STUDYING THE BEHAVIOUR OF DEEP EXCAVATION ADJACENT TO OLD BUILDINGS USING PLAXIS 3D

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ABSTRACT

Due to space limitations in urban areas, a challenging trend to go deeper into the ground, and increase the space required for providing basements, car parking and for utilities etc. Major concern for projects involving deep excavation is the impact of construction related ground movements on nearby structures. This paper studying a case history in Chicago Avenue and State Street Subway Renovation Project in Chicago. A monitoring system was performed during excavation in all the surrounding buildings for the excavation using deformation gauges and settlement points. In this paper, 3D Finite element model is developed using PLAXIS-3D to represent the effect of excavation stages on the wall deformation and settlement below adjacent structure. The analysis is carried out considering non-linear behavior of soil using Hardening soil Model. Results of the models are compared with the real field investigations. In general, better lateral wall movement and ground surface settlement are obtained from the model. Computer simulation technique was an effective method to analyze the influence of pit excavation on the adjacent structures.

Key Words: Strutted excavation, settlement, wall deformation, building response, 3-D Simulation Analysis, Hardening Soil Model.

1- INTRODUCTION

land Space limitations lead to high cost of land in urban areas, a challenging trend to go deeper into the ground, and increase the space required for providing basements, car parking and for utilities etc. The foundation pit with the support system had become widespread. Before site excavation, the soil is in the equilibrium state, the excavation process lead to ground deformations. Some of the deep excavations are very close to existing old buildings and utilities. The safety of the adjacent structures and facilities and may be significantly affected by the ground movement induced by the construction of excavation if no appropriate construction measures are provided. Deformations of the soil around pit and settlement profile under the adjacent building were obtained. Fig. (1) indicates the effect of deep excavation and the response of the nearby structure.

The excavation cause ground deformation (lateral deformation and vertical settlement) below the building and resulting a distort-ion in the structure. The response of buildings to excavation by the ground movements are in the form of deformations and cracks. This paper aims to present a simplified three-dimensional finite element study of a deep excavation in clays. The FEM program, PLAXIS 3D, is selected as the numerical tool and a Subway renovation project nearby existing School building in Chicago selected as case study. The analysis focuses on the initial input of the soil conditions and the constitutive soil models. All the FEM simulations are compared with the data from field investigations.

2. PREVIOUS STUDIES

Many researchers are working in the area of deep excavation and it is observed that the geometry and sequence of construction must be modeled accurately to obtain reasonable predictions with finite element analysis.

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Several relations were made to present the settlement troughs at different distance from the pit wall Bentler (1998) execute a finite element analysis for deep excavations and compare between finite element results and case history. It was concluded that the finite element analysis of deep excavation is a good tool for understanding the behavior and response of deep excavations. Goh (2003) studied a response of pile located adjacent to braced excavation; the study was carried out using numerical model and was compared with field data, which was matching with field data. The maximum detected lateral displacement of the pile was 28 mm.

Choy (2004) has carried out centrifuge modeling tests to investigate the effect of diaphragm wall casting on nearby deep foundation for a soil of dense fine sand. Relations between movement of pile (lateral movement or settlement) and relative slurry level drop were shown. It was concluded that the system stability could be improved by decreasing the trench length and increase the distance of the pile from trench.

3. MODELING

For the numerical simulation, three dimensional finite element program PLAXIS 3D was used. Hardening soil model is used to simulate the soil conditions. The Hardening-Soil model represents a more advanced model for the model of soil behavior. The hardening model is described by three different values of young's modulus. The three different parameters are E_{50}, E_{ur}, and E_{oed}. It gives more accurate description using the three different input stiffness. E_{50} is the tri-axial loading stiffness, E_{ur} is the tri-axial unloading-reloading stiffness, and E_{oed} is the oedometer loading stiffness. For various soil types, the value of the tri-axial unloadding-reloading stiffness (E_{ur}) approximately equals three times the value of the tri-axial loading stiffness (E_{50}). The value of the tri-axial loading stiffness (E_{50}) approximately equals the value of the oedometer loading stiffness (E_{oed}), except for very soft and very stiff soils that tend to give other values of E_{oed} / E_{50}".Structure and supporting wall are modeled using plate elements and struts / Anchors are used to support the wall. Standard boundary conditions are adopted with U_x=0 on vertical sides and U_x =U_y =0 at the horizontal base. Entire calculation was carried out in stages with sufficient number of calculation steps to obtain equilibrium state. The properties of different materials used in the present work are given in Tables (1 and 2).

Table 1 - Hardening Soil Parameters for numerical model (From Blackburn, 2005)

Hardening Soil Model		Undrained Stiff clay	Undrained Medium clay	Undrained Soft clay
Type	Unit			
γ_{unsat}	[kN/m^3]	20	18.1	18.1
γ_{sat}	[kN/m^3]	20	18.1	18.1
$K_x = K_z$	m/day	0.00015	0.00015	0.00015
K_y	m/day	0.00009	0.00009	0.00009
E_{50}	[kN/m^2]	14847	6550	2350
E_{oed}	[kN/m^2]	4267	2380	1600
E_{ur}	[kN/m^2]	44510	19650	10000
C_{ref}	[kN/m^2]	0.05	0.05	0.05
ϕ	°	33	29	24.1
ψ	°	0	0	0
ν	-	0.2	0.2	0.2
ρ^{ref}	[kN/m^2]	100	100	100
power (m)	-	1	1	1
K_0	-	1.5	0.55	0.59

Table 2- Hardening Soil Parameters for Sand Fill and Clay Crust Layers (From Blackburn, 2005).

Hardening Soil Model		Drained Sand Fill	Drained Crust clay
Type	Unit		
γ_{unsat}	[kN/m^3]	18.85	18.8
γ_{sat}	[kN/m^3]	18.85	18.8
$K_x = K_z$	m/day	9.1	9.1
K_y	m/day	9.1	9.1
E_{50}	[kN/m^2]	7185	14370
E_{oed}	[kN/m^2]	7185	14370
E_{ur}	[kN/m^2]	21555	43110
C_{ref}	[kN/m^2]	1	1
ϕ	°	37	40
ψ	°	5	15
ν	-	0.2	0.2
ρ^{ref}	[kN/m^2]	100	100
K_0	-	0.398	0.357

4. SITE DESCRIPTION AND SUBSURFACE SOIL CONDITIONS

The Chicago Avenue and State Street Subway renovation project in Chicago, included the in a soft to medium clay to expose the existing subway station. Figure (2) shows plan and cross section of the excavation pit. The excavation along State Street was about 40.0 m long and 24.0 m wide and was advanced to an average final depth of 12.50 m. The excavation along Chicago Avenue was about 24.0 m long and 7.0 m wide and was advanced to a depth of 8.20. Two structures were the adjacent to the excavation, the Frances Xavier Warde School located at distance about 2.0 m away from the excavation pit side, and the Chicago and State Street subway tunnel-station located underground crossing the excavation area and at level about -2.60m. The school is a three-story reinforced concrete frame structure with a basement. The floor system at each level consists of a reinforced concrete pan-joist system supported by reinforced concrete beams. The beams are supported by concrete columns at interior locations and by masonry bearing walls around the perimeter. The bearing walls rest on a reinforced concrete strip footing, which is at a depth of 4.0 m below ground surface. The interior columns are supported on isolated footings. The continuous wall footings were located at 1.2 m from the excavation along State Street.

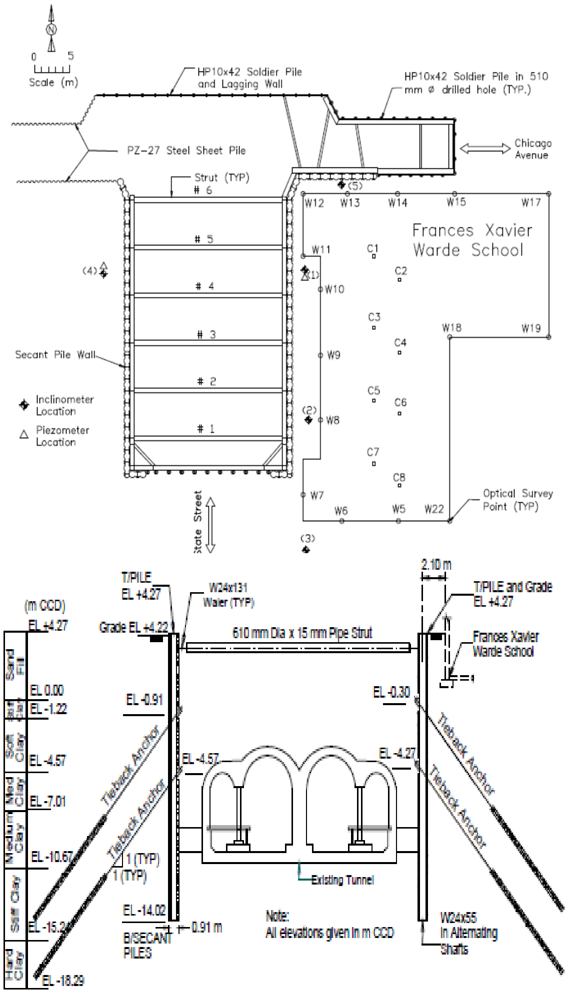


Fig.2- Plan and section View of Excavation Site (After Bryson, 2002)

The section showed an east-west cross-section of the side support system. It was consisted of a secant pile wall with three combined levels of supports. Struts are used to support the first level of the wall and tiebacks were used to support the second and third levels. The combined support was required because the 3.0 m deep basement of the "Warde School" disallowed using tiebacks for the first level and the presence of the tunnel did not permit the use of struts for the second and third levels. The retaining wall was constructed with overlapping 0.915 m diameter secant piles, filled with concrete grout with unconfined compressive strength of 7.0 MPa. Each pile overlapped adjacent pile by 0.15 m. W 24×55 (formed steel section) sections were placed in alternating shafts. The first level of support consisted of 610 mm diameter steel pipe struts with a nominal wall thickness of 17 mm. The pipe struts were installed without preload at a depth of 0.6 m below ground surface and at a 6.1 m center-to-center horizontal spacing. Tieback anchors were used for the second and third levels of support. The 150 mm diameter tieback anchors were installed at 1.5 m center-to-center spacing and at 45°angle with the bonded zone (9.1-10.7 m) located within the stiff and hard clays. Unbounded lengths were at least 9.1 m. The tiebacks consisted of a bundle of four or five, 15 mm, 1860 MPa strands stressed to at least 1.3 times its design load, and subsequently unloaded to 80% of its design load.

Figure (3) shows the subsurface conditions, index properties, and un-drained shear strengths obtained from both laboratory and field tests for the Chicago and State project site. Bryson (2002) defined the soils at the Chicago and State project site as primarily lightly over-consolidated glacial clays.

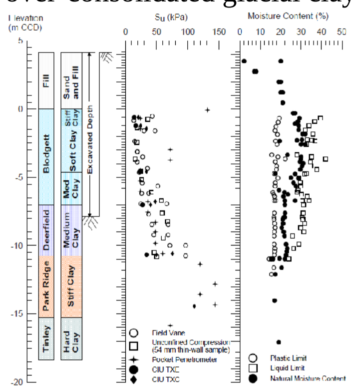


Figure 3 Subsurface Profile (After Bryson, 2002).

5. MODELING OF CONSTRUCTION SEQUENCE

The construction in numerical modeling is executed in stages simulating the exact site process to get a good correspondence. The construction procedure concerning the existing building and its loading. The displacement is reset to zero before starting excavation stages. After the construction of the wall the excavation is carried out in stages.

Table (3) shows the PLAXIS calculation phases used for the simulation of the Chicago and State Street Subway Station and the Francis Xavier Warde School. In table (3), the first column indicates the modeled element, the second column shows the number of calculation phase, the third column explains the purpose of the calculation phase, the fourth column indicates the type of calculation, and the last column specifies the load input condition.

Figures (4,5) show a Schematic of PLAXIS 3D Model Input. Figure (6) shows the distribution of the horizontal displacement in the side wall at the various stages of excavation. It can be noted that the horizontal deformation increases continuously during the excavation.

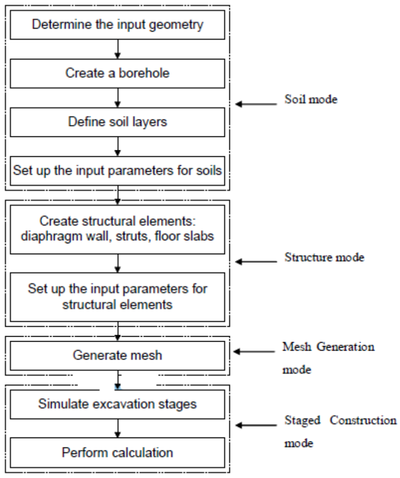


Fig. 4- procedure of modeling in PLAXIS 3D (By the researcher)

Table 3- PLAXIS Calculation Phases (Station Excavation and School). (By the researcher)

Element	Phase	Identification	Calculation	Load Input
Initial stress field	0	Initial phase	K_0 procedure	Staged construction
School construction (late '50s)	1	excavation for school, Place basement wall and footings Backfill surrounding soil	Plastic	Staged construction
	2	Activate school loads	Plastic	Staged construction
	3	Consolidation for 40 years	Consolidation	Ultimate time
Excavation stages of Chicago avenue station	4	Wall installation washed in place	Plastic	Staged construction
	5	Excavation down to level -1.50 m	Plastic	Staged construction
	6	Place first raw of struts @ level -0.6 m	Plastic	Staged construction
	7	Excavation down to level -5.5 m	Plastic	Staged construction
	8	Installation of 1st raw of Anchors @ level -5.0 m	Plastic	Staged construction
	9	Excavation down to level -9.5 m	Plastic	Staged construction
	10	Installation of 2nd raw of Anchors @ level -9.0	Plastic	Staged construction

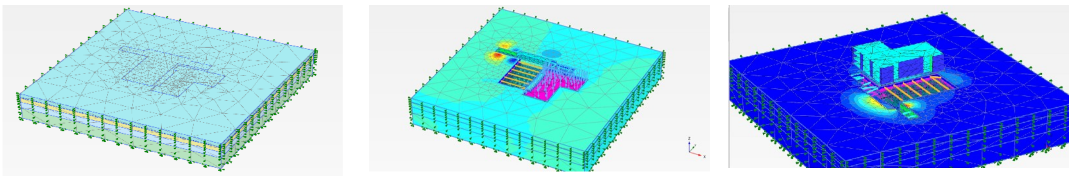


Fig. 5 -Schematic of PLAXIS 3D FOUNDATION Model Input a) 3D view showing Model of soil layers meshing and boundary conditions using PLAXIS b) 3D.considering uniform surcharge c) considering simulation of adjacent building. (By the researcher)

6. RESULTS AND DISCUSSION

As mentioned above the aim of the present study is to determine the ground movements due to deep excavation and to study its influence of the deep excavation on adjacent structures. For this purpose, displacements are determined at various locations in ground and wall movement are obtainned along the depth in the supporting wall. Figure (7) presents the results of the finite element simulations performed to investigate the effects of modeling adjacent structures and the effects of the employed soil model on the lateral deformation due to excavating.

Three different models were used to compare the effect of simulation of adjacent building: (i) a model that simulates the building by a uniform surface load only on the whole area of the school considering 10 kN/m^2 /floor; (ii) a model that consider the building substructure (footings with uniform load) using area method to calculate the load per column and divide the load per footing area to get the pressure under each footing; and (iii) a complete model simulates the building super structure and substructure (floor, basement wall and spread footings) considering own weight, flooring and live load. The effects of modeling the adjacent structures (school) can be seen clearly in Inclinometers 1, 4, and 5. Fig. (7) shows a comparison of lateral movements measured at inclinometers 1, 4 and 5. As shown in fig. (8) the comparison showing that the maximum lateral deformation at inclinometer 1 for the three models (All building, uniform load on building area and uniform load at footings) are 41.2, 24.6, 25.1mm, respectively compared with 38.0mm actual reading. For inclinemeter 4 the deformation values are 57.2, 53.8 and 45.12 MM respectively compared with 55.1 mm actual reading.in addition to that, the values of deformation at inclinometer 5 are 11.5,4.75, 9.95 MM in the mentioned three models respectively compared with 13.2 MM in the actual reading. Furthermore, it is observed that within the clay layers, where the most reliable soil data was obtained, the predicted lateral deformations for Inclinometer 1, 4, and 5 are in better agreement when the school structures are included in the model. Note that the location of the maximum lateral movement moves up to the dredge line agreeing with the measured data.

Figure (9) showing the settlement data for section taken perpendicular to the east secant pile wall through the inclinometer locations. The vertical settlement the comparison shows a good agreement between the results from models and observed actual readings. As presented in figure (3), the maximum values of settlement in the three models (All building, uniform load on building area and uniform load at footings) are 26.9, 15.6 and 15.2 MM respectively comparing with 30.0 MM actual reading.

7- CONCLUSIONS

The results provide an understanding of the effect of braced side supporting system to reduce the ground movements during deep excavation nearby buildings. The following are some important conclusions from the study.

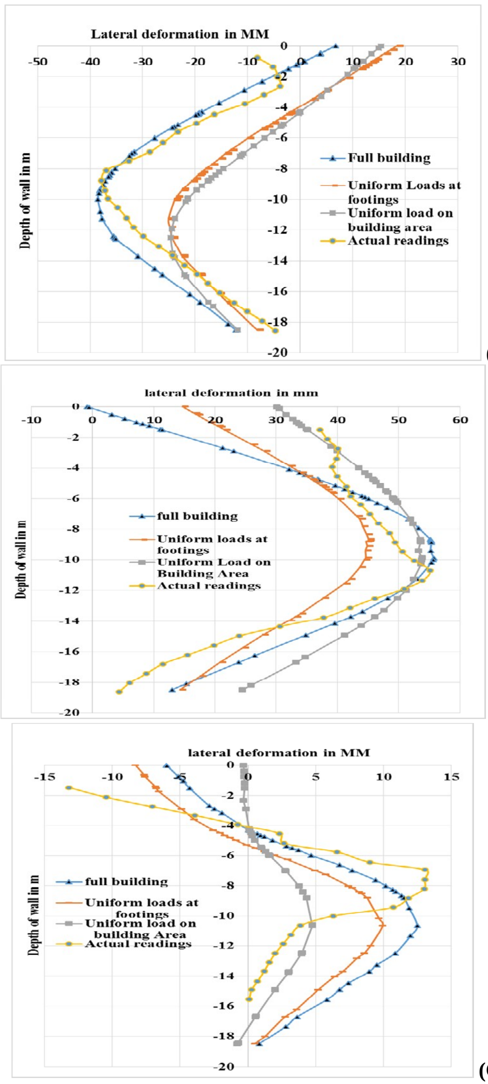
Inclinometer measurements from field showed that the 3D effects on the long sides of the pit wall are small compared to the effects on the short sides. This evidence confirmed other studies on the 3D effects of deep excavations.

-Field technique of deep excavation can be modeled in the numerical model using PLAXIS 3D and the deformation characteristics of the ground and the structure can be computed at any stage.

-The predicted surface settlement profiles coincided with the observed data within the Primary Influence Zone. However, the ground surface settlement measurements did not extend far enough to make a comparison in the Secondary Influence Zone.

-However the values of lateral deformation and vertical settlement are matches with the observed values in case of considering the building simulation in the model, the values are generally accepted when considering the uniform load from adjacent building with reasonable differences.

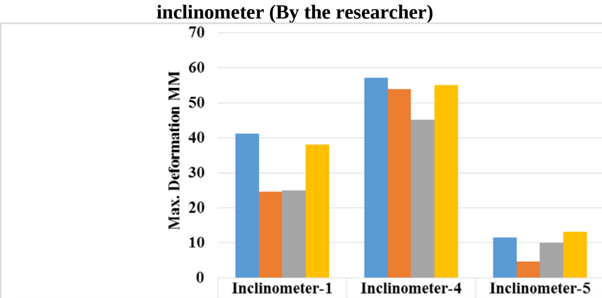
-It is recommended in cases where the designer is involved in the excavation deformation only to model the building as a uniform load to reduce the time and number of elements.



(A) (B) (C)

Figure 7 comparison of wall deflection between simulation and

observation: (a) Wall deformation at inclinometer 1, (b) Wall deformation at inclinometer 4 and (c) Wall deformation at inclinometer (By the researcher)



	Inclinometer-1	Inclinometer-4	Inclinometer-5
Full Building	41.2	57.2	11.5
Uniform Loads ar footings	24.6	53.8	4.75
Uniform Load at Building Area	25.1	45.12	9.95
Actual Reading	38	55.1	13.2

Figure 8 comparison of wall deflection between three models (Full building, uniform load at footings and uniform load at building area versus Actual readings at observation of inclinometers 1, 4 & 5(By the researcher)

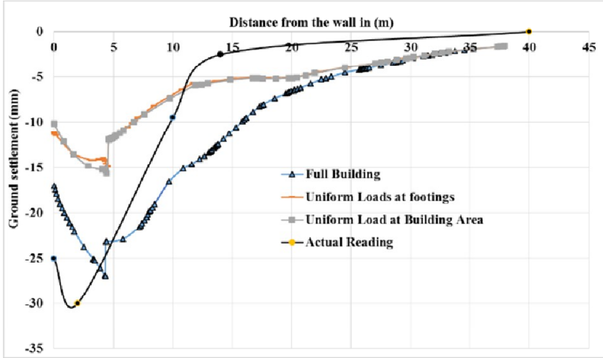


Figure 9 Ground surface settlement diagram behind wall along the center of excavation (By the researcher)

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