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Effect of Deep Excavation on Adjacent Buildings By Diaphragm Wall Technique Using *PLAXIS*

Dinakar K N[1] and S K Prasad[2]
[1]*(PG Student, Department of Civil Engineering, Sri Jayachamarajendra College of Engineering, Mysore, India)*
[2]*(Professor, Department of Civil Engineering, Sri Jayachamarajendra College of Engineering, Mysore India)*

ABSTRACT
Inadequate space in urban settings has set forth a challenging trend to go deeper into the ground, and increase the space required for providing public amenities, parking and for housing utilities. Closely spaced structures in the vicinity of excavation, presence of underground utilities, and restriction of lateral ground movements have made the supporting systems a formidable task to execute. Deep excavations are supported by systems like conventional retaining walls, sheet pile walls, braced walls, diaphragm walls and pile walls etc. Deep excavations are designed to be stable and to limit deformations due to excavation to acceptable levels on adjacent buildings. In this study, 2D Finite element model is developed using PLAXIS to represent the performance of diaphragm wall on the stress distribution and deformation characteristics of ground below adjacent structure at vulnerable locations. The analysis is carried out considering non-linear behavior of soil using Mohr-coulomb failure criteria. An typical building load is idealized and its effect on excavation and supporting system is analyzed in terms of bending moment, shear force and displacement of diaphragm wall. Results of the study reveal that diaphragm wall method is stable to limit ground movements under buildings considerably and the excavation can be carried beyond 25m safely.

Keywords: *Deep excavation; Diaphragm wall; Finite element analysis; Non-linear behavior; Mohr Coulomb Model.*

1. INTRODUCTION

In urban areas, heavy traffic and lack of adequate space has compelled civil engineers to excavate deeper into the ground to create additional floor space to meet increasing space requirements for amenities, parking and for housing of building utilities. Deep excavation is required for several reasons and can be achieved by different ways. Support provision for excavation depends on the type of soil in the area, the depth of the excavation, and the space around the excavation. Advantages offered by diaphragm walls weigh more favorably for both technical and economical reasons while other methods have distinct limitations. Major advantages of diaphragm wall are as follows.

- It is a permanent structural wall.
- It can be installed to deeper depths and for load bearing elements.
- It requires less temporary propping.
- It can be used for water retainable structures.
- It is preferred for rigid structures that induce considerable ground movements.

Fig 1 indicates the effect of provision of diaphragm wall to support deep excavation and the response of adjacent structure. The effect of excavation is to deform the ground below the structure and cause its movement both horizontally and vertically resulting in distress to structure. The response of buildings to excavation by the ground movements are in the form of cracks and deformations.

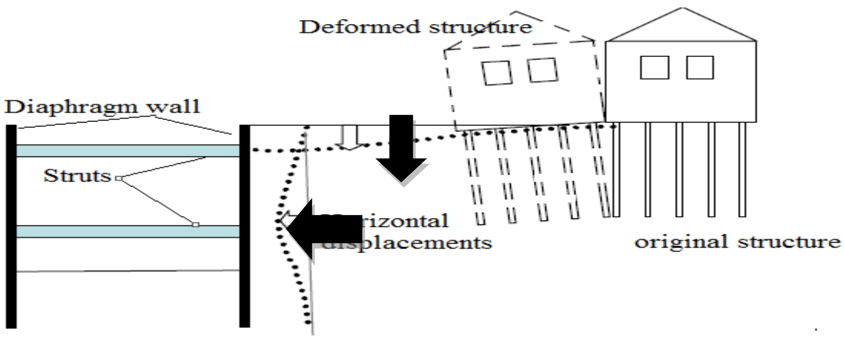

Fig 1: Response Of Structure To Deep Excavation

2. IMPORTANCE OF THE WORK

Since years there are many structural and soil failures due to lack of improvement in deep excavation and due to improper supporting systems. Hence proper measures should be taken for deep excavation. Performance of deep excavations is related to both stability and deformation [1]. Deep excavations are designed to be stable and to limit deformations to acceptable levels. A stable deep excavation is an excavation whose walls do not collapse, and whose base does not heave uncontrollably [2] . Ground deformations around excavations can damage adjacent buildings. The severity and extent of damage depends on the magnitude and pattern of ground movements around the excavation. Prediction of performance of deep excavation involves analysis of 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 and it is observed that the geometry and sequence of construction must be modeled accurately to obtain reasonable predictions with finite element analysis [3]

3. CONSTRUCTION OF DIAPHRAGM WALL

Diaphragm wall is a reinforced concrete structure constructed in-situ panel by panel. The wall is usually designed to reach very great depth. RC Guide walls of 1m to 1.5m depth are mainly used to assist the trenching operation. Each panel is excavated by using cable operated mechanical clamshells suspended from crawler, throughout the excavation Bentonite slurry is maintained at the top of the excavated trench for wall stability.

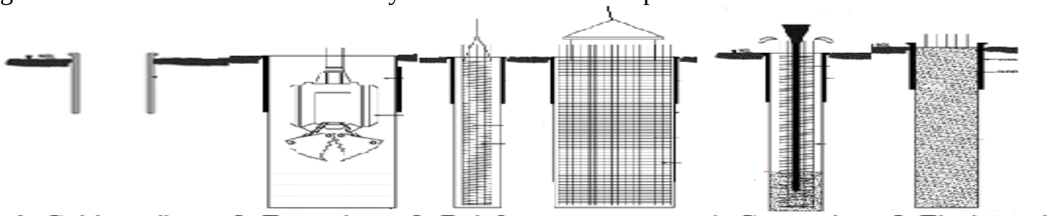

Fig 2 : Construction Sequence of Diaphragm Wall

On completion of excavation, the Bentonite slurry which may have become contaminated with the soil is cleaned by recycling through de-sanding equipment. The reinforcement cages are then lowered into the slurry filled trench, with each unit spliced to the other, to form a continuous cage to the required depth. Placing of concrete is done using tremie pipes to avoid the segregation of concrete as concrete is poured down. Diaphragm wall cannot be constructed continuously for a very long section due to limitation in size of the mechanical plant which is joined by one another by semi circular grooves to provide continuity.

4. MODELING

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. Fig.3 indicates the effort to ensure that the convergence criteria are satisfied. For this purpose, modeling of diaphragm wall adjacent building and the soil is made using very fine mesh size to coarse mesh size. At the most vulnerable location in the ground, horizontal displacement is computed under different mesh sizes. It is observed that idealization with medium mesh size yielded satisfactory results. Fig 4 presents the efforts towards fixing the boundary of semi-infinite soil mass. For this purpose the 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 5B on either side. Structure and diaphragm wall are model using plate elements and struts are used at 5m intervals to support the wall. 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 properties of different materials used in the present work are given in Table 1.

Table 1: Properties of Soil and Diaphragm Wall

Soil Properties(Drained)	Diaphragm wall	Strut & Beam elements
Modulus Of Elasticity = 20 MPa Cohesion = 20 kN/m^2 Frictional Angle = 30 Degrees Unit weight = 18 kN/m^3	Height = 20 m Thickness = 1 m Concrete grade M35 Modulus Of Elasticity = 29.58 GPa	Strut modulus = 300 GPa Strut thickness = 500 mm Beam element 300 mm X 450 mm Grade of beam M25

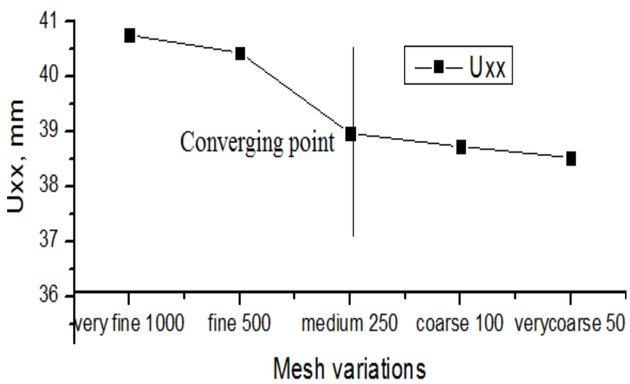

Fig 3 : Convergence Effect With Variation In Mesh Size

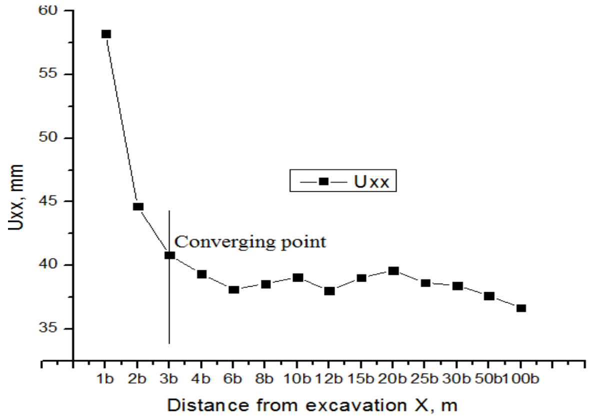

Fig 4 : Boundary Effect With Increasing Distance Of Boundary From The Location Of Excavation

5. CONSTRUCTION SEQUENCE

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. 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 diaphragm wall. After the construction of the wall the excavation is carried out in stages. Fig 5 shows the variations of horizontal displacement in ground below the building and adjacent to excavation at the various stages of construction. It can be noted that the horizontal movement below the structure continuously increases during the excavation. Whenever, soil movements are beyond control diaphragm walls and struts are introduced to bring down the displacements within safe limits.

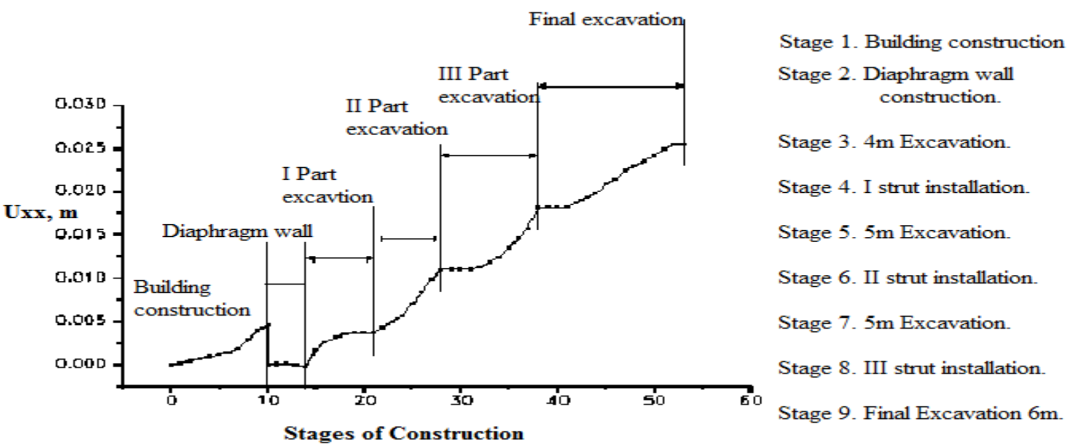

Fig 5: Graph Representing Stages Of Construction From Numerical Model Plaxis

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6. RESULTS AND DISCUSSION

The objective of the present study is to determine the strength and deformation characteristics of ground due to deep excavation and to study the impact of deep excavation on neighboring structures because of ground movement. For this purpose, stresses and displacements are determined at various locations in ground and wall movement, shear force and bending moment are computed along the depth in diaphragm wall support system.

Fig.6 and Fig.7 show the models of deep excavation and structure at adjacent locations in ground with and without diaphragm wall respectively. From Fig.6, 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 diaphragm wall and strut, the excavation can be made to be stable up to 25 m. The structure remains stable without lateral movement and vertical settlement with the introduction of diaphragm wall and struts system as seen in Fig. 7.

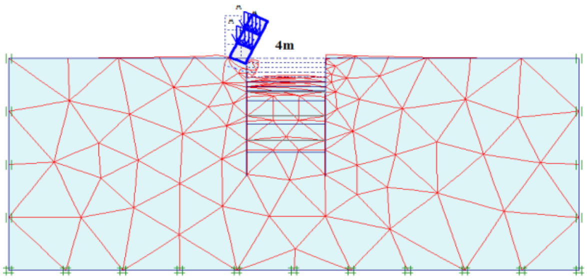

Fig 6. Excavation without Diaphragm Wall

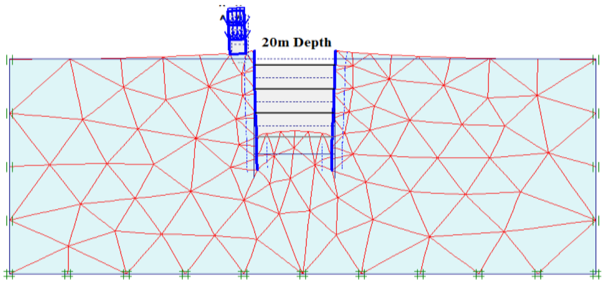

Fig 7. Excavation with Diaphragm Wall

The results of deep excavation with the introduction of diaphragm wall and strut system are presented in Fig. 8 to Fig. 15. Fig. 8 presents the variation in horizontal and vertical displacement at vulnerable location in ground with increase in horizontal distance of structure from the excavation. The location is below the structure near the base of excavation. It can be seen that the maximum displacements both in horizontal and vertical direction decrease with increase in distance of structure from the excavation. The vertical displacement is much more pronounced than the horizontal displacement. Fig.9 shows the variation of shear stress in ground with the distance of structure from excavation. It can be seen that the effects of excavation are more pronounced when the structure is closer to it. Fig.10 presents the distribution of horizontal displacement in the ground diaphragm wall and structure system. It can be seen that the magnitude of horizontal displacement is more pronounced in the bottom region of diaphragm wall. Further, the effect of this displacement on the structure is visible as the structure is leaning in opposite direction. Fig.11 presents the distribution of shear stress across the system of ground, diaphragm wall, structure and excavation. It can be seen that the stresses are more pronounced near the bottom of diaphragm wall indicating the need to consider the safety of the region.

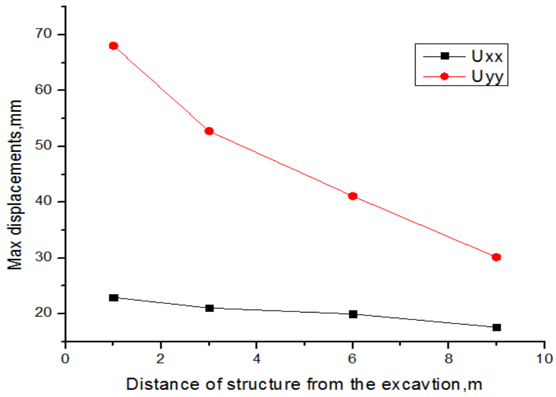

Fig 8: Horizontal and Vertical Displacements in ground with increase in distance of Structure

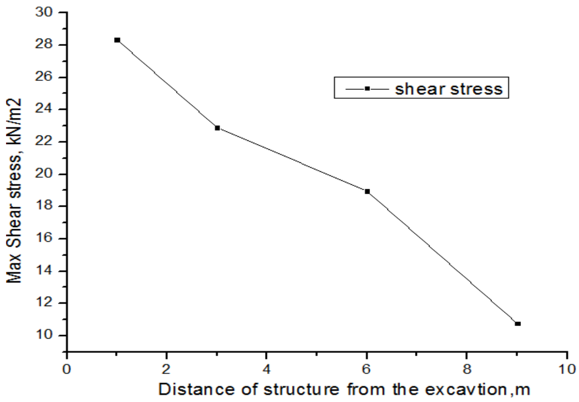

Fig 9: Variation in Shear Stress in ground with

From Excavation **increase in distance of Structure From Excavation**

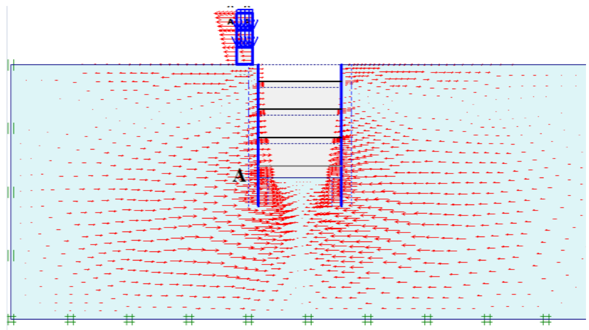

Fig 10: Distribution of Horizontal Displacement in ground and adjacent structure

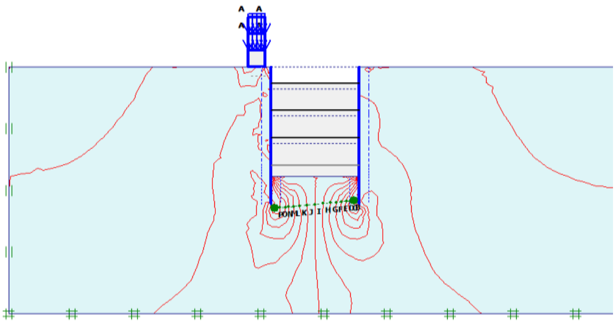

Fig 11: Distribution of Shear Stress in ground and adjacent structure

Further, Fig.12 and Fig.13 are plotted to determine the most suitable thickness of diaphragm wall for the given configuration. For this purpose, the stresses and displacements are determined at various locations in the ground with varying thicknesses of diaphragm wall. It can be seen from Fig.12 that the maximum horizontal and vertical displacements in ground decrease with increase in thickness of diaphragm wall. Initially, the rate of decrease is more. But, after reaching an optimum thickness, the decrease is insignificant. In Fig.13 similar trend is seen with shear stress. In the present work, it has been observed that the optimum thickness is 1000 mm. Further, it is observed that wall movement (0.10% < d/H < 0.3%) and wall depth (1.5% < L/H < 2%) are within the range estimated by previous contributors [5], [6]. Here, d is the horizontal displacement of wall, H is the Depth of excavation and L is wall depth.

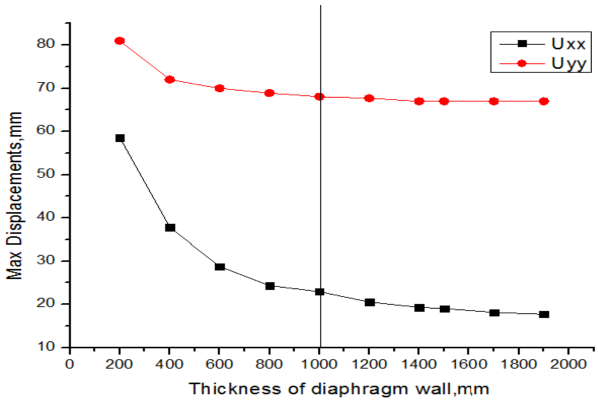

Fig 12: Variation in Ground Displacements with thickness of Diaphragm Wall

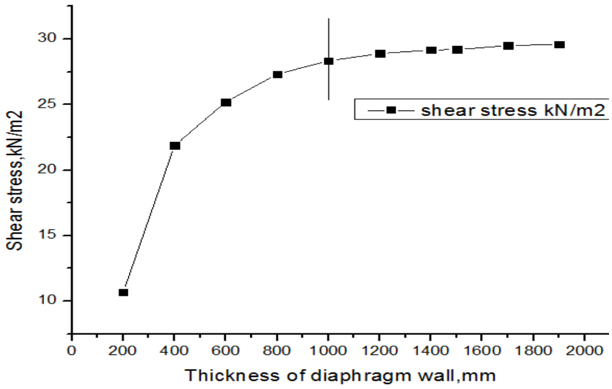

Fig 13 : Variation in Shear Stress in Ground with thickness of Diaphragm Wall

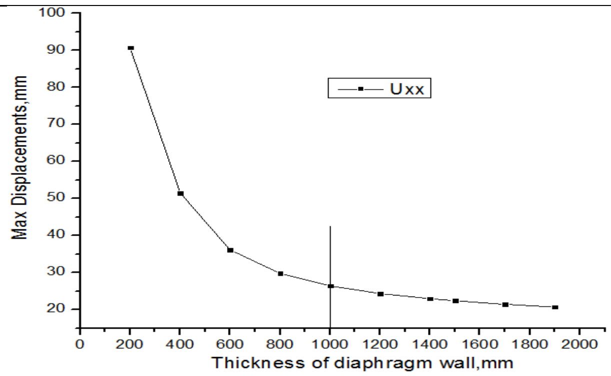

Fig 14 : Variation in horizontal Displacement of wall with thickness of Diaphragm Wall

Fig.15 shows the variation of horizontal displacements, shear stresses and bending movements of wall along the depth with respect to the ground deformations. It can be seen that the horizontal movement of wall increases with increase in depth of excavation. Bending moment and shear force in the wall are dependent on the location of strut members. Whenever there is a need to reduce the magnitude of bending moment or shear force, a strut member can be introduced.

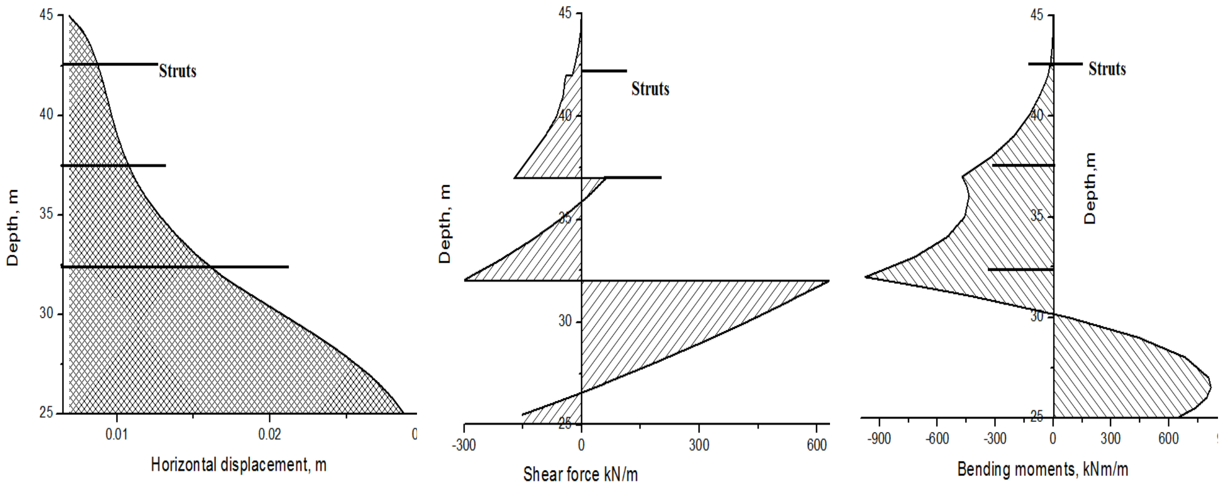

Fig 15: Variations in Horizontal Displacement, Shear Force and Bending Moments of Diaphragm Wall with depth due to Ground Movements

7. CONCLUSIONS

The results provide an understanding of the effect of diaphragm wall technique to reduce the ground movements during deep excavation adjacent to structures. The following are some important inferences from the present study.

- Diaphragm wall can be a good technique to hold the sites adjacent to deep excavation in stable condition.
- 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.

- Provision of diaphragm wall to a thickness of about 1 m can allow excavation up to about 25 m in soil with medium strength. In the absence of wall the soil fails at around 4 m.

- For 20m depth of excavation with diaphragm wall the wall movements within 0.1% to 0.3% could be achieved indicating the suitability of this technique for deep excavation in urban areas.

- Horizontal and vertical displacements as well as shear stress in ground decreased with increase in distance of the structure from the excavation almost linearly. Therefore the minimum distance of excavation from existing structure can be estimated based on allowable stresses and displacement of ground.

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