

NUMERICAL MODELING OF A TYPICAL EXCAVATION IN GUWAHATI CONSIDERING ON IN-SITU FIELD DATA IN PLAXIS-2D

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ABSTRACT: Considering ongoing scenario due to rapid development of Guwahati city, there is frequent requirement of deep excavation supported by retaining wall, diaphragm wall, sheet pile etc. for underground parking facilities, basement etc. This has been witnessed during numerous projects. In addition, due to space limitation, typically in important areas, excavation is often located near existing buildings or utilities. Thus, in addition to excavation, ensuring the safety of support to adjoining structure as well as understanding the subsoil behavior during various phases of excavation, is very important for overall success of the project. In the present study, finite element method (FEM) based modeling of excavation, at typical site along Guwahati-Shillong (GS) road, is done using PLAXIS 2D. Settlement of surrounding soil as well as the deformation of diaphragm wall, along the depth of excavation and with respect to the stages of construction, are determined to ensure overall safety of the site.

Keywords: Excavation, Guwahati, diaphragm wall, adjoining structure, FEM.

1. INTRODUCTION

With the rapid urbanization of Guwahati city, there follows an increase in traffic flow. There are innumerable shopping mall rising up and thus resulting in lack of adequate space for parking facilities. This has consequently compelled the civil engineers to create additional floor space by excavating deeper into the ground, to meet increasing space requirements for parking, housing of building utilities etc. The faces of the excavation need to be protected by support systems which basically comprises of two parts i.e. vertical wall and supports like struts, anchors etc. This is provided in order to keep the lateral deformation and settlement of soil around the excavation within allowable limits, and to ensure that these above deformations do not compromise the safety of adjoining structures.

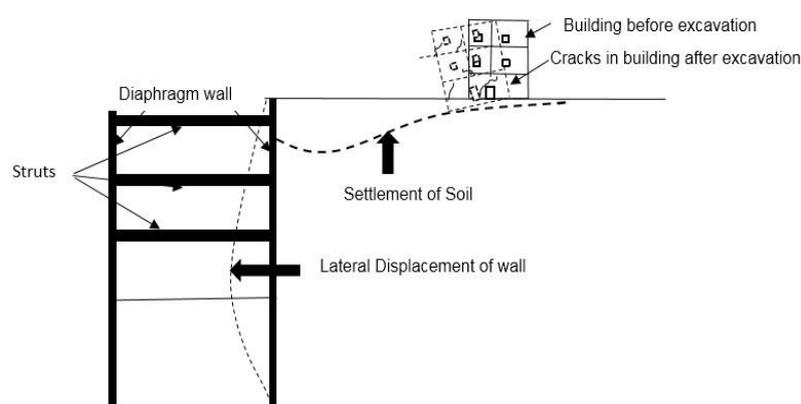


Figure 1: Interaction between excavation and adjacent building

1.1 Site Area:

Guwahati, is the largest city of Assam, situated in India. It is the largest urban area in Northeast India, situated on the bank of the river Brahmaputra. It is one of the fastest growing cities in India. Along the G.S road of Guwahati city, there are several hospitals like Apollo hospital, downtown

hospital, Nemcare hospital etc. There are also many shopping malls like rodraksh, central mall etc., many cinema hall, restaurants to name a few. Thus, it forms the hub of the city because of presence of such important government building. This will create tremendous chaos in traffic condition on the streets. Guwahati falls within the top 20 cities nominated for smart city project in the year 2016. For the above-mentioned reasons, the state government gave contract to make feasibility report and to prepare detailed project report on the introduction of metro rail and a bus rapid transit system (BRTS) to M/S Rites Ltd. by the GMDA.[6] For the present study, borehole data from the project report as shown in Figure 2 is utilized to model the excavation.

0 m	Description of strata	SPT N Value	C (kN/m ²)	Φ (degree)	G	γ _d (kN/m ²)
7.5m	Yellowish silty clay with fine sand mixed pebbles	15	12	24	2.68	14.8
14m	Blackish grey silty clay	29	22	7	2.68	14.1
16.5mm	Yellowish clay	38	22	8	2.69	13.5
18m	Yellowish black fine sand layer	42	0	30	2.66	16

Figure 2: Bore-log data of considered site

In the above borelog, the SPT N value is given which is used to calculate the Young's Modulus of all the soil layers using equation 1 and 2 [1] . Cu is determined from a plot between Cu and N value for clay [11].

$$\text{Clayey Soil, } E = 600 C_u \dots\dots\dots(1)$$

$$\text{Sandy Soil, } E = 750 + 80N \dots\dots\dots(2)$$

By utilising the value of dry uni weight of soil γ_d , Specific Gravity G, of all layers from bore log data the void ratio is determine using equation 3. Which in turn used to calculate the unsaturated unit weight of soil γ_{sat} for each layer with the help of equation 4 [3]

$$\gamma_d = \frac{\gamma_w G}{1+e} \dots\dots\dots(3)$$

$$\gamma_{sat} = \frac{\gamma_w (Gs+e)}{1+e} \dots\dots\dots(4)$$

2. NUMERICAL MODELLING:

The site chosen for the present study consist of four layers of soil as shown in Figure: 2. First layer consists of yellowish silty clay with fine sand mixed pebbles having 7.5m thickness. Second layer consists of blackish grey silty clay of 6.5m thickness followed by third layer of yellowish clay having thickness of 2.5m. Fourth layer is a yellowish black fine sand layer having thickness of 1.5m. This way, a total domain of 18m is modelled.

The numerical modelling of the site selected is done with the help of PLAXIS 2D V 8.0 software as can be seen in Figure 3. The site is approximated as a plain strain model, comprising of 15-noded

elements. Mohr-coulomb model is used to model each soil layer, based on layer properties obtained from borelog. The Mohr-coulomb model is a linear-elastic-perfectly-plastic model, which consists of five parameters, namely Young's modulus, Poisson's ratio, Frictional angle, Cohesion and Dilatancy angle to approximate soil behavior. Based on in-situ subsoil properties mentioned for each layer in Figure 2, Young's Modulus of each of the soil layers are calculated using equations 1 and 2 [1]. It has to be highlighted here that C_u is determined from a plot between C_u and N value for clay [11].

The excavation considered is 9m in depth. Further, for the stability of the excavation, above excavation is done in three stages of 3m each. According to Peck (1969) [9], the maximum settlement, in case of soft to medium clay, which lie directly besides the wall, should be in the range of 1-2%H. Further, this settlement should decrease with increase in distance away from the excavation, up to a distance of 3 to 4H, where H represents the depth of excavation. For this reason, present analysis is done considering the length of soil domain, on either side of excavation, to be 4H i.e 36m .

The diaphragm wall and the struts used for the analysis are modelled using plate elements. The diaphragm wall has a axial stiffness, $EA = 3.32 \times 10^7$ kN and bending stiffness, $EI = 2.769 \times 10^6$ kNm². The E value of the wall is determined using $5000\sqrt{f_{ck}}$, [5] in the present analysis , compressive strength of concrete f_{ck} is assume to be 50 N/mm². The strut is provided with axial stiffness, $EA = 2 \times 10^6$ kN and spacing between successive rows of struts in the vertical plane is equal to 3m [8]. A frame building of height 4m and longitudinal span of 5m supported by two footings separated by 3m, is used to represent the superstructure having a uniform load of 15 kN/m² [8].

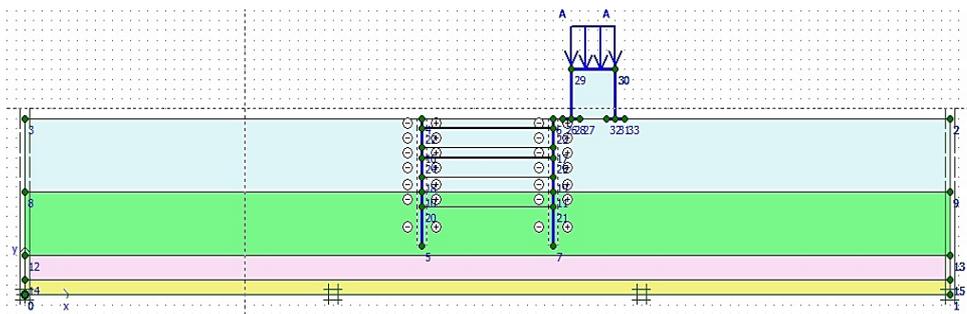


Figure 3: Illustration of the geometry considered

3. RESULTS AND DISCUSSION:

Based on above discussed input parameters, the analysis is done in PLAXIS 2D V 8.0. Since the objective here is to analyze the effect of soil behavior during excavation on the safety of adjoining structure, outputs in terms of variation in shear stress, settlement and lateral displacement at various locations along the excavation are observed.

In the first attempt, the excavation is modelled without diaphragm wall. In this case, it is observed that during first 3m of excavation itself, the side of the excavation becomes unstable with rotation and collapse of the structure. This is due to release in vertical stresses at 3m depth, along with loss of lateral support to the soil around the excavation. As it is a layer of soft clay, it does not have enough stiffness of its own. Hence, second attempt is made considering diaphragm wall as lateral support. This diaphragm wall is provided to support the excavation. Based on this second analysis, it is observed that the wall can support the soil up to 5m of excavation. However, in case of excavation beneath that depth, the excavation becomes unstable , resulting in rotation of the structure as can be observed in Figure 4.

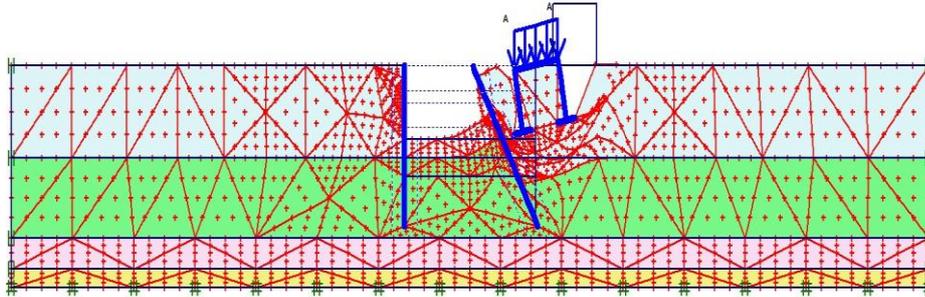


Figure 4: Deformed mesh of the excavation when diaphragm wall is considered without struts

In further analysis, an attempt is made to check if the increase in thickness of the wall would suffice the stability of the excavation. Earlier the thickness of wall considered was 1000mm. Attempts are made by increasing the wall thickness at constant rate up to 2000mm and the analyses are repeated. Collectively, it is found that even with the increase in the thickness of diaphragm wall, the excavation becomes unstable on excavating beyond 5m depth from ground surface. Thus, the diaphragm wall alone will not be sufficient for the overall stability of excavation.

Thus, a strut is provided firstly at a depth of 1m from the ground surface and the analysis is carried out. This time it is observed that the support system is able to retain the soil up to the desired excavation depth i.e. 9m without failure. According to Long (2001) [7] for excavations with struts in soft clay, the maximum horizontal displacement and vertical displacement for soft to medium clay is $0.39\%H$ i.e. 35mm and $0.5\%H$ i.e. 45mm respectively, where H represents the depth of excavation. In the present work with strut at 1m depth, it was observed that horizontal and vertical displacement were 80.30mm and 97mm respectively, which are much higher than the allowable displacement. In addition, the differential settlement of the adjacent structure is also checked for this case, which is found to be 23mm. According to Coduto (1994) [3], the allowable differential settlement for framed building of reinforced concrete- $0.0025-0.004L$ ie 20 mm, where L is the longitudinal span of the structure. Thus, both in terms of allowable total displacement as well as differential settlement of adjoining structure, the excavation is found to have failed.

In the next step, analysis is revised by providing one more strut at 4m depth from the ground surface. Again, the horizontal and vertical displacements are checked. It is observed that both these displacements are decreased to 15.18mm and 23.22mm respectively, which fall well within the allowable limit as highlighted earlier. Further, the differential settlement of the structure in this case is 2mm. Thus, all the parameters are well within the permissible limit. Thus, based on the present analysis, two struts in addition to the diaphragm wall are used as support for the excavation ensuring displacement within allowable limits.

Horizontal distance between the excavation face to adjoining structure is another important parameter to decide the effect of excavation of the structural stability. Thus, in further work, the variation in horizontal and vertical displacement as well as shear stress of the soil at the most vulnerable location on the ground surface is checked with the change in distance of structure from the excavation. It has to be highlighted here that the effect of horizontal distance is checked keeping the positioning of struts and thickness of diaphragm wall as constant. It can be observed from the Figure 5, that with increase in horizontal distance of structure from the excavation, there is a decrease in both maximum horizontal and vertical displacement. The vertical displacement i.e. settlement of soil underneath the structure is much more pronounced than the horizontal displacement i.e. lateral displacement of wall. In addition, it can be seen that the effects of excavation are more pronounced when the structure is closer to the excavation. As mentioned earlier, the allowable settlement and lateral deformation for excavation in soft soil is 45mm and 35mm. Thus by comparing it with the maximum vertical and horizontal displacement induced in the excavation, it can be stated that it is safe to excavate at 1m distance from the structure with respect to allowable displacement. From strength point of views, Figure 6 shows the variation of shear stress with the increase in distance of structure from the excavation. It is observed that similar to the displacement, the shear stress also decrease with increase in distance of the structure. On calculating the shear strength of different layer, it is found that the second layer of soil has the least shear strength of 53.86 kPa. Thus, on

comparing the shear strength with the maximum shear stress induced, it can be concluded that it is safe to be excavated at 1m from structure.

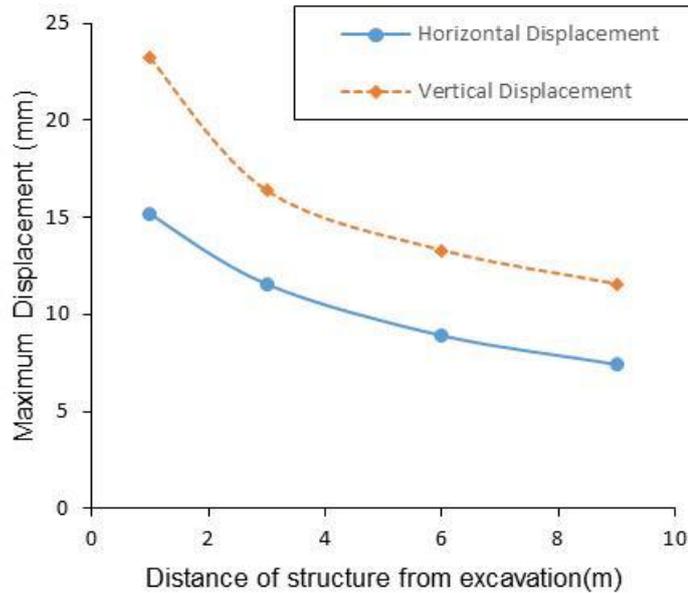


Figure 5: Variation in horizontal and vertical displacement of the ground with change in distance of the structure from the excavation

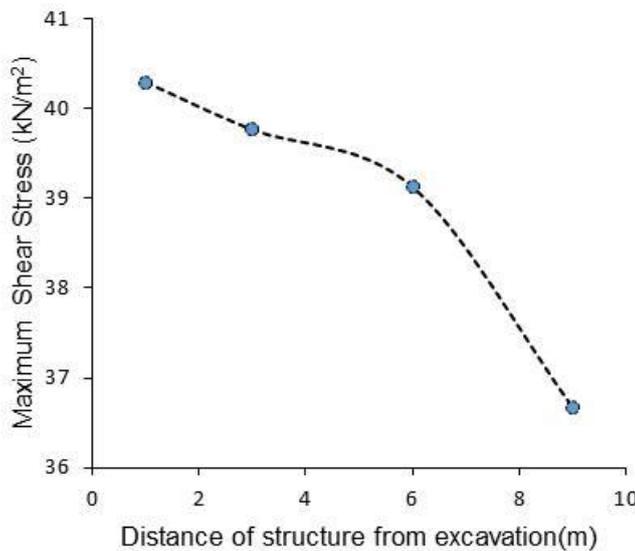


Figure 6: Variation of Maximum Shear stress with change in distance of the structure from the excavation

CONCLUSION:

This paper presents a numerical modeling of an excavation in presence of an adjacent structure. Initially, the excavation failed during first 3m depth of excavation when done without any support system. In second analysis, it is observed that with the addition of a diaphragm wall as support, the excavation is stable up to a depth of 5m and becomes unstable when excavated beyond this depth. In addition, increasing in the thickness of the diaphragm wall is also not effective solution in case of excavation beyond this depth. Therefore, in addition to a diaphragm wall, additional support in the form of strut is attempted. Providing a strut at 1m depth from the ground surface along the diaphragm wall enables excavation up to considered depth of 9m. However, it exceeded the allowable horizontal



and vertical displacement. Providing another strut at 4m depth from ground surface, the horizontal and vertical deformations are found within permissible limits. The effect of the horizontal distance of the structure from excavation is also checked for overall stability. It is observed that the structural elements affect the movement of the soil and walls induced by excavation work. The horizontal and vertical displacements as well as shear stress in ground are observed to decrease with increase in distance of the structure from the excavation. It is also observed that for the present case considered, the excavation can be done safely at 1m distance from an adjacent structure keeping developed stresses within the strength as well as displacement within permissible limits. This judgment is made by comparing the induced settlement, lateral deformation and shear stress of vulnerable location on ground with the allowable limits.

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