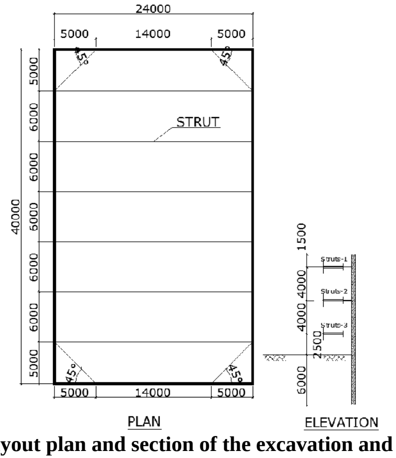

Fig. 1- Layout plan and section of the excavation and strutting system (By the researcher)

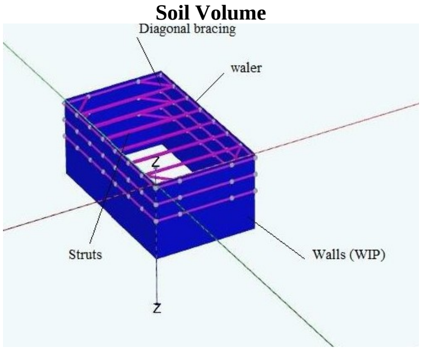

Fig. 2- Structural elements in 3D model of the strutted excavation (PLAXIS 3D) (By the researcher)

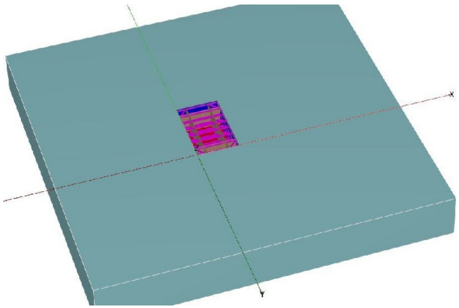

Fig. 3- Stages of excavation using PLAXIS 3D(By the researcher)

Table 1 Parameters of Hardening Soil Model for Medium Clay used in the Analysis (By the researcher)

Hardening Soil Model		Undrained Medium clay
Type	Unit	
γ_{unsat}	$[kN/m^3]$	18.85
γ_{sat}	$[kN/m^3]$	18.85
$K_x = K_z$	m/day	0.00015
K_y	m/day	0.00009
E_{50}	$[kN/m^2]$	5000
E_{oed}	$[kN/m^2]$	4000
E_{ur}	$[kN/m^2]$	15000
C_{ref}	$[kN/m^2]$	0.05
ϕ	°	25.6
ψ	°	0
ν	-	0.2
ρ^{ref}	$[kN/m^2]$	100
power (m)	-	0.85
K_0	-	0.568

5- ANALYSIS AND DISCUSSION

5-1- Corner effect on the ground deformations

Ground deformation means both the lateral deformation and vertical settlement. Vertical settlement has a major effect on the distortion of buildings and horizontal deformation affected the lateral stain which cause cracks.

In figure (4), the amount of ground surface settlement is affected by the corner effect, the closer to center of excavation a settlement measurement point is (being farther from the corner), the larger the amount of ground surface settlement that will occur. Therefore, the maximum ground surface settlement took place at the approximate middle position of the wall, and settlements in corner positions were comparatively smaller due to the arching effect with a magnitude of 25%-50% of the maximum settlement.

According to the studies by Ou et al., ground surface settlements are of two types: (1) Concave type and (2) Spandrel type. In either type, the settlement trough consists of a primary influence zone and a secondary influence zone. The slope of the settlement curve in the primary zone is steep, and more heavily influences adjacent buildings. Meanwhile, the slope of the settlement curve in the secondary zone is relatively flat, and has a minor influence to buildings.

As shown from the figure, the primary ground surface settlement lies within a distance of about 1.5 He (He is the excavation depth), and the secondary ground surface settlement lies within a distance of 1.5 to 2 times the excavation depth. Also, the settlement profile shape changed from concave shape at the center of excavation to Spandrel shape near to the corner.

From Figure (5 and 6), it could be seen apparently that the non-uniform deformations of long side of the diaphragm wall occurred, the middle part of diaphragm wall had a greater tendency to deform toward the excavation, and this trend was weak in end of excavation side, the results came from the strengthening effect of corner stiffness of the side supporting wall, which could effectively limit the lateral deformations of the wall in the excavation corners, the maximum lateral deformation was negative (toward the excavation pit) 29.3 mm.

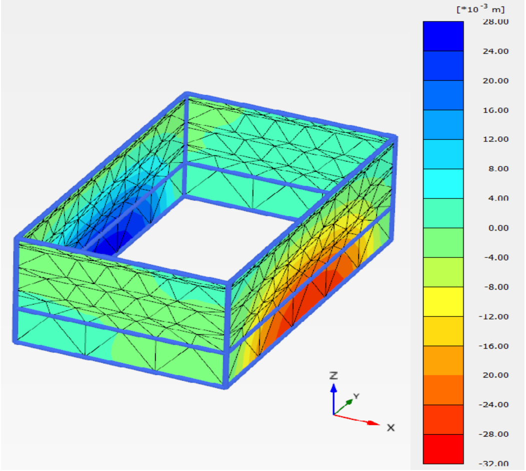

Fig.5- Contours of lateral deformation of the wall in 3D, (By the researcher)

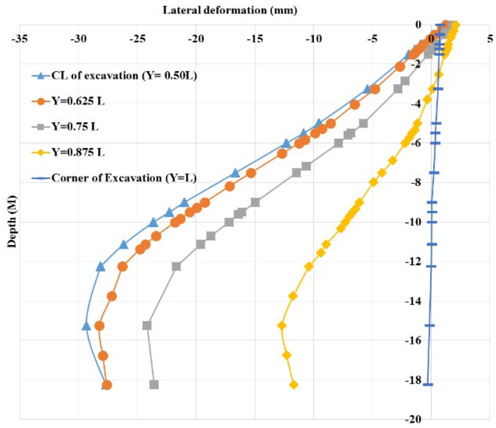

Fig. 6 -Curves of Lateral deformation of the wall at different locations along the excavation side wall(By the researcher)

5-2-Variation of ground deformation with depth

1- Spatial effects of lateral deformation in the horizontal direction with depth

Figure (7) were the lateral deformation curves of long side of the supporting wall in their whole length at the final stage of excavation. It could be seen from the Figure that these curves had the common characteristics, and they first maintained the approximate line for the segment length in the central part of excavation for the depths near to surface, and then converted into a curve at depth near to middle of the excavation depth (0.5 He). In Fig. (7), simultaneously taking 2.0m depth and 14m depth curves for example, the 2.0m depth curve maintained the straight section for about 10m, while the 14 m depth curves maintained a parabola curve. Thus, the side length of pit and a diaphragm wall depth would have an impact on the spatial effects of lateral deformations in the horizontal direction.

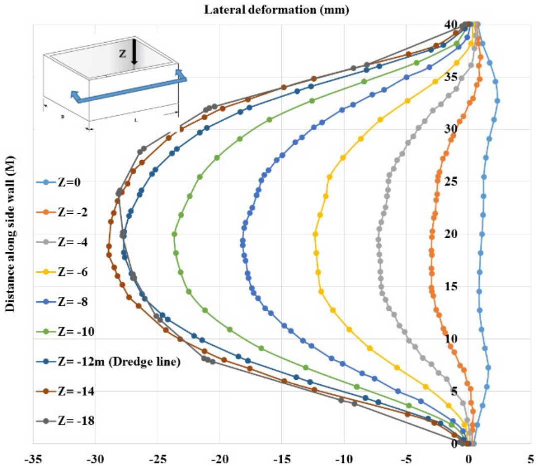

Fig. 7- Lateral deformation of the wall at different levels along the excavation side wall (By the researcher)

2- Variation of settlement with depth

It is important to know the settlement at different levels behind the wall in order to check the deformation of the adjacent buildings and utilities. As shown on figure (8) the variation is about 15% from the settlement at surface and settlement at depth 12m. The percentage is not significant and can be ignored. Engineer can consider the maxi-mum settlement profile in calculations.

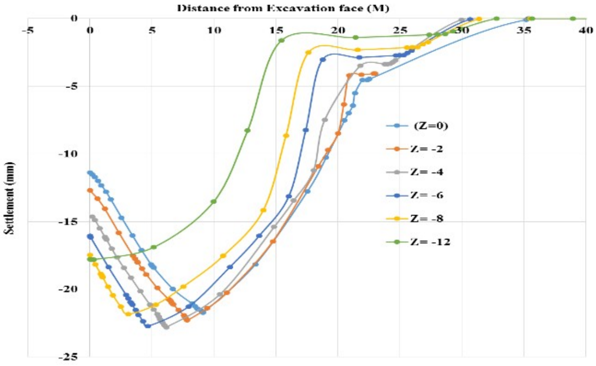

Fig. 8- Settlement profiles behind the wall at different Levels at centerline of excavation (By the researcher)

5-3- INFLUENCE OF THE GEOMETRY OF EXCAVATION (THE EXCAVATION WIDTH)

A series of parametric studies was performed by varying the excavation length and width to evaluate the 3D effects of the excavation on the wall displacement. In the parametric study, the input parameters for the soils and structures described in the basic model (case of medium clay) remained unchanged. Only the dimensions of the excavation (i.e., L and B) were varied; the values of B/L are (0.25, 0.3, 0.5, 1.0, and 1.0). A total of five 3D simulations were conducted in the parametric study Figure (4.3) display the 3D model on PLAXIS 3D.

Clough and O'Rourke (1990) found that the wider the excavation, the larger the deformation of the retaining wall. As a matter of fact, for a typical excavation the wider excavation, the larger are the unbalanced forces; the larger the unbalanced forces, the greater is the wall deformation.

From Figures (9 to 12) present the settlement profiles behind the wall and lateral deformations with varies B/L ratios, respectively. The B/L ratio would have a significant impact on the ground deformation. The effect of B/L ratio comes from the corner effect, which will be discussed in details in the next sections.

In general, the shorter the plan dimension of the excavation wall, the smaller the movement that will be measured near the center of that excavation wall due to the stiffening effects of the corner. From figure (9) and (11), it was found that the maximum settlement decreased at corner by about 30% of the value at center of excavation. Figure (12) show that there is no significant lateral deformation at the corner.

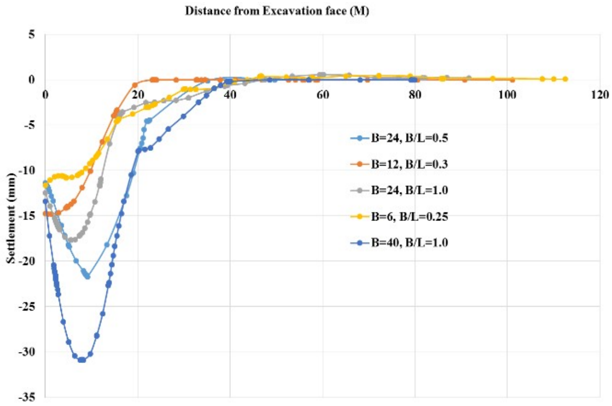

Fig. 9- Settlement profiles behind the wall for different B/L ratios at centerline of excavation (By the researcher)

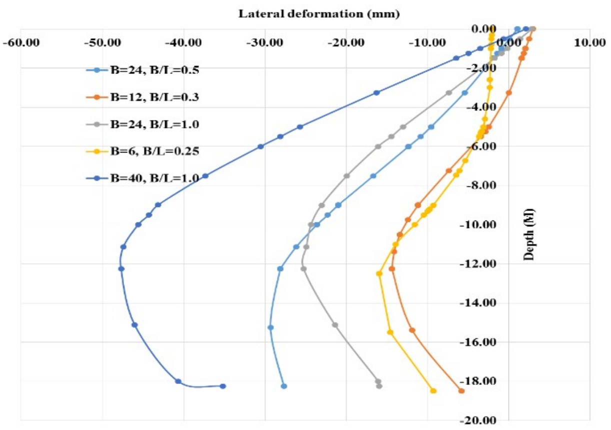

Fig. 10- Lateral deformation of the wall for different B/L ratios at centerline of excavation (By the researcher)

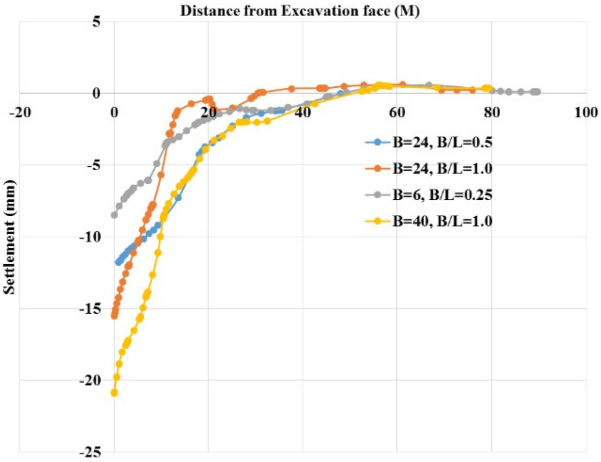

Fig. 11- Settlement profiles behind the wall for different B/L ratios at corner of excavation (By the researcher)

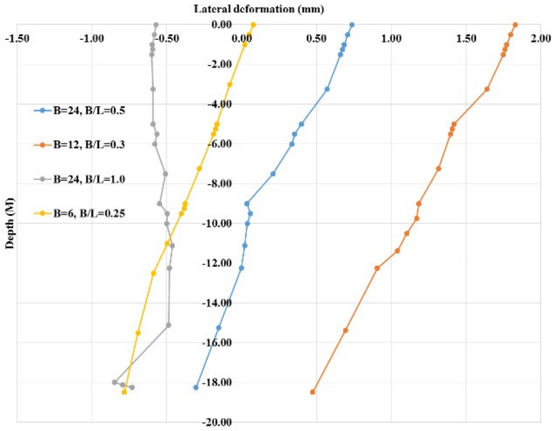

Fig. 12- Lateral deformation of the wall for different B/L ratios at corner of excavation (By the researcher)

6- CONCLUSION

- shorter the plan dimension of the excavation wall, the smaller the movement that will be measured near the center of that excavation wall due to the stiffening effects of the corner.

- The middle part of side wall had a greater tendency to swell toward the excavation pit, and this trend was weak at end of excavation side due to the corner effect.

- 3D analysis is preferred to study the effect of deep excavation on the adjacent building near to the pit corner.

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