Diaphragm Wall Deflection Due to Site Condition, Soil Condition, Construction Method, along with Seismic Load

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Abstract:
In recent years, industrialization has had a greater influence on the use of land for many different purposes. The potential for subsidence in subterranean soil arises from its heterogeneous properties, which might provide challenges in the context of subterranean building. The use of diaphragm walls presents an optimal resolution for addressing the aforementioned issue, as it offers substantial reinforcement to unstable soil conditions. Additionally, this technique proves advantageous in the construction of subterranean infrastructures such as subway systems and parking facilities. However, the diaphragm wall may also experience displacement owing to different factors such as seismic effects, restrictions arising from site conditions, soil conditions, and building techniques. An study was conducted on diaphragm walls under critical conditions, including factors such as soil properties, loads, and building techniques. The analysis was performed using finite element analysis software and other numerical software tools. In this document, we provide an overview of the research conducted by many authors on the deflection of diaphragm walls caused by a range of factors.

Keywords: Wall of the diaphragm; lateral load; deflection; soil condition

I. Introduction

The expansion of the population has led to an escalation in the use of land, road infrastructure, underground pipelines, subway tunnels, and subterranean caverns. In order to mitigate land use, it is essential to implement subterranean infrastructure. During the development of subterranean infrastructure, challenges may occur due to the absence of soil support, leading to potential collapse inside the trench. The development of subterranean structures may encounter challenges as a result of this. Diaphragm walls are used as a means to address this issue. It is important to mitigate soil movement in the vicinity of the aperture. The diaphragm wall serves as a retaining structure, thereby mitigating the risk of soil movement that might potentially provide a hazard.

II. DIAPHRAGM WALL

The diaphragm wall is a kind of durable retaining structure that is used to provide lateral support to unstable soil masses during the process of excavation. The construction in question is an earth retaining system that incorporates a slurry gain wall. The use of this technique is often seen in the construction of deep excavations, tunnel approaches, subways, pumping stations, hydraulic structures, and industrial buildings, where it serves as a cutoff wall. These structures are designed with the purpose of extracting soil and water throughout the building process. It finds use in the construction of tall structures. The building method used is known as caste-in-situ. The use of soil reinforcement techniques in subterranean construction has been increasingly recognized and favored due to its ability to offer support to the soil. Consequently, it is anticipated that this approach will become the preferred alternative for mitigating land usage constraints.

III. METHODOLOGY

The academic investigation was conducted using finite element software. The use of software such as Plaxis 2D has been employed to ascertain the deflection, deformation, and settling of the diaphragm wall. The Mohr-Coloumb Soil model was used in the Finite Element Method (FEM) study [1]. The Plaxis 2D program was used to assess the deflection at the upstream and downstream cutoff walls, as well as to evaluate the pressure exerted on the upstream cutoff wall and its subsequent impact on the downstream cutoff wall. The FLAC 3D program was used to assess the deflection and bending moment in a diaphragm wall throughout various phases of construction [3]. This software facilitated the comparison of analytical findings with field observations. An analysis was conducted to assess soil displacement under both drained and un-drained situations in various scenarios. In order to determine the magnitude of fluctuations resulting from variations. The identification of fractures, cavities, and sludge that have formed at the joints is crucial. To address this issue, the use of GPR Max 2D software has been implemented [7]. The FLAC 2D software has been used to ascertain the optimal building strategy for the dam.

IV CONSTRUCTING THE DIAPHRAGM WALL

Development of the diaphragm wall is being done in situ using caste. It is an in situ caste structure made of reinforced cement concrete. Because it is being built below, the adjacent structure's influence is crucial. Top down and bottom up building methods for diaphragm walls were compared by Wanchai Teparaksa & Jirat Teparaksa (2019). The Rosewood Hotel and the BOT headquarters were the two buildings that were taken into account. Top down construction was used to build the BOT head office, whereas bottom down construction was used to build the Rosewood office. To measure the diaphragm wall's deflection, an inclinometer was affixed to each of the diaphragm walls. Using Plaxis 2D software, the FEM technique was also used to analyze the diaphragm wall's deflection, and the outcomes of the two approaches were compared.

The greatest ground surface settlement measured by an inclinometer at the BOT head office was 23.7 mm, whereas a FEM study indicated a maximum displacement of 28.2 mm. Figure 1 presents the findings. In the example of Rosewood Hotel, the FEM approach yielded a displacement of 42 mm, whereas the greatest displacement reported by the inclinometer was 28.41 mm. The findings are shown in figure 2[1].

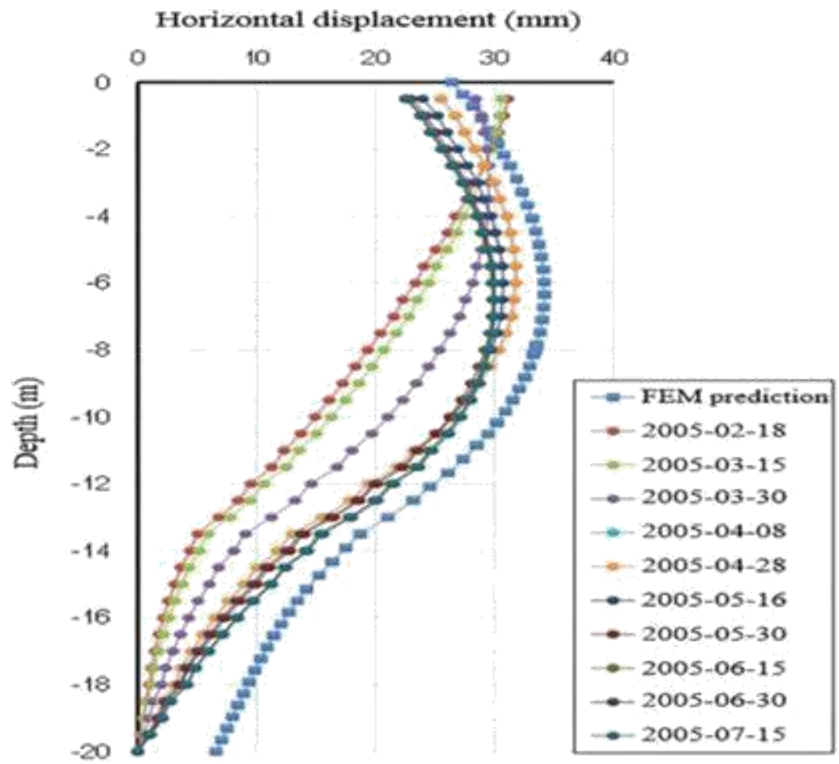

Figure 1 (adapted from Wanchai Teparaksa & Jirat Teparaksa) shows the monitored movement of the lateral diaphragm wall at the BOT head office in relation to the expected movement using FEM analysis.

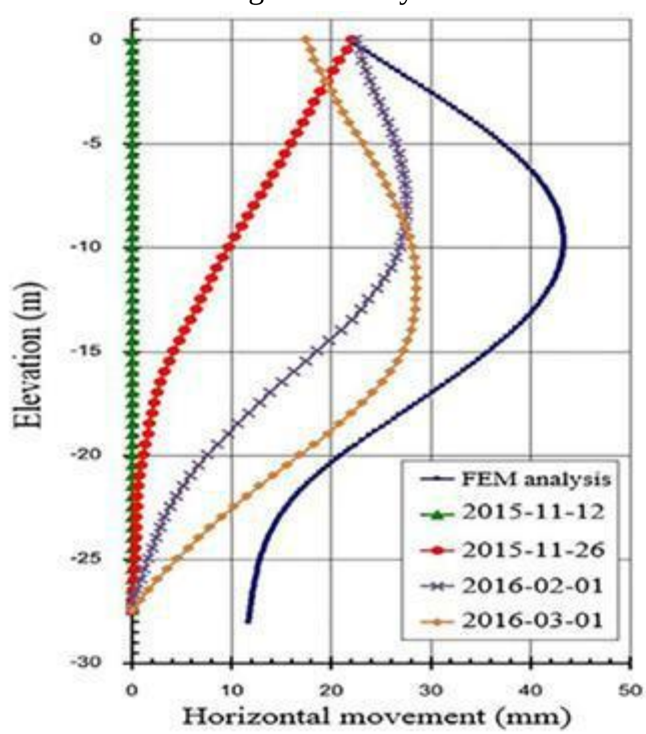

Figure 2 demonstrates the displacement of the lateral diaphragm wall of the Rosewood Hotel; it was sourced from Wanchai Teparaksa & Jirat Teparaksa.

V. EFFECT OF SITE CONDITION ON DIAPHRAGM WALL

In the research they investigated, Shivkumar, Begum, and Premlatha (2018) conducted an examination on a cantilevered cutoff wall that experiences lateral loads as a result of earth pressure and water pressure differential. The investigation has focused on the displacement seen at the cutoff wall located both upstream and downstream. The authors used Kosla's theory to determine the pressure exerted at the crucial point on the diaphragm wall. The finite element approach was used to analyze the cantilever diaphragm wall, using Plaxis 2D software. The deformation was plotted against changing pressure head and the normalized displacement was displayed against the depth of the upstream and downstream cutoff wall in Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, and Figure 9 [2].

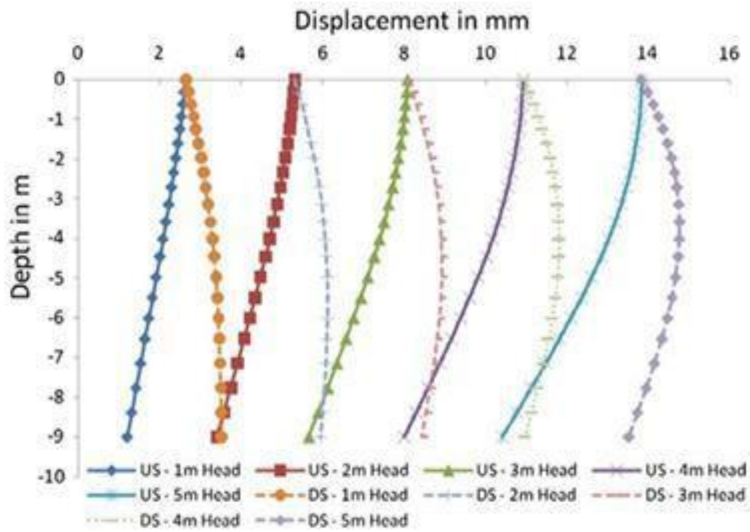

Figure 3 illustrates the displacement of the upstream (US) and downstream (DS) cutoff walls in response to different pressure heads.

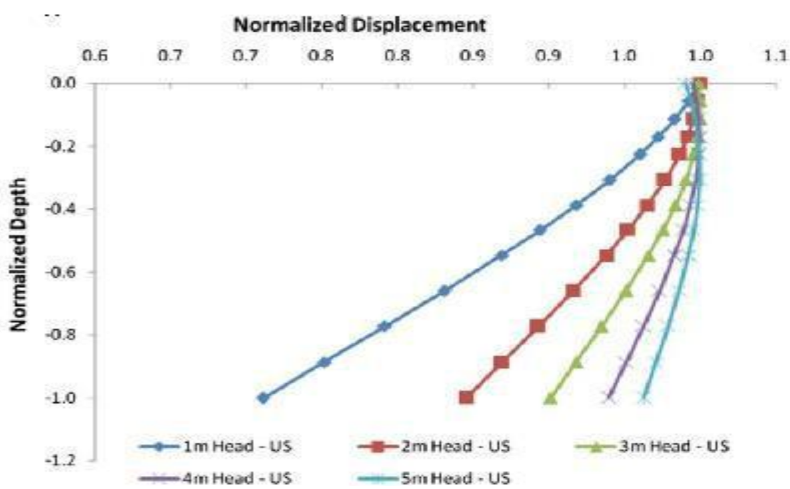

Figure 4 illustrates the normalized displacement of the US Cutoff Wall in response to variable pressure head.

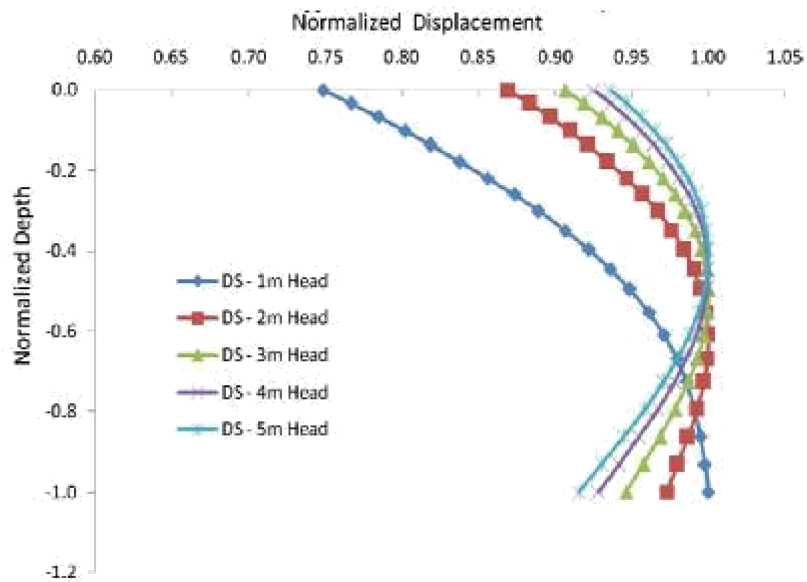

Figure 5 illustrates the normalized displacement of the DS Cutoff Wall in response to variable pressure head.

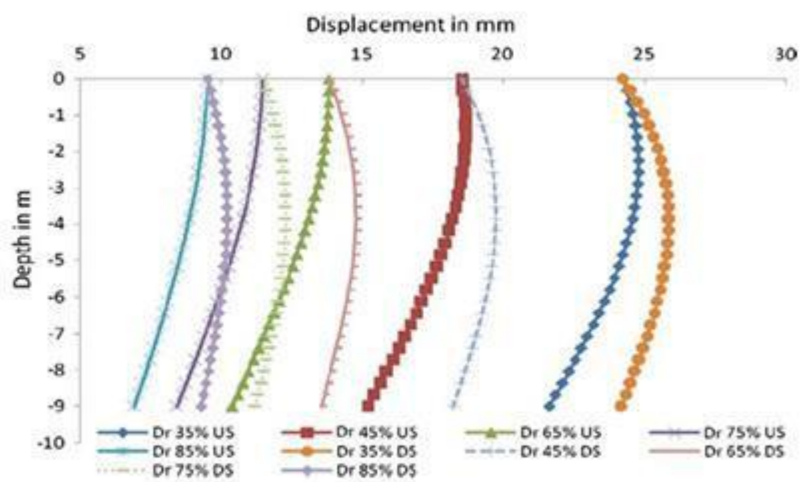

Figure 6 illustrates the displacement of the upstream (US) and downstream (DS) cutoff wall for different relative densities.

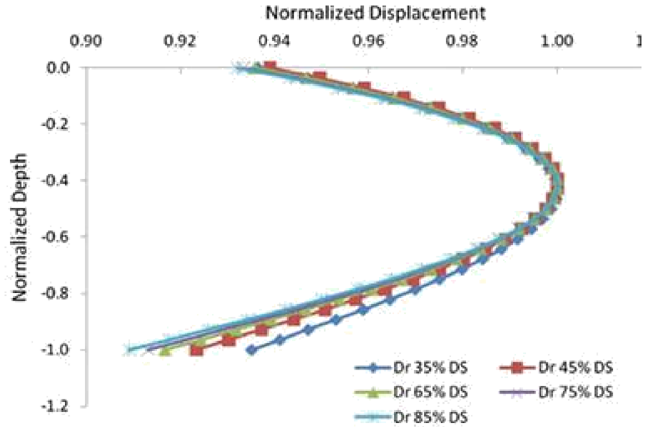

Figure 7 illustrates the normalized displacement of the DS cutoff wall at different levels of relative density.

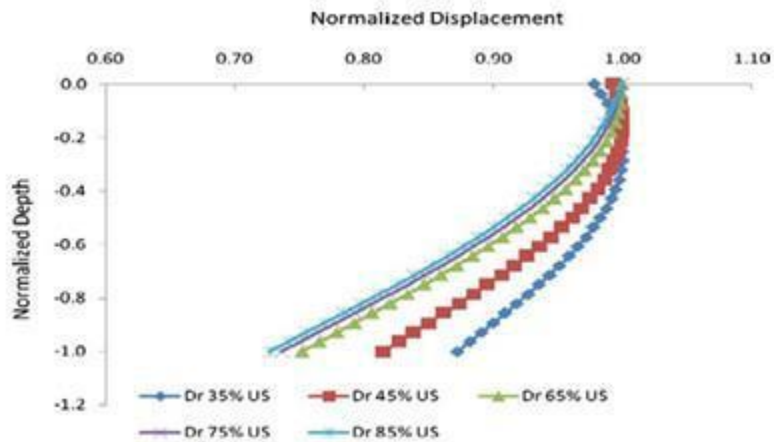

Figure 8 illustrates the normalized displacement of the US Cutoff wall in relation to changing relative density.

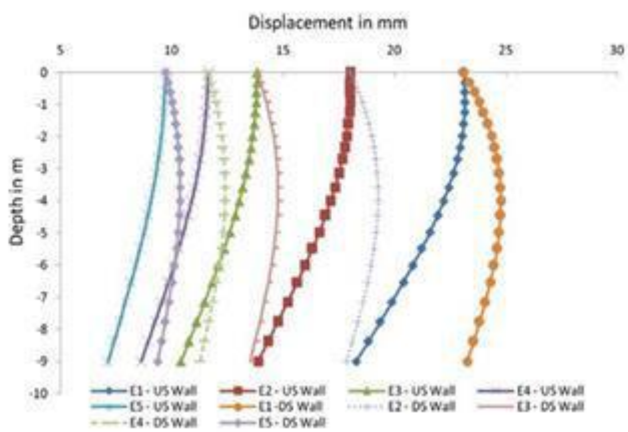

Figure 9 illustrates the displacement in both upstream (US) and downstream (DS) cutoff walls in response to a change in soil modulus.

The numerical investigation of the impact of excavation diaphragm wall onto deep pile foundation was carried out by Ahmed Mohammad, Marawan Shahin, and Herbert Klapperich. The program used for this analysis was FLAC 3D. A comparison was made between the numerical analysis and the field results. The deflection at different points was evaluated by the author, and it was observed that the settlement value rises with an increase in staging and decreases with an increase in depth [3], as seen in Figure 10.

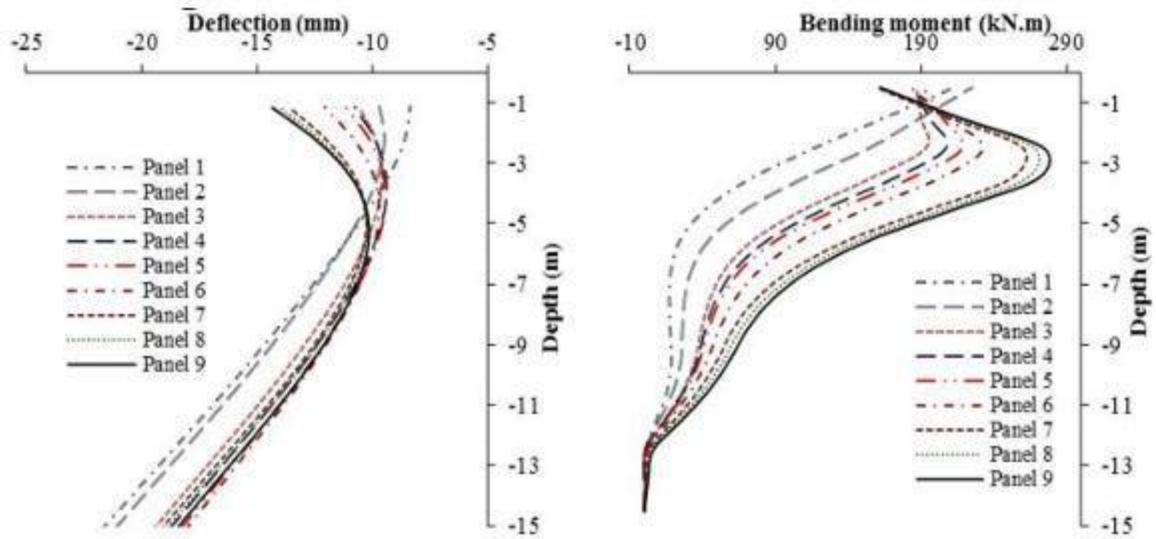

Figure 10 illustrates the impact of different phases of panel building on the deflection and bending moment of a linked pile group.

Enrico Conte and Antonello Troncone performed a study to investigate the behavior of a cantilevered diaphragm wall in cohesive soil under both drained and undrained conditions. A basic equation is used for the purpose of analysis. During the study, it was determined that the net normal stress exerted on all points up to a distance X from the excavation level exhibited a linear variation after a certain point. In this study, the author conducted a comparison between the analytical results and the practical results. Additionally, the results obtained using the equilibrium technique were also included in the comparison. The findings of the study revealed that the wall experiences rotation at a certain position near its base [4].

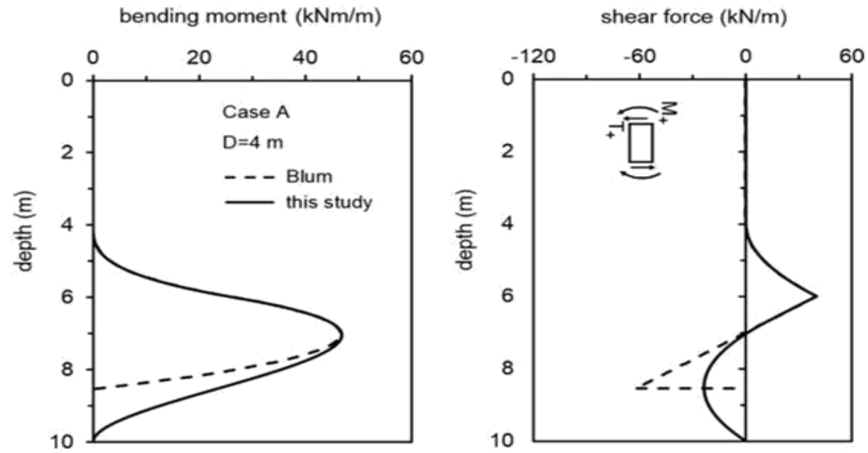

Figure 11 illustrates the distributions of bending moment and shear force for Case A, with a diameter (D) of 4 m. The calculations were performed using both the current approach and Blum's method.

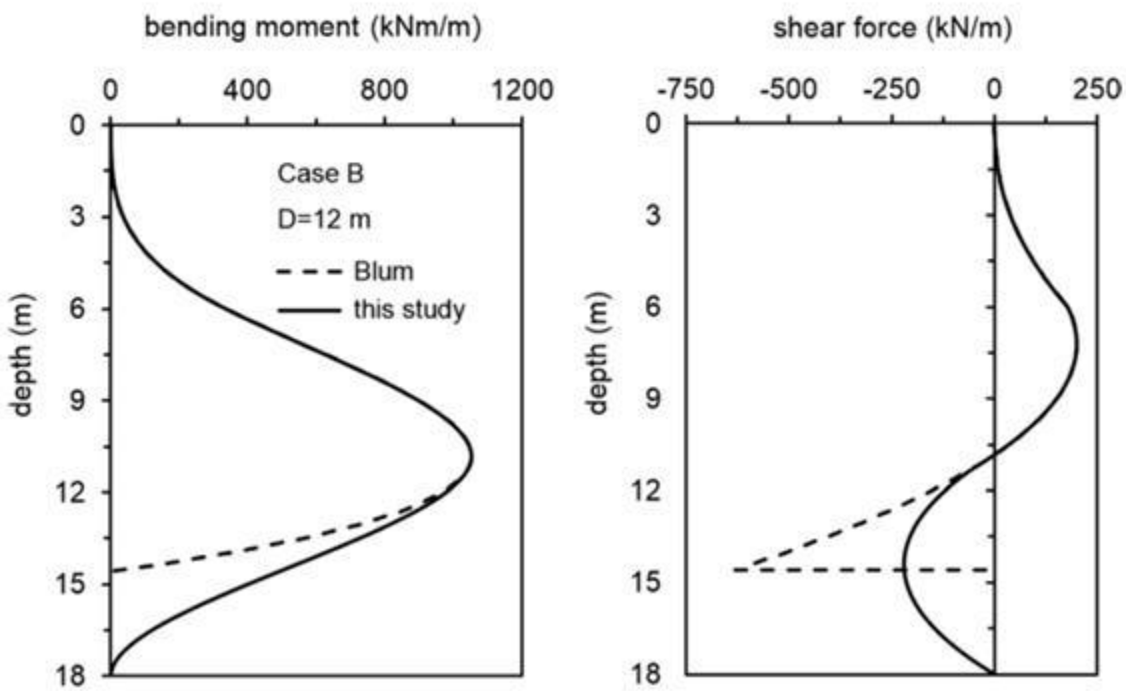

Figure 12 illustrates the distributions of bending moment and shear force estimated using both the current technique and Blum's method for Case B, with a value of D equal to 12m.

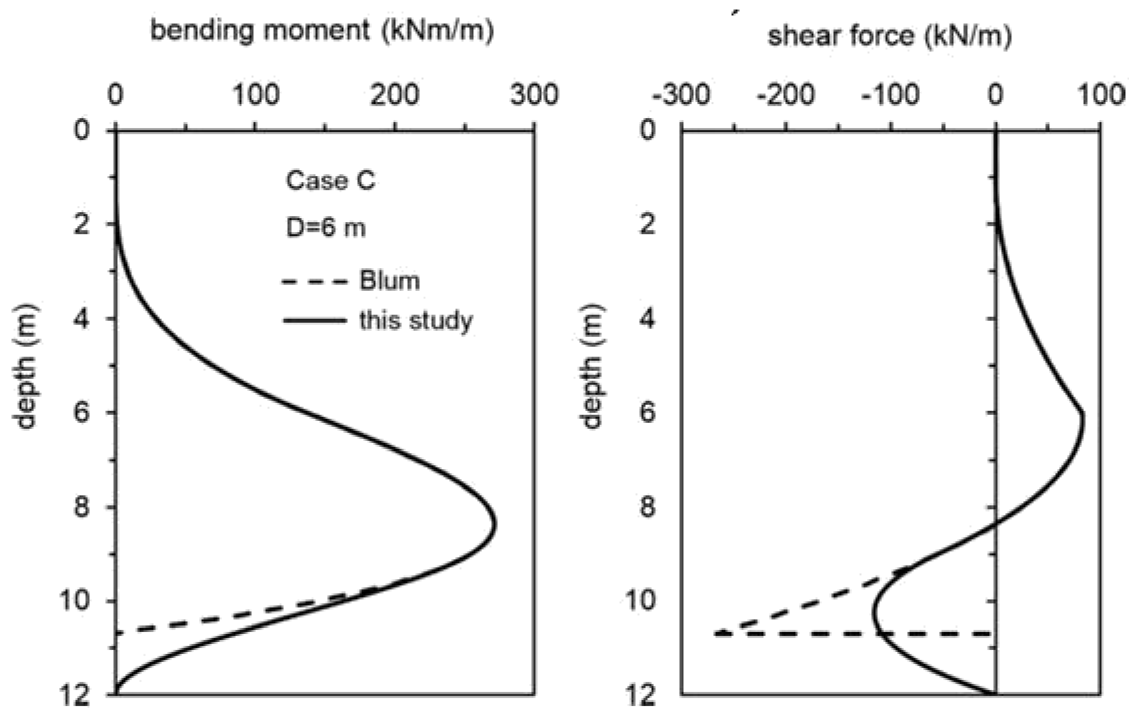

Figure 13 illustrates the distributions of bending moment and shear force for Case C, with a span length of 6m. These distributions were estimated using both the current approach and Blum's method.

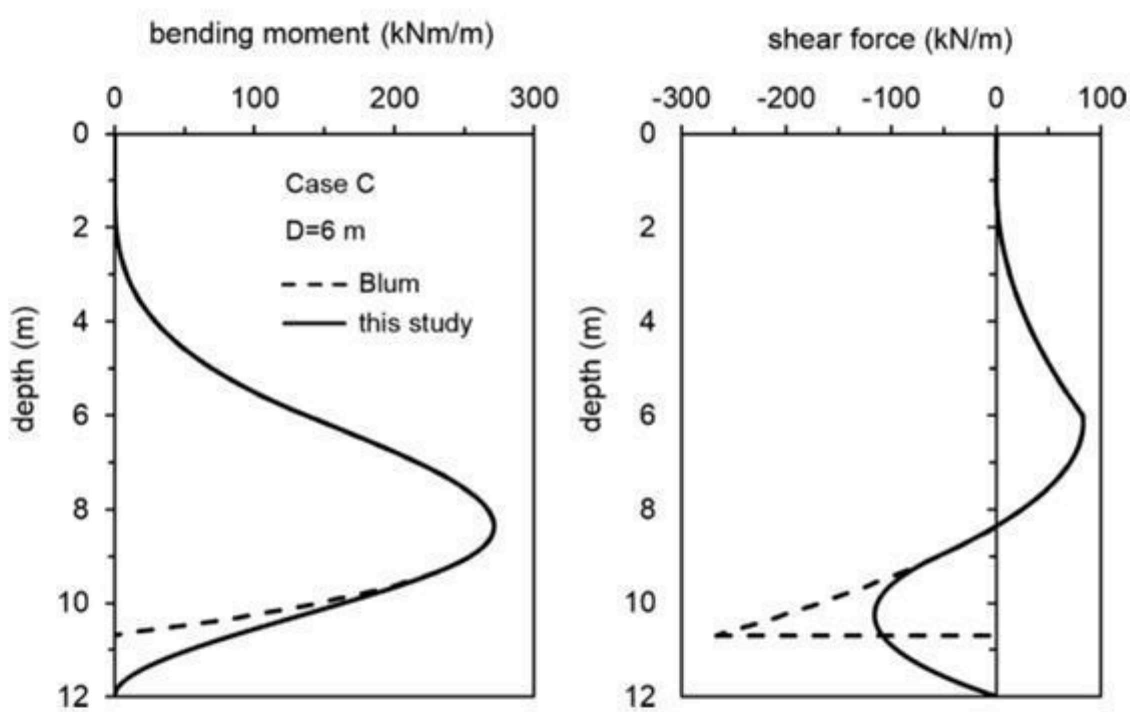

Figure 14 illustrates the distributions of bending moment and shear force estimated using both the current technique and Blum's method for Case C, with a value of D equal to 12 m.

M. Kawa and W. Pula Truty performed a study on an overhanging diaphragm wall constructed in sand with spatially variable properties, using a soil model. The author constructed a soil model using an effective friction angle. A finite element study was performed on a diaphragm wall having a total height of 10m, with 5m of the wall's depth being immersed into the earth. The probability distribution approach was used to determine the magnitude of volatility. The analysis focused on assessing the likelihood of collapse of the diaphragm wall under different levels of variation. According to the findings shown in Figure 17, it can be seen that the chance of failure exhibits a range of variation from 3% to 14% when the scale of fluctuation is varied from 1 to 1.8 [5].

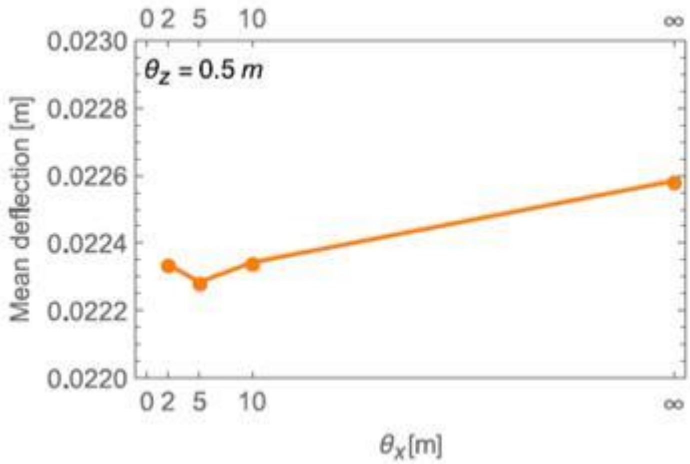

Figure 15 illustrates the average value of deflection.

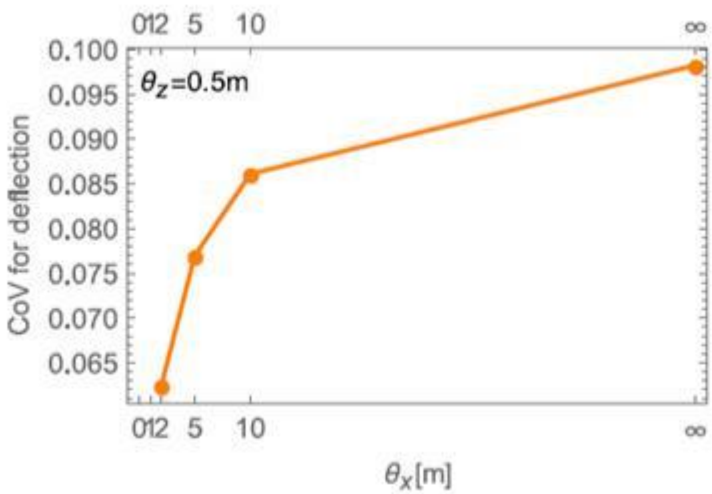

Figure 16 demonstrates the coefficient of variation (COV) pertaining to the deflection of the wall.

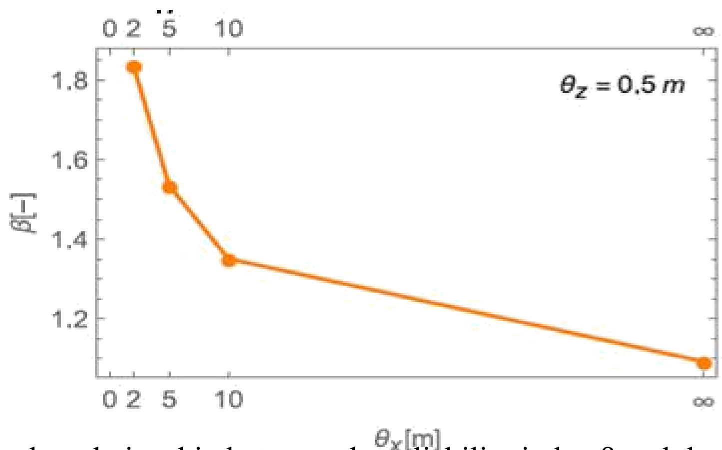

Figure 17 illustrates the relationship between the reliability index β and the horizontal state of failure (SOF).

Askar Zhussupbekov, Abdulla Omarov, Gulzhanat Tanyrbergenov conducted investigation of Diaphragm wall with problematic soil using analytical method. For this analysis the Plaxis 2D software was used by the author. It was observed from table 1 that tension forces increase up to the capacity of tendons up with factor of safety. The deflection in the actual structure and the software analyzed structure were observed. The observation of deflection in diaphragm wall was observed using a 3D laser technique. The deflection found were indicated on the drawing using color marks on it. The color shows the intensity of deflection on diaphragm wall[6].

Table I: Plaxis Calculation

Anchorage Summary	Number anchors			
	1	2	3	4
Level(-)	3.0	9.0	13.0	17.0
Spacing,m	2.2	1.65	1.65	1.65
Free length, m	15	13	8	5
Grout length, m	10	10	8	8
Angle, degree	20	20	30	30
Total length, m	25	23	16	13
Prestressing load , kN	460	560	570	640
Calculated anchorage load	607	672	670	675
Test load, kN (=Cal*1.25) (=Tw*1.25)	759	840	838	844

Locking load kN(=Cal*1.25) (=Tw*1.25)	668	739	737	743

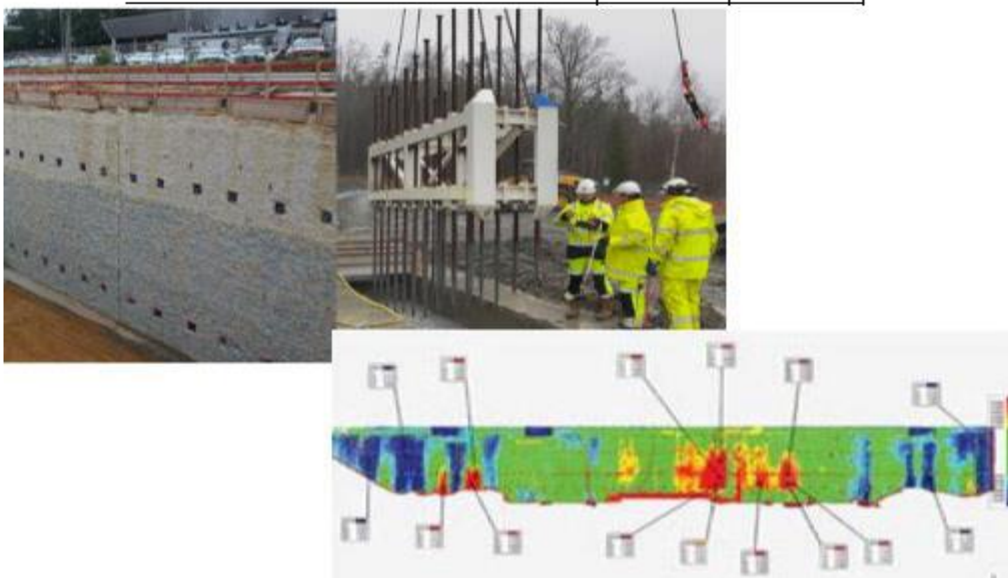

Figure 18: Diaphragm wall model

Hui Qin, Xiongyao Xie, Yu Tang, and Zhengzheng Wang conducted a study on the detection of deflection in diaphragm walls using the cross hole Ground Penetrating Radar (GPR) approach. The authors provided a summary of several sorts of flaws, as seen in Figure 19, and proceeded to describe the Ground Penetrating Radar (GPR) methodology. A panel model of 2 meters by 4 meters, with a grid size of 0.02 meters in both directions, is used to imitate a diaphragm wall panel.The locations of the transmitter and receiver of the crosshole ground penetrating radar (GPR) are established along the left and right boundaries of the model. These positions are shown in Figure 20, where red dots represent the transmitter positions and black crosses represent the receiving sites [7].

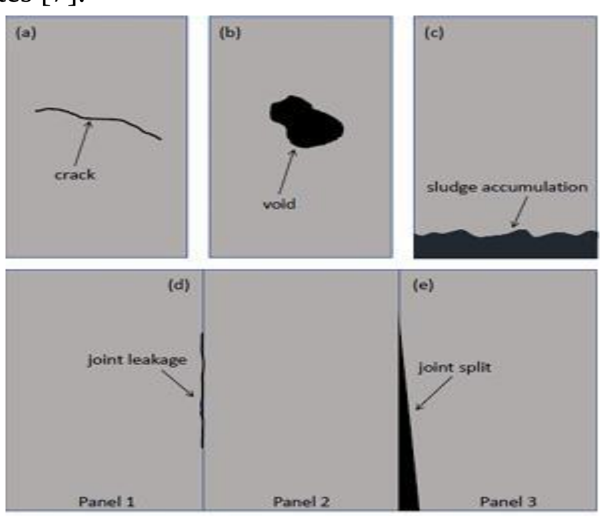

Figure 19 illustrates several defects often seen in diaphragm walls, namely: (a) cracks, (b) voids, and (c) sludge formation.

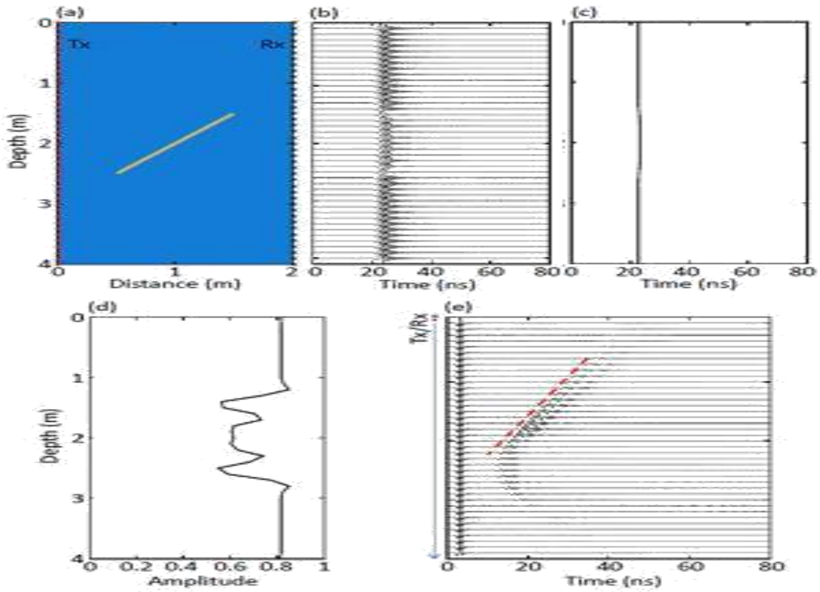

Figure 20 illustrates the process of crack detection.

VI. SEISMIC IMPACT ON DIAPHRAGM WALL

The evaluation of seismic analysis of strutted diaphragm wall was done by Mohammad Bahrami, Mohammad Imam Khodakarami, and Abdolhosein Haddad. The author conducts an analysis of the behavior of a strutted diaphragm wall under seismic conditions. The author used FLAC 2D, a finite difference numerical program, to do the study. The model developed by the author incorporates a depth of 10 meters and applies seismic vibrations to the bedrock at depths of 30 meters, 60 meters, and 90 meters. Two rows of struts were positioned at intervals of 2 and 6 meters. The deflection pattern of the diaphragm wall was seen to have a similar pattern for three different types of earthquakes. The analysis of Figure 21 reveals that an increase in foundation depth from 30m to 60m results in a reduction in bending moment by about 24% in the Tabas and Whittier Narrows regions, and a reduction of approximately 27% under the Northridge earthquake conditions. The diaphragm walls were found to experience bending moment and shear force under seismic stresses that exceeded the corresponding permitted limits by a factor of 2.8 and 2.7, respectively. Additionally, it has been shown that lateral bracing serves as an effective approach for ensuring excavation safety when subjected to static stresses. However, steel struts demonstrate inadequate performance when exposed to dynamic loads [8].

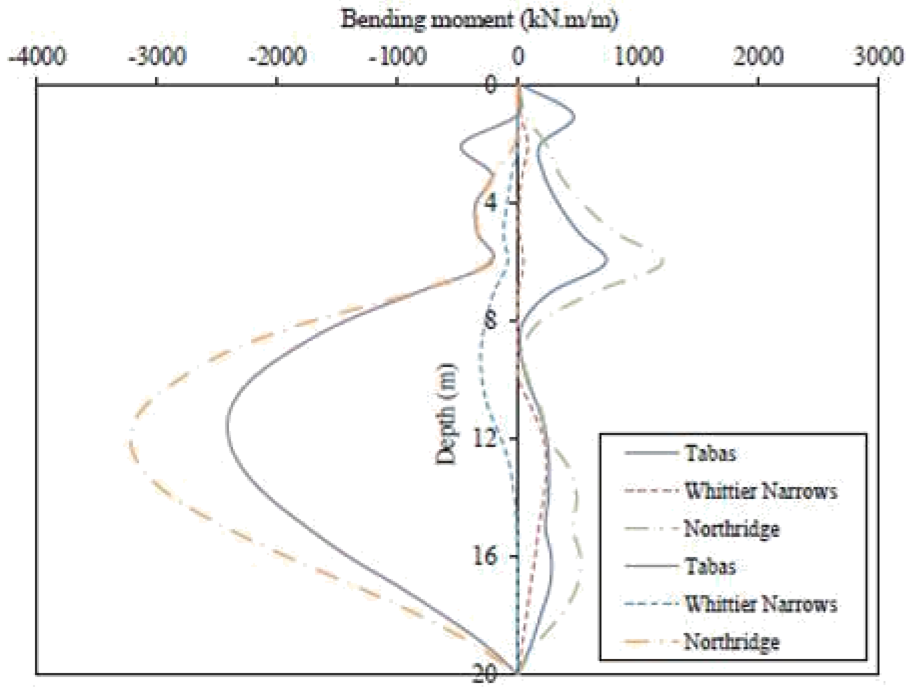

Figure 21 depicts a comparative analysis of the flexural wall response when subjected to different seismic events.

Haiyang Zhauang, Rui Wang, Peixin Shi, and Guoxing Chen conducted an analysis on the seismic reaction of a two-storey subway station situated in China. The author used the finite element technique to analyze the deflection of the diaphragm wall. The Kobe wave and EI Centro wave were implemented at the bedrock level. The diaphragm wall was simulated using an artificial constraint boundary and an artificial transmission boundary condition. The author conducted a comparative analysis of the subway with and without a diaphragm wall. It was noticed that starting at a depth of 28 meters, there was a linear rise in inclination up to a height of 3 meters. Figure 29 illustrates the relationship between the inclination of the diaphragm wall and its burial depth, with a maximum depth of 3 m. It is seen that when the vibration frequency exceeds 2.5 Hz, the diaphragm wall exhibits deflection. This observation was made based on the data shown in Figure 30[9].

VII. RESULT

The table below displays the deflection observed at the BOT main office and Rosewood Hotel.

Table II: Deflection at the Rosewood Hotal And The Bot Head Office [1]

Project Name	Actual Deflection(mm)	FEM Deflection(mm)
BOT Head office	23.7	28.2
Rosewood Hotel	28.41	42

Table III. Variable pressure the head deflection at upstream and downstram cutoff wall

Pressure Head (m)	Deflection upstream cutoff wall (mm)		Deflection downstream Cutoff Wall (mm)	
	0 m depth	9 m depth	0 m depth	9 m depth
1	2	1.8	2	3.5
2	5.3	3.5	5.3	6.1
3	8	5.9	8	8.8
4	10.9	8.1	10.9	11.5
5	14	11	14	13.5

VIII. CONCLUSION

- The deflection of the BOT head office is reduced in comparison due to the increased rigidity of the bottom slab, achieved by the use of the top-down construction approach. The deflection of the Rosewood Hotel was greater due to the use of steel bracing as the building technique. The findings indicate that the field measurement yielded lower values compared to the projected results obtained by Finite Element Method (FEM).
- The stretching of the downstream cutoff wall consistently exceeds the displacement seen at the upstream cutoff wall. The displacement of a cutoff wall has a strong correlation with its depth of embedment into the ground. The occurrence point in the upstream cutoff wall changes towards the downstream cutoff wall as the differential pressure increases. Similarly, in the downstream cutoff wall, the occurrence point shifts towards an increase in differential pressure. The deflection in the downstream boundary condition consistently exhibits a larger magnitude compared to the upstream boundary condition, regardless of any alterations made to the border condition.
- The reliability of the settlement findings achieved by numerical computation is higher.
- The occurrence of deformation in the top section of the diaphragm wall is seen to be consistent in both the analytical technique and Blum's method. However, this consistency is not observed in the lower section of the wall.
- The use of the HS model for the numerical analysis of diaphragm walls is seen to be both cost-inefficient and too cautious.
- The rise in bedrock elevation may lead to a decrease in both bending moment and shear force. The bending moment is also influenced by the characteristics of the soil. The use of strutted bracing diaphragm walls as a building method is not considered ideal in situations involving thick sand.
- The reciprocal reinforcement technique is a viable approach for controlling systems under seismic conditions in thick soil.
- The deflection of a diagram wall is contingent upon two key factors: the stiffness of the diaphragm wall and the depth at which the wall is embedded into the ground. The deflection decreases as the embedment depth rises. To mitigate deflection in diaphragm walls, it is necessary to enhance the stiffness of the structure.

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