

2D FINITE ELEMENT MODEL TO UNDERSTAND THE BEHAVIOUR OF DEEP EXCAVATION WITH DIAPHRAGM WALLS AND STRUT MEMBERS

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Abstract

Due to the soil's low strength and high sensitivity to deterioration, designing and building in soft soil is extremely challenging and can result in structural damage. Insufficient space in urban areas has presented a challenge to excavate deep into the earth, and it is increasing the required area for the provision of public services. The function of the diaphragm wall and supporting strut member was modeled in this study using a 2D Finite element model developed with PLAXIS2D software. The excavation was designed to stabilize and limit aging due to excavation at acceptable levels nearby buildings. The analysis took into account the soil's indirect conduct using the Mohr-coulomb failure method. Results of the study show that up to the depth of 8 m the ground surface can be safely excavated without any structural support. Beyond this limit, soil failure occurs due to the release of vertical stress and loss of lateral support. The diaphragm wall with two strut systems is sufficient to restrict ground movement under structure loading by providing lateral stability to excavation sides. The performance of the diaphragm wall is independent of the cross-sectional shape of strut members. However, the I section is more economical.

Keywords: Deep excavation; diaphragm wall; finite element analysis; Mohr Columb model; Strut member

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Introduction

Building on soft to extremely soft soils is quite problematic from a geotechnical design perspective. Due to the poor shear strength and sensitivity to deterioration of various types of soils, their usage throughout construction and project lifespan might result in structural damage (Briaud and Kim, 1998; Dinakar and Prasad, 2014; Felix *et al.*, 2024; Hajialigol *et al.*, 2024). Overcrowding and a lack of available space in urban areas have forced construction engineers to dig deeper. Deep excavation's efficacy is determined by both stability and conversion. Deep excavation is used to maintain stability and keep ageing to a minimum stable excavation is defined as one whose walls do not collapse. Common signs of excavation failure include the collapse of the reinforcing system and a significant inward displacement of the surrounding soil (Hsieh *et al.*, 2008). Over the past 20 years, a great deal of research has been done on how braced excavations function. Soil response during excavation is measured by acceptable data, which is part of the study. Deep excavation efforts necessitate careful consideration of the structural elements' strength and stability during construction (Do *et al.*, 2016; Chabokpour and Azamathulla, 2022). To build an acceptable numerical model of deep excavation performance, a detailed two-dimensional and three-dimensional model is usually necessary. The analysis must account for soil non-linearity and the initial stress level in the ground (Finno *et al.*, 1989; Gourvenec *et al.*, 2002; Dong *et al.*, 2016). Many researchers have assessed how deep excavation will affect, and the erosion of a diaphragm wall in the basement. It was found that generally the system stability could be amended by truncating the trench length and incrementally increasing the pile offset distance from the trench (Simpson, 1992; Bloodworth and Bloodworth, 2002; Gourvenec *et al.*, 2002). A study also describes the effect of the construction stage on the retaining wall on the nearby structures, displacements, and bending moment (Hamza *et al.*, 1999; Mohamed *et al.*, 2013; Ghazaly *et al.*, 2017; Sobala and Rybak, 2017). With the help of finite-element analysis, PLAXIS2D, and 3D software, it is possible to forecast how a diaphragm wall will behave under different loading situations and about soil deformation. It is possible to calculate the ground's and a structure's deformation characteristics at any point (Wood and Perrin, 1984; Bhanuchitra and Prusty, 1985; Bentler, 1998; Rahman and Taha, 2005; Leung and Ng, 2007; Mohamed *et al.*, 2016). According to experts from Aberystwyth University in North Wales and the University of Groningen (Greece) in the

Netherlands, the diaphragm wall technique is robust enough to significantly reduce vibrations and movements of ground under structures, and the excavation may be carried out safely beyond 25 m (Hsiung, 2009; Tan and Wang, 2013). The structural elements affect the movement of the soil and walls induced by excavation work on the site work is being also carried out by various researchers (Goh, 1990; Do *et al.*, 2013; Cookson, 2019).

The construction cost of a diaphragm wall is 1.8 to 2.4 times higher than that of a traditional construction method. The cost of labour and the amount of concrete needed for a construction pit is also much higher found. The economic value of such a wall depends on the size of the project, with the lower limit being about 600-800 m² for a large-scale project (Powrie and Li, 1991; Arai *et al.*, 2008; Cookson, 2019). Over the past years, many kinds of literature have discussed on settlement of buildings and associated damage, construction-induced movements of in-situ walls, observed performance of deep excavation, lateral wall deflection of braced excavation, settlements induced by deep excavation, the performance of diaphragm wall, ground movement prediction for deep excavation, field monitoring, and case histories of deep excavation, building response by deep excavation, effects of excavation on adjacent piles and buildings and few of them were reviewed (Bfer, 1985; Boscardin and Cording, 1989; Johnson, 1989; Wong and Broms, 1989; Wong and Patron, 1993).

The findings gained with some additional support to the diaphragm wall during the excavation process are used in this work to supplement earlier research by adding further information. The goal of the current study is to assess the impact on the functionality of a diaphragm wall built close to a river to support the excavation process with the provision of strut members having variable cross-sectional shapes. This is also discussed in the paper with the availability of various bending moment and deflection diagrams. The PLAXIS2D version 8.2 software, which is based on the finite element approach, is used to carry out the entire investigation through the use of numerical simulation. A numerical model of the excavation site is created using the various characteristics of the soil and sand. Therefore, the objective of the present study is (1) to evaluate the effectiveness of the diaphragm wall, coupled with strut members, during the excavation process near a river. (2) Analyze the response of diaphragm walls subjected to constant loading from a single-story building by considering the available bending moments and a deflection diagram.

Table 1. Material properties of the sand and clay layer and the interface

Parameter	Name	Clay layer	Sand layer	Unit
Material model	Model	Mohr-Coulomb	Mohr-Coulomb	-
Type of material behavior	Type	Drained	Drained	-
Soil unit weight above phreatic level	γ_{unsat}	17	19	kN/m ³
Soil unit weight below phreatic level	γ_{sat}	20	22	kN/m ³
Permeability in hor. Direction	k _x	0.001	1.0	m/day
Permeability in ver. Direction	k _y	0.001	1.0	m/day
Young's modulus (constant)	E _{ref}	10,000	40,000	kN/m ²
Poisson's ratio	ν	0.38	0.3	-
Cohesion (constant)	C _{ref}	30	1.0	kN/m ²
Friction angle	ϕ	20	35	°
Dilatancy angle	ψ	0.0	2.0	°
Strength reduction factor	R _{inter}	0.5	0.67	-

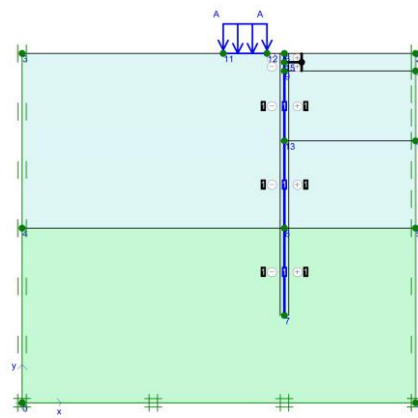
Materials and Methods

In 2D finite element modeling of deep excavations with diaphragm walls and strut members, temperature influences soil behavior significantly. Temperature changes impact soil characteristics such as stiffness, adhesion, and angle of friction, which are essential for the precise simulation of soil-structure interaction. Thermal gradients can cause variations in settlement or strains in the soil, which can affect the stability and efficiency of excavation support systems. Accurately considering temperature changes is crucial for making realistic forecasts of stress distribution, deformation patterns, and overall structural integrity. This is vital for developing and enhancing deep excavation projects in various climatic situations.

In the present study, sand and clay soils were collected from the excavation site of Raipur, Chhattisgarh, India. The soil properties were evaluated from the laboratory and presented in Table 1.

Modeling

The two-dimensional finite element method based on PLAXIS version 8.2 was used for the numerical simulation. The Mohr-coulomb model was used to simulate soil. The linear-elastic-perfectly-plastic Mohr-coulomb model incorporates the soil unit weight, permeability, Young's modulus, Poisson's ratio, frictional angle, cohesion, and dilatancy angle. A numerical model of the excavation site was developed using different properties of soil i.e., sand and clay achieved by respective laboratory tests in the lab. The excavation has a width of 30 m and a depth of 20 m. It stretches the longitudinal side a long way, allowing the plane model type to function. Diaphragm walls are 30 m long and attached to horizontal struts at a distance of 5 m to support the excavation sides. During excavation, a single-story building's greater load

**Figure 1. Numerical Model of Excavation System**

was considered. The load was applied between a distance of 2 m and a distance of 7 m from the diaphragm wall and has 30 kN/m²/m intensity. Because the excavation model was symmetric, just half of it, the left side, was statistically simulated, as shown in Figure 1. The steps of the numerical model of the excavation system are described below.

Simulation of Ground Surface Condition

In this step, a model with a width of 45 m and a depth of 40 m was simulated to show the ground condition of the excavation site. The model was divided into two layers of equal depth i.e., 20 m. The upper 20 m layer is modeled as a layer of homogeneous clay. Beneath this layer, 20 m of stiffer sand is simulated. The soil data parameters used to simulate the clay and sand layers are discussed in Table 1. The water table is simulated at a 2 m depth from the top surface of the ground.

Excavation Sequence

The excavation was carried out in the following phase discussed below.

Table 2. Material properties of the diaphragm wall (Plate)

Parameter	Name	Value	Unit
Type of behavior	Material type	Elastic	
Normal stiffness	EA	1.495×10^6	kN/m
Flexural rigidity	EI	5.19×10^8	kNm ² /m
Equivalent thickness	D	1.5	M
Weight	W	15.0	kN/m/m
Poisson's ratio	ν	0.0	-

Table 3. Material properties of the strut (anchor)(I-section)

Parameter	Name	Value	Unit
Type of behavior	Material type	Elastic	
Normal stiffness	EA	2.06×10^6	KN
Spacing out of plane	Ls	8.0	M
Maximum force	Fmax,comp	$1 \times 1,015$	KN
	Fmax,tens	$1 \times 1,015$	KN

Table 4. Material properties of the strut (anchor) (circular section)

Parameter	Name	Value	Unit
Type of behavior	Material type	Elastic	
Normal stiffness	EA	2.45×10^6	KN
Spacing out of plane	Ls	8.0	M
Maximum force	Fmax,comp	$1 \times 1,015$	KN
	Fmax,tens	$1 \times 1,015$	KN

Phase-I: External Load and Diaphragm Wall

A 30 kN/m^2 external load was modeled as a distributed load system of 30 kN/m^2 , 2 m away from the diaphragm wall. A 30 m long diaphragm wall was modeled as a plate member with varying parameters specified in Table 2 to support the excavation sides. The wall was located at a 5 m distance from the right edge of the model. Using the interface applied on both sides, the interface between the wall and the soil was represented.

The methodology for developing a 2D finite element model for deep excavation with diaphragm walls and struts entails dividing the soil and structural components into finite elements. The software utilizes soil constitutive models such as Mohr-Coulomb and structural elements like beams for struts, incorporating the necessary material properties. The simulation includes modeling boundary circumstances, such as excavation phases and the installation of support systems. We simulate the interaction between soil and structure by incorporating interface elements that account for contact behaviour and weight transmission processes. Analyzing entails assessing the

distribution of stress, deformation patterns, and stability variables under different loading and boundary conditions.

Uncertainties in 2D finite element modeling of deep excavations include simplifications in representing complex 3D soil-structure interactions, potentially affecting accuracy. Assumptions such as the linear elasticity of materials, the isotropic behaviour of soil, and the uniformity of boundary conditions may overly simplify the complexities of real-world settings. Uncertainties can also arise from factors such as soil quality, soil-structure interaction, and construction procedures' impact. Furthermore, assumptions about temperature effects, such as assuming a homogeneous thermal distribution and disregarding transient thermal gradients, may affect projections.

Phase-II: First Stage Excavation

In this phase, the first excavation on the ground up to the depth of 2 m was simulated in the numerical model.

Phase-III: Installation of Strut

In this phase, a single strut member as the anchor was modeled at a 1 m distance from the top of the surface of the ground. The required design parameters of strut members are given in Table 3 and Table 4.

Phase-IV: Second (Submerged) Excavation Stage

In this stage of execution, additional soil excavation up to a depth of 10 m below the top the ground surface was simulated. The pore water pressure was automatically engaged while the soil cluster was deactivated in some places because the water table was present at a depth of 2 m below the surface of the ground. As a consequence, this scenario simulates submerged excavation by having water stay in the area that was excavated.

Phase-V: Third Excavation Stage

This phase is the final stage of excavation as no further excavation is carried out in this analysis. In this phase, the excavation of the last excavated ground is simulated up to the depth of 20 m from the top ground surface. The above model is simulated to assess the diaphragm wall's performance with single strut support. To assess the diaphragm wall's performance with an increase in support, a few more strut members are provided in the model at 5 m intervals, and the whole simulation of the mode is revised by the following phase.

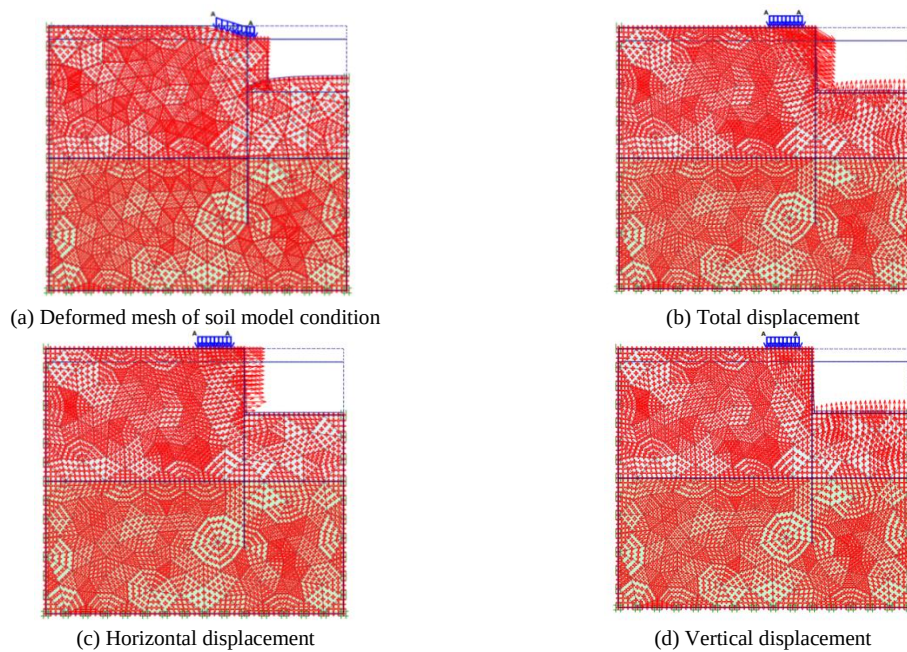


Figure 2. Behaviour of Excavation without structural support

Results and Discussion

The goal of the study was to assess the effectiveness of the diaphragm wall connected with strut members throughout the excavation process close to the ground conditions along a river. The strut members are provided with varying cross-sectional shapes having the same cross-sectional area. This paper has also discussed the behavior of diaphragm walls under constant single-story building loading with the help of available bending moments and a deflection diagram. To know about the optimum numbers of strut members that can be provided maximum stability, some extra strut members are provided and 5 m of the interval and the whole model was analyzed with PLAXIS2D.

In the first attempt, the numerical model of excavation, when no such structural support i.e., the diaphragm wall and struts provided were modeled. It is observed that up to the depth of 8 m the ground surface can be safely excavated. Beyond this depth, further excavation cannot be provided on the given site condition, as soil failure occurs as shown in Figure 2. This is due to the release of vertical stress at and in the loss of lateral support around the excavation. Hence, to provide safety against such soil failure, a second attempt was made.

Figure 2(a) shows the deformed mesh of the soil model condition of excavation without structural support. Figures 2(b), 2(c), and 2(d) show the deformed mesh for total displacement,

horizontal displacement, and vertical displacement respectively. The observed values of displacements are presented in Table 5.

In this second attempt, an RCC wall was provided for the discussed parameter, as it provides lateral support to excavation. Based on the second attempt it was observed that the wall can support the excavation up to the depth of 20 m. However, in the case of excavation below this depth, excavation becomes unstable as the rotation of structural members occurs as shown in Figure 3.

Figure 3(a) shows the Deformed Mesh of the Soil Model Condition of Excavation with Diaphragm Wall. Figures 3(b), 3(c), and 3(d) show the deformed mesh for total displacement, horizontal displacement, and vertical displacement respectively. The observed values of displacements are given in the Table 6.

Table 5. Observed values of displacements for excavation without structural support

Displacement	Observed values
Total Displacement (U_{tot})	183.04×10^{-3} m
Horizontal Displacement (U_x)	163.18×10^{-3} m
Vertical Displacement (U_y)	104.35×10^{-3} m

Table 6. Observed values of displacements for excavation with diaphragm wall

Displacement	Observed values
Total Displacement (U_{tot})	361.12×10^{-3} m
Horizontal Displacement (U_x)	360.76×10^{-3} m
Vertical Displacement (U_y)	96.15×10^{-3} m

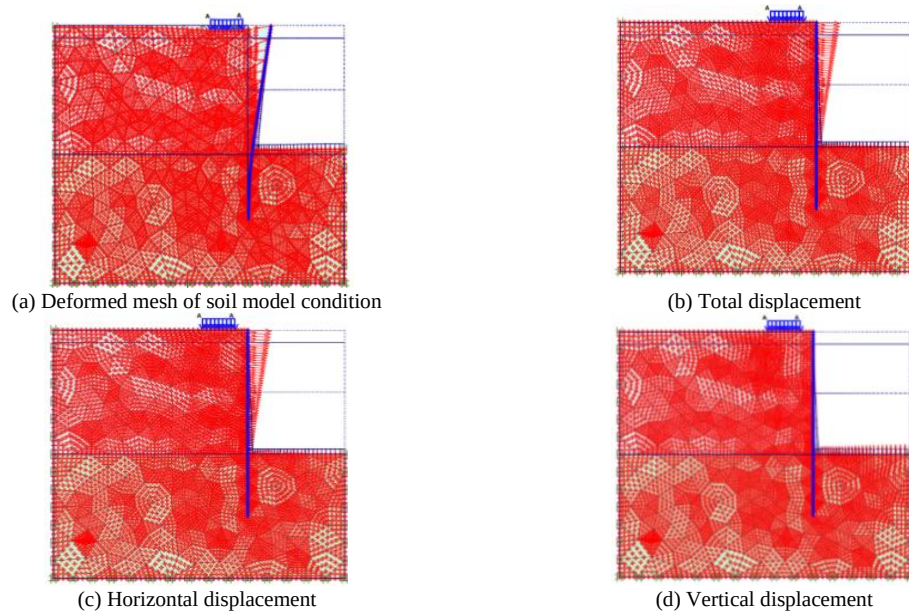


Figure 3. Behaviour of excavation with diaphragm wall



Figure 4. Variation of shear and bending forces in diaphragm wall

The shear force and bending moment fluctuation in the RCC Diaphragm wall are shown in Figures 4(a) and 4(b). Additionally, Table 7 discusses the measured values of shear force and bending moment.

In further analysis, an attempt was made to check if the provision of strut members would suffice the stability of excavation and overcome the rotation of the diaphragm wall. I-section strut member of the discussed parameter was provided at a 1 m depth from the top surface as shown in Figure 5. The observed values of displacements are presented in Table 8.

Figure 5(a) shows the Deformed Mesh of the Soil Model Condition of Excavation with a Diaphragm Wall and single I-Section Strut Member. Figures 5(b), 5(c), and 5(d) show the deformed mesh for total displacement, horizontal displacement, and vertical displacement respectively. The observed values of displacements are presented in Table 8.

The fluctuation in shear force and bending moment in the RCC Diaphragm wall is shown in Figures 6(a) and 6(b). Additionally, Table 9 presents the measured values of shear force and bending moment.

Table 7. Shear force and bending moment acting on wall

Forces on wall	Observed values
Shear forces	-278.80 kN/m
Bending moments	1.45×10^3 kNm/m

Table 8. Observed values of displacements for excavation with diaphragm wall and strut member

Displacement	Observed values
Total Displacement (U_{tot})	86.90×10^{-3} m
Horizontal Displacement (U_x)	86.89×10^{-3} m
Vertical Displacement (U_y)	76.79×10^{-3} m

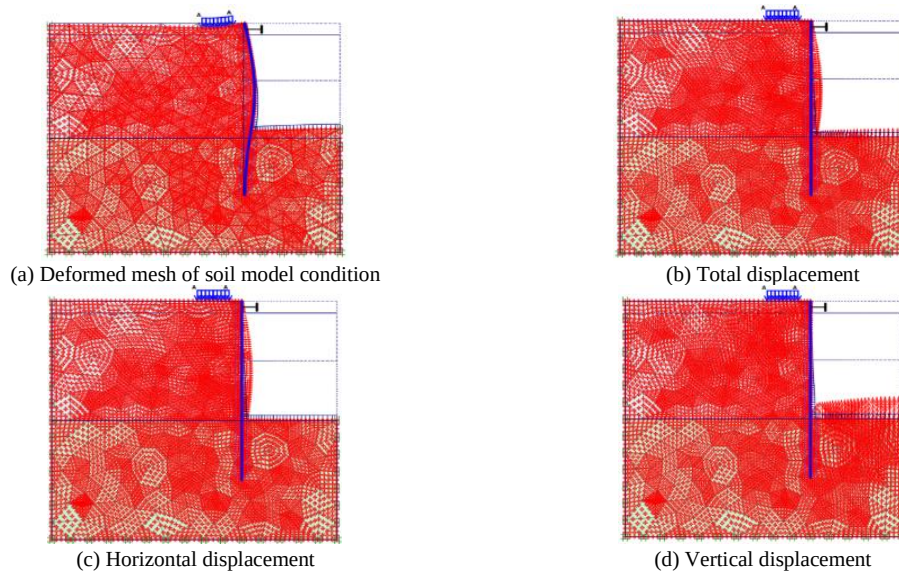


Figure 5. Behaviour of excavation with diaphragm wall and strut member

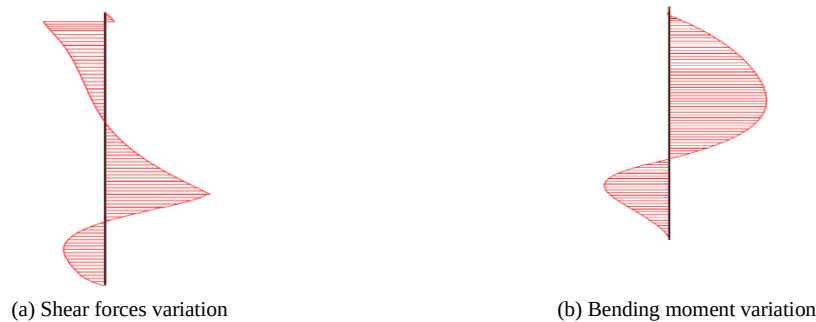


Figure 6. Variation of shear and bending forces in diaphragm wall with single i-section strut member

The analysis of excavation with one strut member at a 5 m distance below the location of the first member was carried out. The objective of this case was to check, to which extent the provision of two strut members would suffice the stability of excavation. It can be observed that there is a considerable change in the performance of the diaphragm wall as shown in Figure 7.

Figure 7(a) shows the condition of the excavation with the diaphragm wall and two I-Section strut members. Figures 7(b), 7(c), and 7(d) show the deformed mesh for total displacement, horizontal displacement, and vertical displacement respectively. The observed values of displacements are presented in Table 10.

Figures 8(a) and 8(b) depict the fluctuation in shear force and bending moment in the RCC Diaphragm wall. Also mentioned in Table 11 are the observed values of shear force and bending moment.

The next step in the analysis was to provide more numbers of I-Section struts at 5 m intervals of

Table 9. Shear force and bending moment acting on the wall

Forces on wall	Observed values
Shear forces	- 432.64 kN/m
Bending moments	-1.26×10 ³ kNm/m

Table 10. Observed values of displacements for excavation with diaphragm wall and two strut member

Displacement	Observed values
Total Displacement (U _{tot})	76.69×10 ⁻³ m
Horizontal Displacement (U _x)	74.76×10 ⁻³ m
Vertical Displacement (U _y)	76.69×10 ⁻³ m

each strut member's position. The objective of this case

was to check to optimum numbers of strut members, which would suffice the stability of excavation, and how much the rotation of the diaphragm wall will reduce from the previous case.

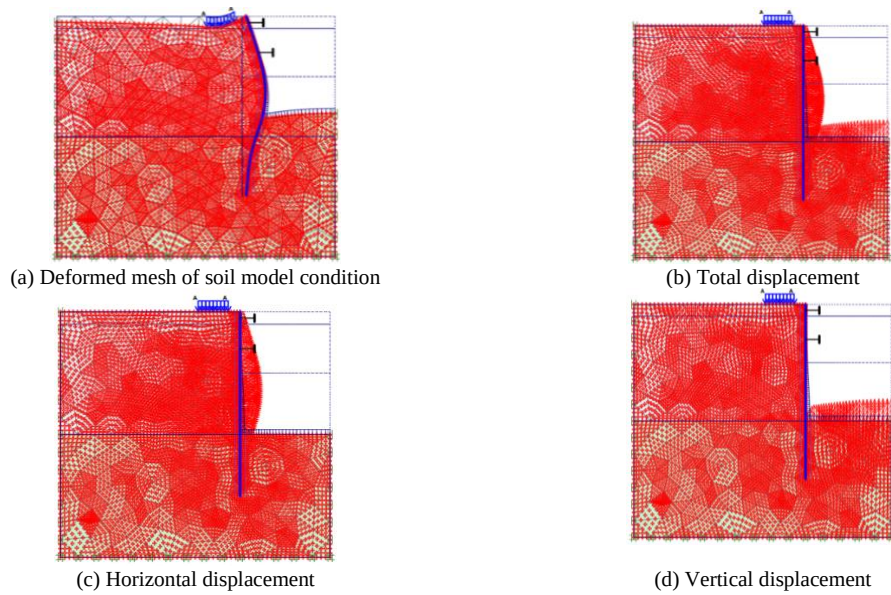


Figure 7. Behaviour of excavation with diaphragm wall and two i-section strut member



Figure 8. Variation of shear and bending forces in diaphragm wall with two i-section strut member

From the results obtained as shown in Figure 9, we observed that there is a negligible change in the performance of the diaphragm wall. Also, the total deflection is not considerably reduced from the case-IV i.e., Excavation with RCC Diaphragm Wall having multiple I-section Strut. Figure 9(a) shows the Deformed Mesh of the Soil Model Condition of Excavation with a Diaphragm Wall and two I-Section Strut Members. Figures 9(b), 9(c), and 9(d) show the deformed mesh for total displacement, horizontal displacement, and vertical displacement respectively. The observed values of displacements are presented in Table 12.

The shear force and bending moment variation in the RCC diaphragm wall are shown in Figures 10(a), 10(b), and Table 13 discuss the observed values of shear force and bending moment.

The above simulation was carried out for steel strut members having an I-shape cross-section. To study the variation in the performance of the diaphragm wall in the above cases was revised

Table 11. Shear force and bending moment acting on the wall

Forces on wall	Observed values
Shear forces	- 424.84 kN/m
Bending moments	-1.16×10 ³ kNm/m

Table 12. Observed values of displacements for excavation with diaphragm wall and multiple strut member

Displacement	Observed values
Total Displacement (U _{tot})	76.65×10 ⁻³ m
Horizontal Displacement (U _x)	74.60×10 ⁻³ m
Vertical Displacement (U _y)	76.65×10 ⁻³ m

Table 13. Shear force and bending moment acting on the wall

Forces on wall	Observed values
Shear forces	- 417.15 kN/m
Bending moments	-1.16×10 ³ kN m/m

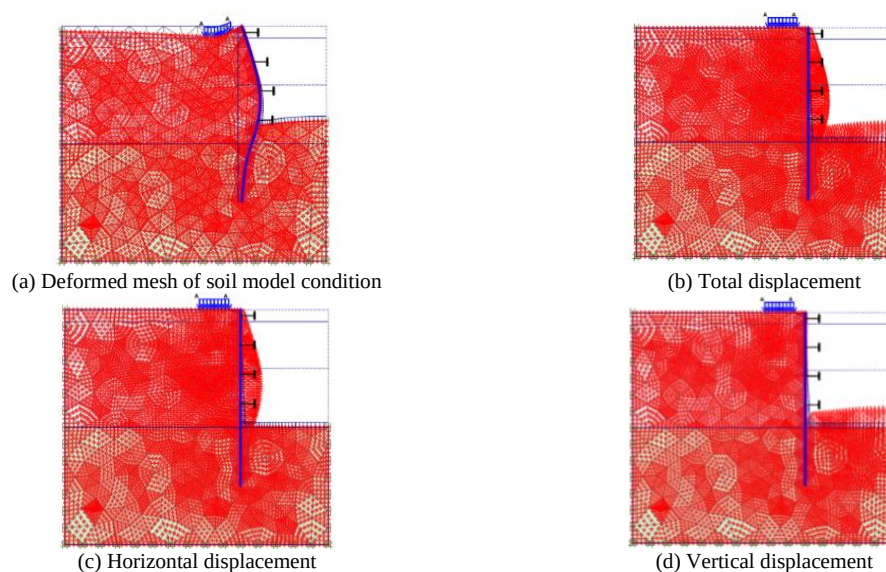


Figure 9. Behaviour of excavation with diaphragm wall and multiple i-section strut member



Figure 10. Variation of shear and bending forces in diaphragm wall with multiple i-section strut member

Table 14. Total displacement, horizontal displacement, and vertical displacement of the diaphragm wall with a circular strut section

Support	Total displacement U_{tot} , (mm)	Horizontal displacement U_{xx} , (mm)	Vertical displacement U_{yy} , (mm)
Diaphragm wall	361.12	360.76	96.15
Wall with one strut member	87.5	87.2	76.79
Wall with two strut members	77.15	74.09	76.68
Wall with four strut members	77.16	74.16	76.81

from case-III to case-V with circular strut members keeping all other design parameters of the model the same. The observed values of deflection and variation of forces in the wall are presented below. In the case of a circular strut member, the observed values of the total displacement, lateral displacement, and vertical displacement of the diaphragm wall are addressed in Table 14.

Table 15 discusses the values obtained of shear force and bending moment for a diaphragm wall with a circular strut section.

Variation in total displacement, horizontal displacement, and vertical displacement of the diaphragm wall with change in cross-sectional shape of strut member

Table 16 discusses the change in the diaphragm wall's total displacement, horizontal displacement, and vertical displacement. From Table 16, We can conclude that there will be a 75.96% of reduction in the total displacement of the diaphragm wall with the provision of the first strut member as strut member provides stability

Table 15. Shear force and bending moment for a diaphragm wall with a circular strut section

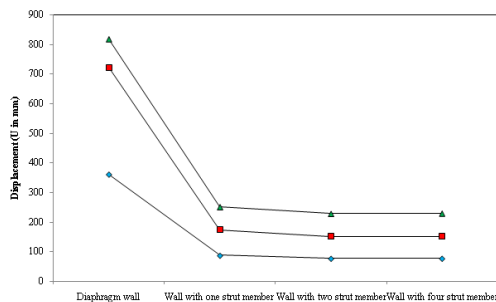
Support	Shear force (KN/m)	Bending moment (KNm/m)
Diaphragm wall	-278.8	1.45×103
Wall with one strut member	-431.28	-1.25×103
Wall with two strut members	-423.64	-1.15×103
Wall with multiple strut members	-415.13	-1.15×103

Table 16. Variation in total displacement, horizontal displacement and vertical displacement of diaphragm wall

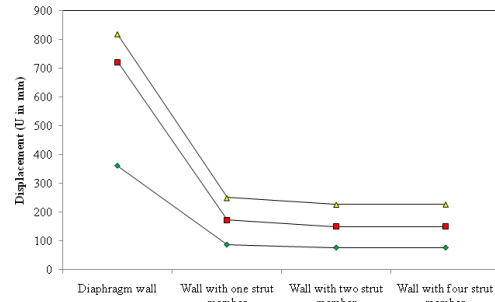
Support	Total displacement U _{tot} , (mm)		Horizontal displacement U _{xx} , (mm)		Vertical displacement U _{yy} , (mm)	
	I- section	Circular section	I- Section	Circular section	I-section	Circular section
Diaphragm wall	361.12	361.12	360.76	360.76	96.15	96.15
Wall with one strut member	86.9	87.5	86.89	87.2	76.79	76.79
Wall with two strut members	76.69	77.15	74.16	74.9	76.63	76.68
Wall with four strut members	76.81	77.16	75.16	74.16	76.81	76.81

Table 17. Variation in max. shear force and max. bending moment diaphragm wall

Support	Max. shear force (KN/m)		Max. bending moment (KNm/m)	
	I-Section	Circular Section	I-Section	Circular Section
Diaphragm wall	-278.8	-278.8	1.45×103	1.45×103
Wall with one strut member	-432.64	-431.28	-1.26×103	-1.25×103
Wall with two strut members	-424.84	-423.64	-1.16×103	-1.15×103
Wall with four strut members	-416.15	-415.13	-1.16×103	-1.15×103



(a) Variation in displacements with I-section strut



(b) Variation in displacements with circular section strut

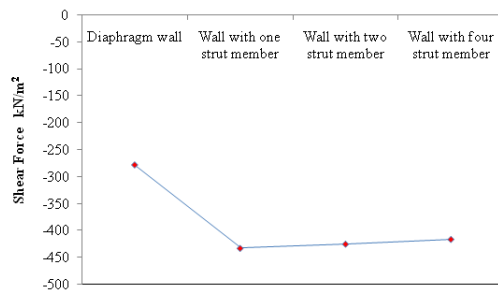
Figure 11. Variations of wall displacements under different structural conditions

against rotation i.e., displacement to the structure, which is further reduced by 11.75% with the provision of another support. After that there will be no considerable reduction in displacement can obtain both sections. Also, from Figure 11(a) and Figure 11(b), we can observe that for I-sec, the variation of displacement with an increase in support is nearly same as of the circular section.

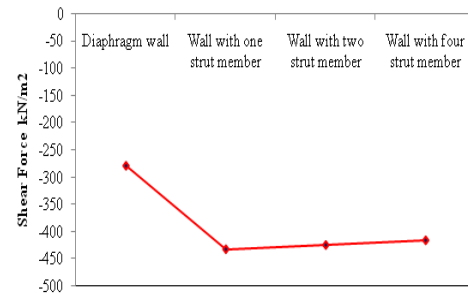
Variation in maximum shear force and maximum bending moment diaphragm wall with change in cross sectional shape of strut member

Table 17 discusses variations in the maximum diaphragm wall shear force and bending moment. With the addition of the third and fourth strut

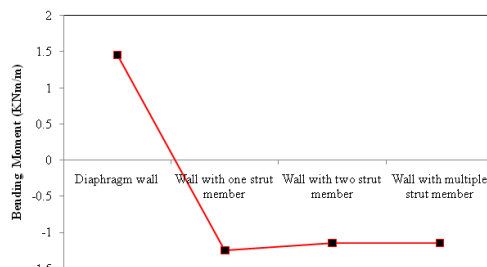
supports, it is evident from Table 17 that the maximum shear force and maximum bending moment will not significantly change. Additionally, it can be seen from Figures 12 and 13 that the maximum shear force and maximum bending moment variations for I-sec are identical to those of circular sections as support numbers rise. As a result, two strut members may be offered as the ideal number of strut supports for the excavation to be as stable as possible. Also, variation in the performance of the diaphragm wall with a change in the cross-sectional shape of the strut member was observed keeping the cross-sectional area constant.



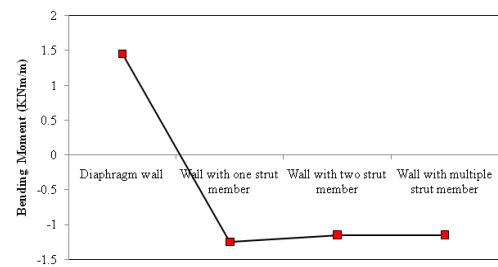
(a) Variation in Shear forces with I-section strut



(b) Variation in Shear forces with Circular-section strut

Figure 12. Variation in Shear forces under different structural conditions

(a) Variation in Bending Moment with I-section strut



(b) Variation in Bending Moment with Circular-section strut

Figure 13. Variation in bending moment under different structural conditions

Summary and Conclusions

The objective of the present study is to evaluate the performance of the diaphragm wall provided with strut members during the excavation process near the riverside soil condition. The strut members were provided with varying cross-sectional shapes having the same cross-sectional area. This paper has also discussed the behavior of diaphragm walls under constant single-story building loading with the help of available bending moments and a deflection diagram. To know about the optimum numbers of strut members that can be provided maximum stability, some extra strut members were provided and 5 m of the interval, and the whole model was analyzed with PLAXIS2D version 8.2. The results provide an understanding of the performance of the diaphragm wall provided with strut members during the excavation process near the riverside soil condition. The following are some important outcomes that we can expect

- While excavating on the given ground, the excavation up to the depth of 8 m from the ground surface can be safely excavated without any structural support, beyond this limit soil failure

occurs due to the release in vertical stress and loss of lateral support.

- The diaphragm wall provides the lateral support excavation wall and allows the excavation up to the depth of 20 m, however, excavation becomes unstable as rotation diaphragm wall occurs.

- The provision of strut members suffice the stability of excavation as it reduces the displacement of the diaphragm wall up to 84.14% wall by providing outward support in the direction of deformation.

- Two strut members are sufficient to provide the optimum value of displacement. Further increase in the number of struts leads to unnecessarily economical burden as there will be no considerable reduction in achieved with increased numbers of struts.

- That performance of the diaphragm wall is independent of cross sectional shape of strut members having the same cross sectional area. However I-section strut member is preferred as the rotation is less of a structure in the case of the I-section than the Circular Section.

Future Scope of the Study

A 2D finite element model is used to thoroughly analyze the behaviour of deep excavations reinforced by diaphragm walls and strut elements. This model enables a thorough analysis of the interaction between soil and structure, the features of deformation, and the distribution of stress during the excavation process. It provides insight into potential problems such as excessive wall deflections or ground settlements by modeling different soil qualities, groundwater conditions, and construction sequences.

Limitations of the Present Study

The 2D finite element model used for deep excavations with diaphragm walls and strut members has many constraints. Firstly, it oversimplifies an intricate 3D circumstance, potentially neglecting the relationships between soil layers and structures that impact stability. The assumptions about plain strain conditions may not adequately account for the individual geometries of a given location. The model's accuracy is highly dependent on input factors, specifically soil qualities, which can fluctuate both spatially and temporally, affecting predictions. In addition, the model assumes that materials behave in a linear manner and does not take into account non-linearities such as soil yielding or structural deformations that go beyond the elastic limits. Often, the model simplifies the interface conditions between soil and structures, ignoring the potential for non-uniform load distributions and the complexities of soil-structure interaction. Additionally, the model may not sufficiently consider the impact of construction sequence effects, such as phased excavation or the installation of support systems, which can have a substantial influence on excavation behaviour. Although there are limitations, 2D finite element models are still effective for early analysis and design optimization of deep excavation projects when used carefully with site-specific data and validated with field observations.

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