BEHAVIOUR OF TIE BACK SHEET PILE WALL FOR DEEP EXCAVATION USING PLAXIS

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Abstract

With the increase in urban population and technological progress, people's demands for a comfortable life have also increased. Shortage of space for parking, public amenities and housing utilities has made necessary to use underground spaces. Deep excavations in urban areas require special measures due to the presence of structures, underground utilities and other engineering constructions existing in the vicinity. Deep excavations are supported by systems like conventional retaining walls, sheet pile walls, braced walls, diaphragm walls and pile walls etc. The design of support systems for deep excavation requires careful analysis, design and monitoring of performance. As such, the performance of support systems for deep excavation requires careful consideration of soil-structure interaction. In this study, 2D Finite element model is developed using PLAXIS to represent the performance of anchored sheet pile wall, stress analysis and deformation characteristics of ground and bending moment distributions in sheet pile wall at all vulnerable locations are identified. The analysis is carried out considering non-linear behavior of soil using Mohr-coulomb failure criteria. The input data include typical building loads, prestressing forces, soil parameters and thickness of sheet pile and hence one of the main focuses is to identify their effects on the performance of tie back sheet pile walls. Results of the study reveal that sheet pile wall method is viable to limit ground movements due to the excavation. Besides, the parametric study shows that considerable reduction in wall deformations and bending moments can be achieved and safe excavation to greater depths is possible with the introduction of tie back sheet pile wall support system.

Keywords: *Deep excavation, Tie back sheet pile wall, Non-linear behavior, Mohr-coulomb criteria.*

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1. INTRODUCTION

Deep excavations are becoming increasingly common for the construction of tall structures, road tunnels, mass rapid transit systems and other facilities in densely built-up areas within the city and suburban areas. Such works would affect nearby structures and their foundations due to ground movement. Excavation can be considered as deep excavation if the excavation is typically more than 4.5 m deep. Deep excavation dictates careful design and planning especially when constructed in urban areas due to the presence of buildings, heavy traffic, lack of space etc. Retaining and support system selection in deep excavation can have significant impact on time, cost and performance

The deep excavations are supported by many retaining systems. The anchored sheet pile wall is quite economical for greater depths. The main advantages of tie back system are

- Adoptable for greater depth and high surcharge load taken with lesser wall movements due to anchorage.
- Lesser penetration depth required due to anchorage.
- Provides high resistance to driving stresses.
- Can act as water resistant structure.
- Flexible, Very simple and rapid implementation.

Sheet pile walls are actually supported by cantilever and tie back system [1]. The cantilever method (Fig-1a) is used for lesser depths (about 5 to 6m) and cantilever walls derive their support solely from the foundation soils, whereas the tie back system (Fig-1b) can be used for deep excavation up to 25m.

a. Cantilever method **b. Tie back method**

Fig -1: Sheet piling methods

Tie back systems are generally very successful in preventing wall movements at the time of construction. The system consists of tendon, which provides the ultimate support for the system, a tension member which transfers the load from the soil retention system to the earth or rock.

2. IMPORTANCE OF THE WORK

There are many structural and soil failures due to lack of improvement in deep excavation and due to improper supporting systems which may cause death at the time of excavation [2]. Excavation accidents and fatalities most frequently involve cave-ins of excavations or trenches, but also may result from a variety of other accident types shown in Fig-2.

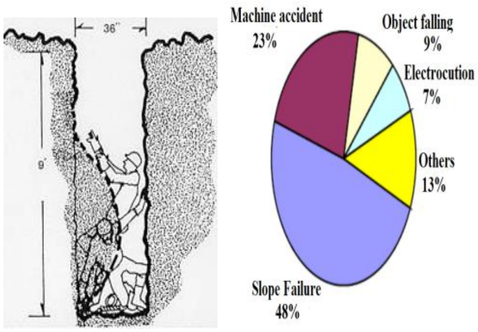


Fig -2: Graphical representation of various causes of deaths during excavation

Another major problem due to the deep excavation is damage caused to the neighboring structures due to the ground movements induced by excavation. Fig-3 shows the response of structure due to the excavation which is in the form of cracks and settlements; Cracks are the main indicators of damage to the building [3].

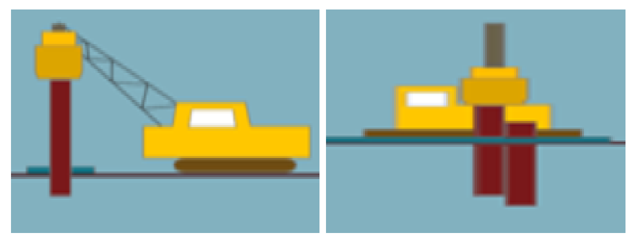
Fig -3: Response of structures to deep excavation

Due to these problems proper measures should be taken for deep excavation. Performance of deep excavations is related to both stability and deformation, Stability can be calculated with sufficient accuracy using simple calculations whereas deformations are more difficult to predict. Finite element analysis is often used for this purpose when ground movements are particularly important. Many researchers are working in the area of deep excavation to reduce the soil failures occurring during the excavation due to supporting systems and structural failures due to excavation.

4. CONSTRUCTION OF TIE BACK SHEET PILE WALL

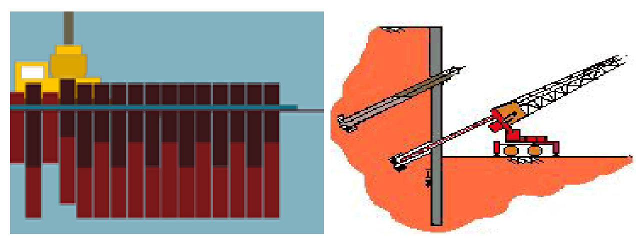
Sheet pile walls are constructed by driving prefabricated sections into the ground. The full wall is formed by connecting the joints of adjacent sheet pile sections in sequential installation. Sheet pile walls provide structural resistance by utilizing the full section.

Vibratory hammers are used to install sheet piles. If soil is too hard or dense, an impact hammer can be used to complete the installation. At certain sites where vibrations are a concern, the sheets can be hydraulically pushed into the ground. Fig-4 shows the stepwise construction procedure of sheet piling.



a. Driving first pile with pilling rig

b. Second pile driving with interlock



c. Repeating process till the desired depth and length

d. Anchoring sheet pile

Fig -4: Construction sequence of tie back sheet piling

Initially a guide beam is placed on the ground to set out the position of sheet pile wall. The pilling rig lifts up the sheet pile and drives it into the ground leaving 1m of the sheet pile at the top for extension of pile for greater depths by welding. The pilling rig drives the second sheet pile into the ground ensuring the inter lock between first pile and second pile. The process is repeated until the desired depth is reached. The anchoring is provided at sufficient depth for stability by prestressing the tendon.

4. MODELLING

For the numerical simulation, two dimensional finite element code PLAXIS [4] version 8.5 was used. Mohr-coulomb model is used to model soil. The linear-elastic-perfectly- plastic Mohr-coulomb model involves five parameters, namely Young's modulus, Poisson's ratio, Frictional angle, Cohesion and Dilatancy angle of ground. The convergence and boundary effects are ensured. Fig-5 indicates the effort to ensure that the convergence criteria are satisfied. For this purpose, modeling of tie back sheet pile, building and the soil is made using very fine mesh size to coarse mesh size. At the most vulnerable location (at 2.5m beside the sheet pile wall) in the ground, horizontal displacement is computed under different mesh sizes. It is observed that idealization with medium mesh size yielded satisfactory results.

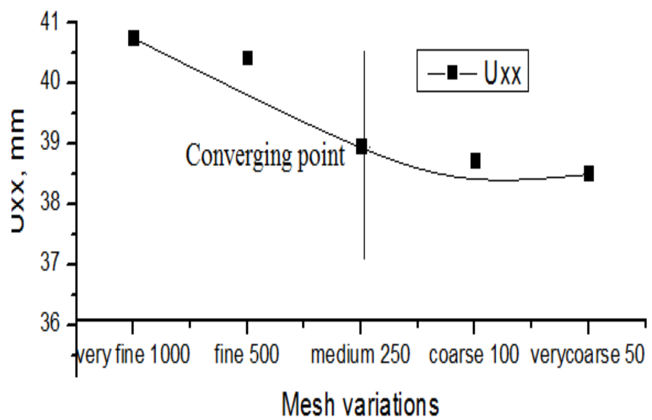


Fig -5: Convergence effect with variation in mesh size

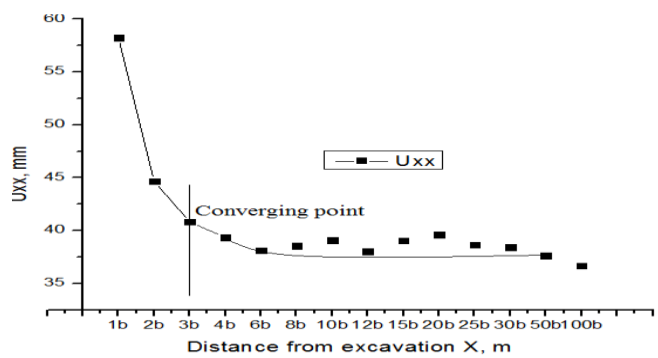


Fig -6: Boundary effect with increasing soil medium either side of Excavation

Fig-6 presents the efforts towards fixing the boundary of semi-infinite soil mass. For this purpose, length of soil on either side of the excavation is considered to be a function of B, where B is the width of the excavation. It is observed that reasonable accuracy is achieved in terms of boundary effect when the length of soil considered on either side of excavation is about 3B. In the present work, analysis is considered with length of soil beyond the excavation as at least 6B on either side. Structure and sheet pile wall are modeled using plate elements and anchors are introduced at 4m intervals to support the wall. The tendon and grout body are used using anchor and geogrids respectively. Structural load of 20kN/m^2 is considered. Standard boundary conditions are adopted with Ux=0 on vertical sides and Ux =Uy =0 at the horizontal base. Entire calculation was carried out in stages with sufficient number of calculation steps to obtain equilibrium state.

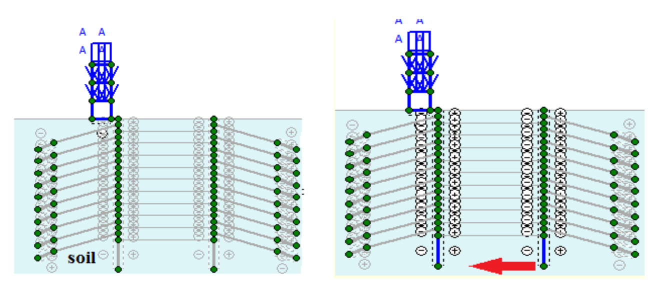
The material properties used for the modeling is given in Table 1.

Table 1: Properties of Soil and Sheet pile wall

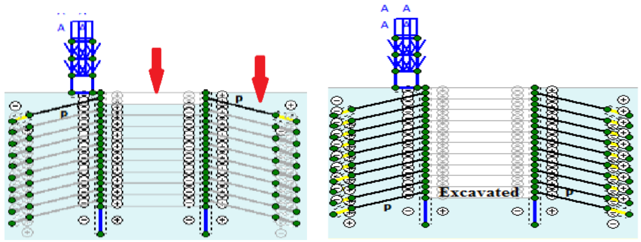
Soil Properties(Drained)	**Sheet pile**
Modulus Of Elasticity = **20 MPa** Cohesion = **20 kN/m^2** Frictional Angle = **30°** Unit weight = **18 kN/m^3**	Height = **20 m** Pile modulus = **200 Gpa** Thickness = **20mm**
Anchor and Grout body	**Beam elements**
Anchor modulus = **200Gpa** Anchor thickness = **25mm** Anchor spacing = **4m** Grout body **M25**	Beam element = **300 mm X 450 mm** Grade of beam **M25**

5. CONSTRUCTION SIMULATION USING PLAXIS

The construction in numerical modeling is carried out in stages simulating the exact field procedure to obtain a good correlation. The construction procedure consists of building the structure on the soil and loading it as shown in Fig-7a. The displacements with gravity loading are neglected. Later with loading there is a rapid increase in the ground movements which are reduced by constructing the sheet pile wall as shown in Fig-7b.



a. Building construction **b**. Sheet pile installation and loading



b. First part excavation and anchoring d. Repeating process till desired depth reached

Fig -7: Construction sequence of tie back sheet pile wall

After installation of sheet pile, excavation is carried out in stages Fig-7c. Later the anchors are introduced and prestressed for wall stability and to bring down the displacements within safe limits.

6. RESULTS AND DISCUSSION

The objective of the study is to understand the behavior of tie back sheet pile wall system to the ground movements caused by excavation. To focus on the deformation and stress characteristics of adjacent structures due to ground movement, soil structure interaction with and without supporting system is modeled and the parametric study is conducted by varying distance of structure from the face of excavation and ground displacements are measured exactly below the structure. Later the effect of penetration depth, stiffness, prestressing force is studied to understand the behavior of sheet pile wall. In this paper bending of wall towards backfill is termed as negative bending and bending away from backfill is termed as positive bending.

6.1 Effect of Supporting System

Fig-8 and Fig-9 show the models of deep excavation and structure at adjacent locations in ground with and without sheet pile wall respectively. From Fig.8, it can be seen that the stability of excavation fails at around 4m resulting in the rotation and collapse of the structure. However, with the provision of supporting system, the excavation can be made to be stable up to 20m. The structure remains stable without lateral movement and vertical settlement as seen in Fig. 9.

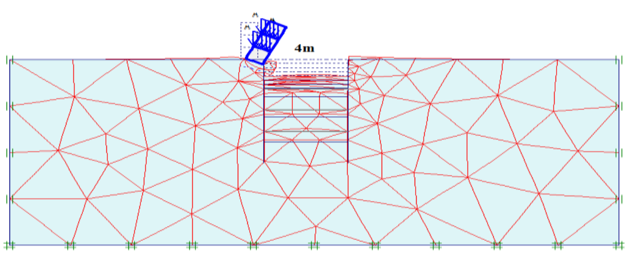


Fig -8: Excavation without supporting system

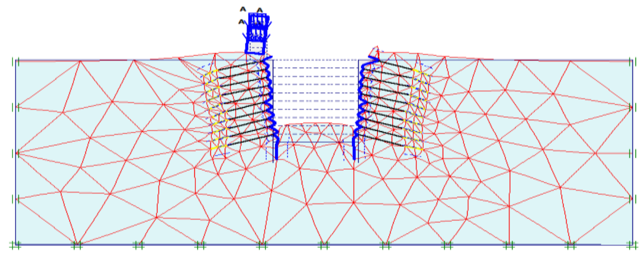


Fig -9: Excavation with supporting system

6.2 Effect of Adjacent Structures and Anchorage Point

The variations in displacements and shear stress exactly below the structure are identified varying the distance of structure from the face of excavation. Fig-10 and 11 show the variation of maximum horizontal, vertical displacements and shear stress, from the graph. It can be seen that horizontal displacements increases with the increase in distance of structure from face of excavation, shear stress in soil appears to decrease with increase in the distance from face of excavation. However, near the end of anchor shear stress appears to increase, perhaps due to soil structure interaction. Hence the anchorage should be done far from the adjacent structures. The vertical displacements are unaffected by anchorage point and displacements decreases with increase in distance of structure from excavation

Fig-12 represents the distribution of horizontal displacement in the ground and structure system. It can be seen that the magnitude of horizontal displacement is more pronounced in the bottom region of sheet pile wall and at anchored point.

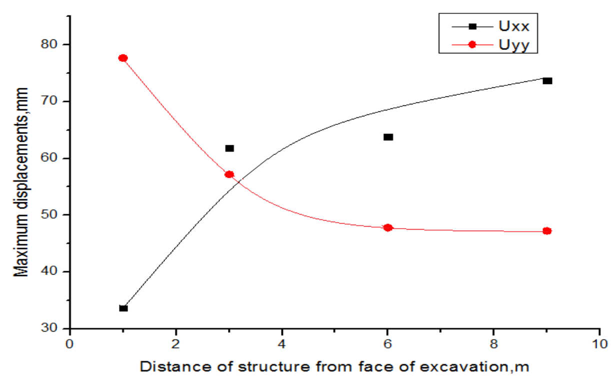


Fig -10: Horizontal and Vertical Displacements in ground with increase in distance of Structure from Excavation

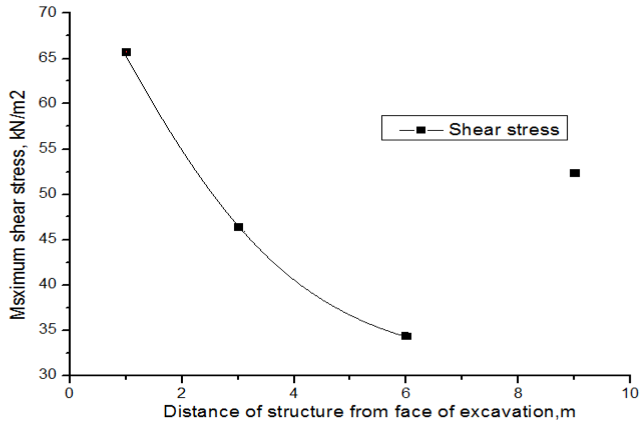


Fig -11: Shear stress variation in ground with increase in distance of Structure from Excavation

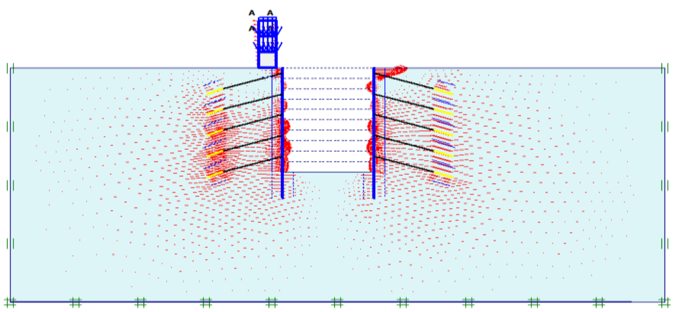


Fig -12: Distribution of Horizontal Displacement

6.3 Effect of Penetration Depth

From Fig-13 represents the variation of horizontal displacements of ground and wall determined at 2.5m beside the wall in soil for ground displacements. The change in wall displacement with increase in depth is minimum because the anchored wall is not displaced both at bottom of the wall and also the anchor position. Although the wall can bend between these positions, the displacement is slightly reduced with increase in penetration depths upto optimum point and remains constant on further increase [5]. Hence minimum provision should be given to the penetration depth due the failure of wall from rotation i.e. upto 3 to5m.

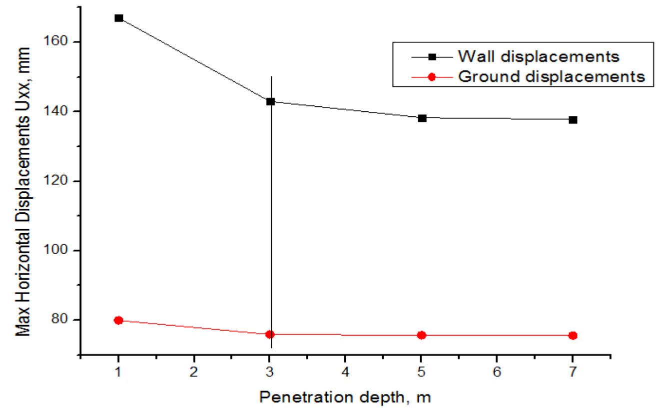


Fig -13: Variation of horizontal displacements with penetration depth

Fig-14 shows the variation of maximum bending moment of sheet pile with increase in penetration depth. The bending moment of wall is passive in nature. It causes negative bending moment, where it increases up to some extent due to passive force and remains constant with further increase in depth.

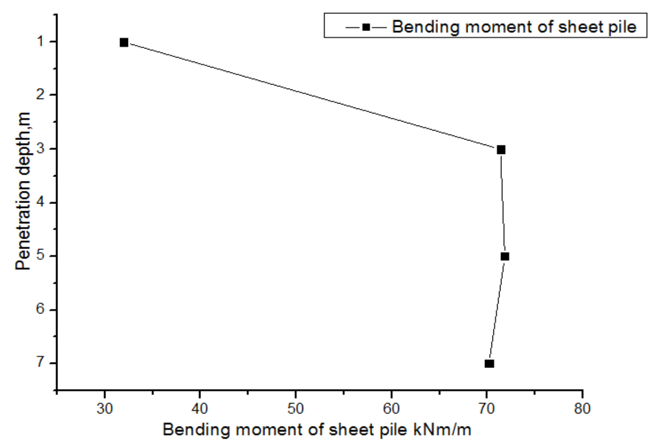


Fig -14: Variation of bending moment of wall with penetration depth

6.4 Effect of Prestresing Force

This parameter helps to identify the force required for the support system to be stable from ground movements. Fig-15 shows the variation of wall, ground displacements of sheet pile wall. Initially displacements are high and are reduced rapidly with increase in force. After reaching optimum force further increase in force may lead to tendon and sheet pile failures. Similar performance is seen with sheet pile bending moment due to the presence of prestressing force the negative bending moment is seen which is shown increasing in Fig-16.

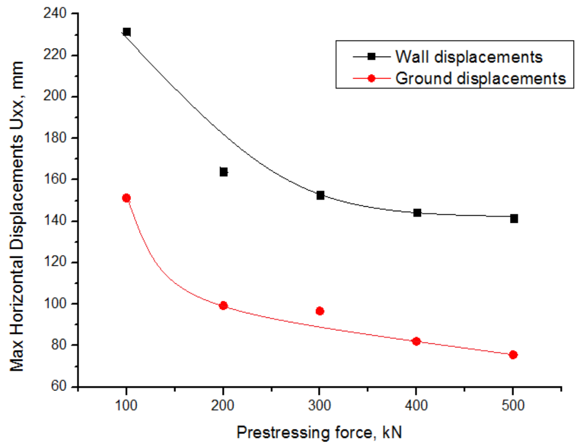


Fig -15: Variation of horizontal displacements with prestressing force

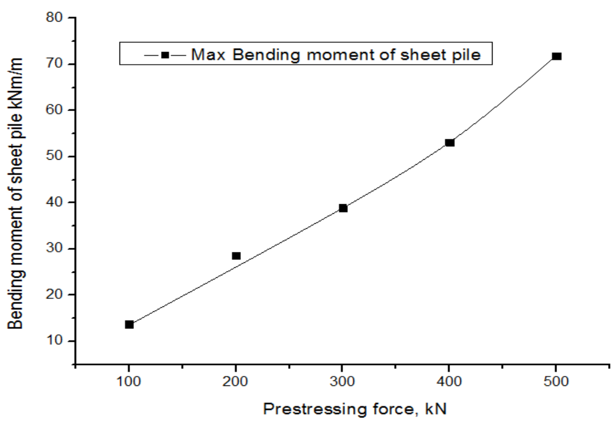


Fig -16: Variation of bending moment of wall with prestressing force

6.5 Effect of Stiffness Of Sheet Pile

Stiffness parameter are considered to determine the most suitable thickness of sheet pile for the given soil condition.

From Fig-17 and Fig-18 it can be seen that with 10mm thickness of sheet the displacement value is very high. With the thickness, depth upto 7m was achieved and further excavation was not possible due to failure of pile. On further increase there is a reduction in displacements and bending moments. In present work 30mm is observed as optimum thickness.

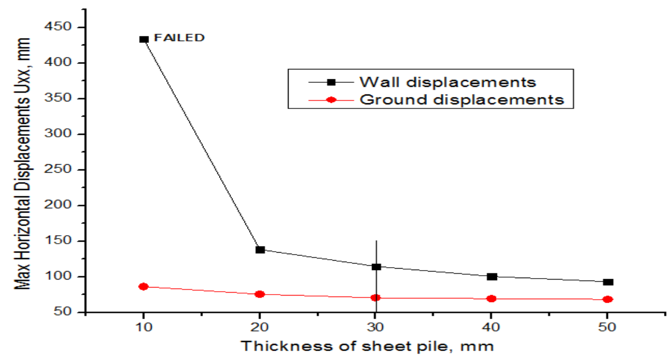


Fig -17: Variation of horizontal displacements with thickness of sheet pile

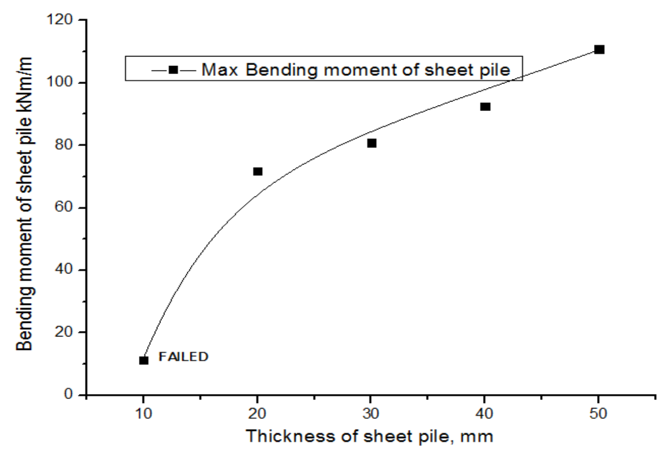


Fig -18: Variation of bending moment with thickness of sheet pile

Further, Fig-19 and 20 shows the variation of horizontal displacements and bending movements of wall along the depth with respect to the ground deformations. It can be seen that the horizontal movement and bending moment of wall increases with increase in depth of excavation. Whenever there is a need to reduce the magnitude of displacement the tie back is adopted at closer spacing.

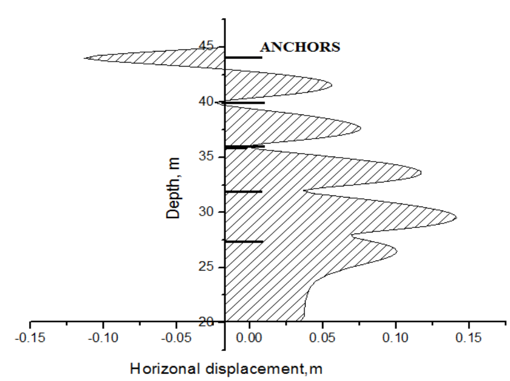


Fig -19: Variation of horizontal displacements

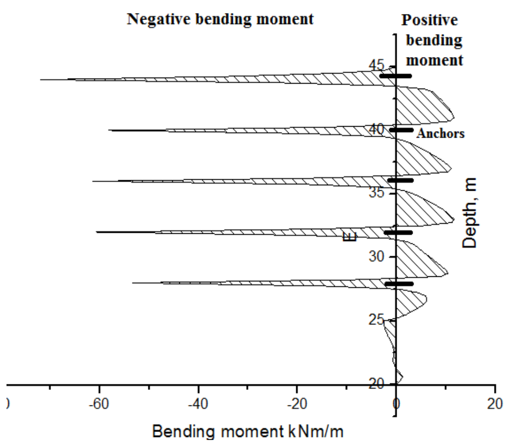


Fig -20: Variation of bending moment

7. CONCLUSIONS

The results provide an understanding of the behavior of tie back sheet pile wall based on the effect of adjacent structures, penetration depth, and pretressing force and stiffness characteristics on the displacements and bending moments of sheet pile. The following are some important inferences from the present study.

- Exact field procedure of deep excavation can be simulated in the numerical model using Plaxis and the strength and deformation characteristics of ground and the structure can be computed at any stage.
- Tie back sheet pile wall method acts as a stable supporting system to excavate for greater depths safely without considerable ground deformations.
- Presence of Anchors below the structure increases horizontal displacements in ground hence anchorage should be done far from the structures.
- Increase in penetration depth reduces 10-15% of wall movements only, whereas there is a drastic reduction in maximum bending moments when walls are anchored. Minimum penetration depth of 3-5m shall be preferred.
- Optimum thickness and prestressing force for the system can be predicted from the analysis.

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BIOGRAPHIES

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