Impact of Neighbouring Excavation on Diaphragm Wall under Seismic Loading

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Abstract

The existing diaphragm walls may be affected by the new structure as well as any excavation work required for the surrounding projects. During an earthquake, this effect can be more pronounced. It is therefore, suggested to create the diaphragm wall and the neighbouring excavation models with the intention of researching the influence of excavation upon diaphragm wall under dynamic conditions. For the investigation, a case study involving a diaphragm wall located in Noida was taken into account. The diaphragm wall and nearby excavation were modelled utilizing the Plaxis 3D program. By altering the space between the excavation and the diaphragm wall and entering the time-history acceleration data from an earlier earthquake, it was possible to examine the impact of the nearby excavation for the new construction on the diaphragm wall under dynamic conditions. The outcomes of three-dimensional numerical analysis were compared.

The study has revealed that the wall's horizontal displacement increases with increasing the space between the wall and the excavation until it arrives at an approximate value that resembles the wall's horizontal deflection without nearby excavation. Graphs of shear force and bending moment were also compared and similar variations were found.

Keywords: Diaphragm wall, Nearby excavation, Dynamic Numerical modelling, PLAXIS 3D software.

Introduction

According to reports, the growth of underground structures in cities is mostly driven by the expanding transportation requirements brought on by a growing city's inhabitants and associated environmental concerns. Excavation is necessary for underground space utilization. Due to the restricted space available for slope excavation, the excavation wall is kept vertical. Retaining structures are used to stop significant and dangerous soil movement in the vicinity of openings. A common retaining wall type employed in underground urban developments is the diaphragm wall. Diaphragm walls are constructed all over the world. With the goal to build these underground structures to be resistant against earthquake loading, it is essential to comprehend their seismic behaviour because they are usually constructed in earthquake-prone areas. The vibrations of the earthquake could cause the diaphragm wall to collapse or the anchors to fail.

The construction of diaphragm walls, their seismic behaviour and lateral deformations during earthquakes have all been the subject of extensive research. Only limited research has been done on the effect of a nearby excavation for the new construction on diaphragm wall during earthquake, in this investigation, the behaviour of these walls during an earthquake has been evaluated when there is nearby excavation using finite element method. Analysis has been done by modelling the existing diaphragm wall and nearby excavation using Plaxis 3D software. Details of anchored diaphragm wall were collected from previous case study conducted by Jasmine and Muttharam[11]. In the present paper, distance between existing diaphragm wall and nearby excavation was varied and analysed using Plaxis 3D software and the outcomes in relation to horizontal deflection, shear force and bending moment of wall were evaluated for all the cases.

Review of Literature

For different soil circumstances in a static situation, the consequences of designing the retaining structure on the nearby ground response have been researched and published by Dibiagio and Myrvoll[6], Farmer and Attewall[7], Tedd et al[21] and Tamano et al[20]. Aspects of the research they conducted included numerical simulations of the consequences of wall construction and the implications of building different types of earth retaining structures on movement of the ground as well as variations in lateral soil and water pressures.

The lateral disturbances of diaphragm walls are normally prevented by lateral anchors or struts. In the past, supported excavation was studied in static situations using numerical approaches. Ou et al[16] investigated the behaviour of deep excavations using 3D finite element models, emphasizing the importance of capturing soil-structure interactions and non-uniform deformations. The study demonstrated that 3D modelling provides more accurate predictions of wall deflections and ground settlements compared to 2D analyses.

Masuda et al[14] focused on predicting the lateral deflection when performing significant excavations of the diaphragm walls. They proposed a method for accurate prediction by considering factors such as soil-structure interaction, wall stiffness and excavation depth, validated through field data and comparisons with existing models.

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Research has been done previously to look into the process of installation in which a diaphragm wall and its influence on the excavated area's stability by doing 2D and 3D analyses of the diaphragm wall is studied while taking into account various variables. The diaphragm wall was modelled using different finite element programs to predict the diaphragm wall's lateral deflection in deep excavations[9]. Conti et al[5] presented impacts of diaphragm walls installation in sand by numerical modelling. The analysis anticipated ground motions.

Numerous studies have also examined the impact of installing a diaphragm wall near the current structure, especially in static condition. Chan and Yap[3] have documented how the installation of diaphragm wall's panels affected the old masonry building next to it, which was built in an area with soft or loose soil. A study on 'Effect of deep excavation on deformation of diaphragm wall and adjacent structures' was conducted by Nam and Nhu[15].

Madabhushi and Zeng[13] investigated the seismic behaviour of gravity barriers using both numerical and experimental techniques. A fresh approach utilising pseudo-static equilibrium was developed by Caltabiano et al[1] for the investigation of wall-soil interactions. Using the computational finite element method, Gazetas et al[8] evaluated the intensity as well as the spread of earth pressures on reinforced earth walls, piled walls with anchors that are either horizontal or sharply inclined and reinforced concrete walls in the L form under dynamic condition. They demonstrated that the outstanding resilience of such retaining structures during intense earthquakes is justifiable as the level of realism in the study grows.

Using technique of finite elements, Psarropoulos et al[17] produced a distribution of soil pressure that was dynamic for both flexible and rigid retaining structures. They found that for functionally or rotationally flexible walls, the outcomes of the Mononobe-Okabe and elasticity-based methods are comparable. By examining four mechanically stabilised earthen barrier beneath Tecoman city, Mexico, Wartman et al[22] examined the behaviour of an earthquake. They highlighted on the reliability and utility of the sliding block and pseudo-static approaches for seismic inquiry based on performance records.

In order to provide design assistance, Callisto and Soccodato[2] looked into how a cantilever bearing structure behaved seismically during two different earthquake scenarios that occurred in Italy on coarse-grained soil in dried conditions. They made use of numerical calculations with plane-strain finite differences. They eventually created an economic design standard for these subsurface structures that depended on the system's ductility. Using finite difference computational techniques, Chowdhury et al[4] examined the diaphragm wall's seismic behaviour following three earthquakes with different peak ground accelerations (PGAs). For a 10–20 m excavation under seismic loads, they advised thickness and penetration depth of the diaphragm walls equal to 6 and 100% of the excavation's final depth.

Konai et al[12] used experimental and numerical methods to assess the anchored excavation's seismic response in dry sand. According to their research, deeper excavations and higher base acceleration amplitudes result in maximum ground surface deformation, bending moment and strut forces. The research highlights how dynamic forces affect lateral wall deflections and ground deformations, providing insights for safer design in earthquake situations.

Material and Methods

The current study modelled the existing diaphragm wall and the nearby excavation process utilising Plaxis 3D software. The site selected for the diaphragm wall was located in Noida (India). Information of soil profile, existing diaphragm wall and anchors to support the diaphragm wall were collected from the earlier case study[11]. It was found that the level of water was around six meters below the normal level of the land. The 3D model of diaphragm wall prepared by using these data was also validated in the previous study[19]. For the 3D numerical modelling and calculations to evaluate the effect of neighbouring excavation on the diaphragm wall, an excavation pit measuring 17 by 22 meters with a depth of 1.5 meters was assumed.

Soil profile description: Table 1 displays the properties of the soil taken into account in the numerical modelling. The site research undertaken by Jasmine and Muttharam[11] in the preceding case study provided the parameters of the soil layers.

Diaphragm wall and anchors details: The purpose of the anchors was to sustain the diaphragm wall while excavating for the basement and to install at three levels. Table 2 summarises the details of the diaphragm wall that was taken into consideration for the analysis. The diaphragm wall's embedded depth in the earth along with the excavation depth is the embedded depth specified in table 2.

Nearby excavation details: An excavation depth of 1.5 metres below earth surface and a width of 15 metres was modelled for the 3D study. Four cases were taken into consideration while modelling the excavated area for the analysis. In the first, second, third and fourth cases, the diaphragm wall was 5, 10, 15 and 20 meters away from the edge of the nearby excavated area. Table 3 contains the designations for all the cases.

Seismic assessment of the diaphragm wall and nearby excavation work: The Plaxis 3D program was used to evaluate the diaphragm wall for seismic events. 10 m thickness of three-dimensional soil element was considered for the 3D model of diaphragm wall and nearby excavation. The diaphragm underwent three stages of 3D modelling. The Mohr-Coulomb model was used to simulate the behaviour of the soil. For the free length and fixed length sections, soil

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anchors were displayed as node-to-node anchors and geo-grid elements respectively, while the 21.2 m deep diaphragm structure was represented as a plate element. Eliminating the soil strata up to 14.2 m depth behind the diaphragm wall was done in order to simulate excavation of such depth for the purpose of continuing the building of basement levels.

Fig. 1 displays the model for diaphragm wall. Additionally, in phase 4, nearby excavation for new construction having 1.5 m depth and 17 m width was modelled as shown in fig. 2. The distance between diaphragm wall and edge of excavated area was varied for the four cases accordingly. For each case, seismic behaviour of diaphragm wall was evaluated in terms of horizontal deflection, shear force and bending moment by seismic numerical analysis. For this purpose, effective peak ground acceleration (EPGA) data and time history graph were input in the Plaxis 3D software.

Results and Discussion

Horizontal displacement (u_{xx}): The analysis findings show that the diaphragm wall's maximum displacement before fresh excavation was 0.02626 m. Maximum horizontal diaphragm wall deflections are displayed in all the cases in table 4. Case 1 represents the case when there is no nearby excavation. Fig. 3 shows the comparison plot of horizontal deflection versus depth of diaphragm wall in various cases considered for modelling and analysis.

Table 1
Soil parameters for modelling of Diaphragm wall[11]

Layers in m		Soil layer description	Unit weight of soil in kN/m³	SPT value (N value)	Young's modulus in kN/m²	Poissons ratio, μ	Friction angle, φ in degrees
Top	Bottom						
0	4	Silty sand (SM)	15	8	22,900	0.25	27
4	8	Sand (S)	16	14	35,900	0.25	29
8	11	Sand (S)	18	20	47,500	0.25	29
11	17	Sand (S)	19	32	64,400	0.25	30
17	22	Sand (S)	19	46	78,400	0.35	30
22	28	Sand (S)	19	52	80,000	0.35	30
> 28		Sand (S)	20	60	85,000	0.35	31

Table 2
Diaphragm wall and anchor details[11]

Thickness of the D-wall in mm	Top level of the D-Wall in m	Depth of open excavation in m	Level of anchors	Embedment depth of D-wall in m	Maximum depth of excavation in m
800	200.58 (Finished Road Level)	0	3 levels (3, 7 and 11 meters from Finished Road Level)	7	14.2 from Finished Road level

Table 3
Designation for all the cases

Cases	Designation
Case 1	No nearby excavation
Case 2	Excavation is at 5m away from diaphragm wall
Case 3	Excavation is at 10m away from diaphragm wall
Case 4	Excavation is at 15m away from diaphragm wall
Case 5	Excavation is at 20m away from diaphragm wall

Table 4
The variation of horizontal deflection in all the cases

Cases	Maximum Horizontal deflection (m)
Case 1	0.02626
Case 2	0.02516
Case 3	0.02554
Case 4	0.02595
Case 5	0.02616

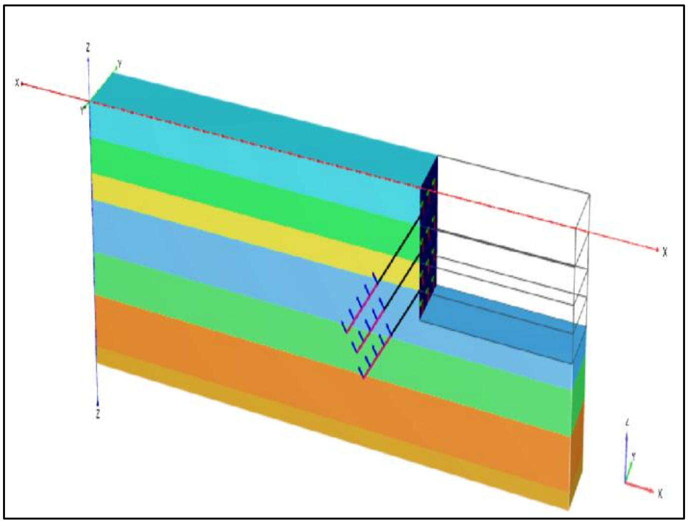

Fig. 1: 3D model of Diaphragm wall

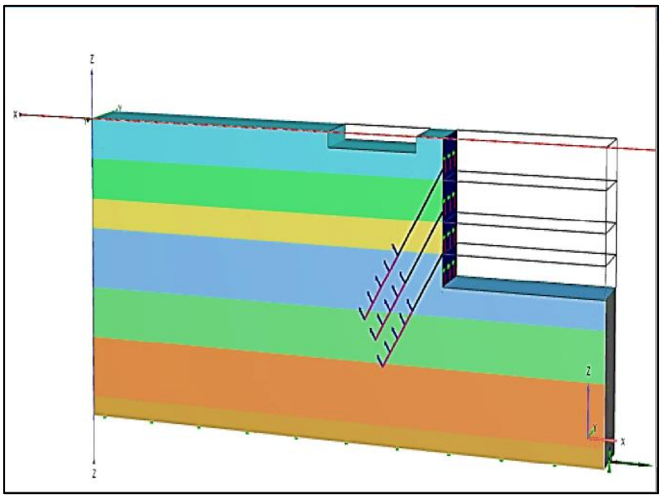

Fig. 2: 3D model of Diaphragm wall and nearby excavation

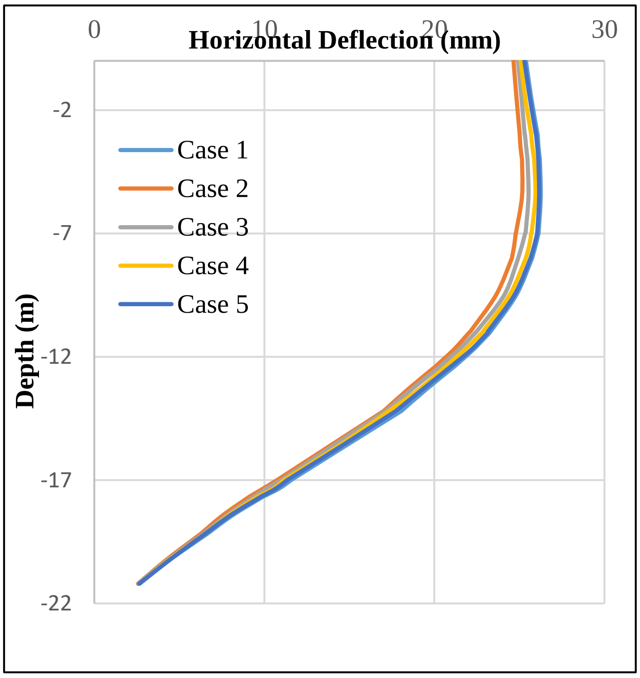

Fig. 3: Comparative graph for horizontal deflection in all the cases

As we can observe from the table and figure, the maximum horizontal deflection of diaphragm wall was more when there is no nearby excavation. Also, maximum horizontal deflection increases with increase in distance between diaphragm wall and nearby excavation.

Shear force (Q): According to the analysis result, the diaphragm wall's maximum and minimum shear forces were discovered to be 294.34 kN/m and -218.04 kN/m respectively. Table 5 shows maximum shear force on diaphragm wall in all the cases. The comparative plot of maximum shear force versus depth of diaphragm wall in various cases considered for modelling and analysis is displayed in fig. 4. Again, case 1 represents the case when there is no nearby excavation. As we can observe from the table and figure, the maximum shear force of diaphragm wall was more when there was no nearby excavation. Additionally, the maximum shear force rises as the distance between the adjacent excavation and the diaphragm wall grows.

Bending Moment (M): According to the analysis result, the diaphragm wall's maximum and minimum bending moment before neighbouring excavation were obtained to be 486.99 kNm/m and -124.80 kNm/m respectively. Table 6 shows the diaphragm wall's maximum bending moment in all the cases. The bending moment versus diaphragm wall depth comparison plot for the several scenarios was taken into consideration for modelling and analysis is displayed in fig. 5. Again, case 1 represents the case when there is no nearby excavation.

Table 5
Maximum shear force in all the cases

Cases	Max Shear Force (kN/m)
Case 1	294.34
Case 2	239.19
Case 3	254.95
Case 4	268.98
Case 5	283.43

The table and figure show that the diaphragm wall's maximum bending moment was higher in the absence of any adjacent excavation. Also, maximum shear force increases with increase in distance between diaphragm wall and nearby excavation.

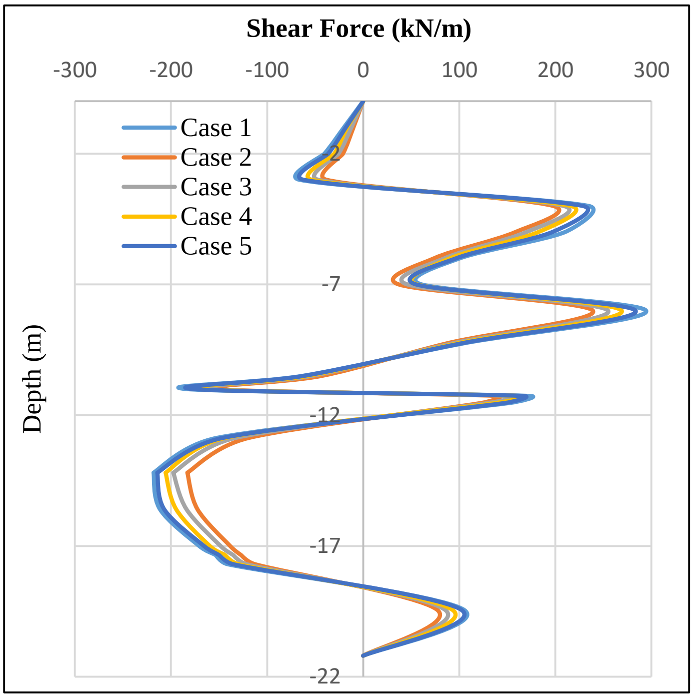

Fig. 4: Comparative graph of Shear Force in all the cases

Table 6
Maximum Bending Moment in all the cases

Cases	Max Bending Moment (kNm/m)
Case 1	486.99
Case 2	422.49
Case 3	445.67
Case 4	459.33
Case 5	476.04

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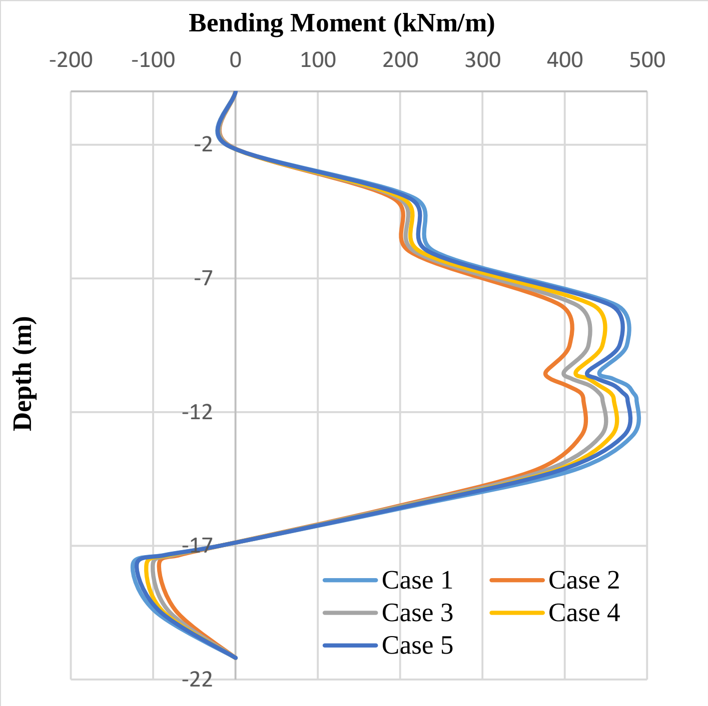

Fig. 5: Comparative graph of Bending Moment in all the cases

Conclusion

The behaviour of the diaphragm wall protecting the deep basement was the main focus of this research. On the 800 mm thick diaphragm wall, 3D analysis was carried out and the diaphragm wall's behaviour was observed to analyse the effect of nearby excavation work on diaphragm wall by varying the distance between nearby excavation and diaphragm wall. The results obtained from the analysis of different cases was compared.

- 3D analysis result shows the diaphragm wall's maximum horizontal displacements, shear force and bending moment before nearby excavation process as 0.02626 m, 294.34 kN/m and 486.99 kNm/m respectively.
- The diaphragm wall's maximum horizontal deflection was more when there is no nearby excavation. Also, the maximum horizontal deflection was reduced by 4.19 %, 2.74 %, 1.18% and 0.38% respectively, when nearby excavation was at a separation of 5, 10, 15 and 20 meters away from diaphragm wall respectively.
- The diaphragm wall's maximum shear force was more when there is no nearby excavation. Also, the maximum shear force was reduced by 18.90 %, 13.68 %, 8.77% and 3.71 % respectively, when nearby excavation was at a separation of 5, 10, 15 and 20 meters away from diaphragm wall respectively.
- The maximum bending moment of diaphragm wall was more when there is no nearby excavation. Also, the maximum bending moment was reduced by 13.24%, 8.48%, 5.68% and 2.66 % respectively when nearby excavation was at a separation of 5, 10, 15 and 20 meters away from diaphragm wall respectively.
- As the separation between the diaphragm wall and a nearby excavation rises, the maximum horizontal deflection, shear force and bending moment increase as well. They eventually reach their approximate maximum value when the distance is 20 m.

Since, values obtained from 3D analysis in case 1 and case 5 show approximately similar values of horizontal deflection and total horizontal stress of diaphragm wall, it can be concluded that there is no effect or less effect of nearby new excavation process on existing diaphragm wall when excavation area is at 20 m away from diaphragm wall. Thus, this work provides useful guidance for monitoring the behaviour of diaphragm walls during seismic conditions utilizing 3D analysis.

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References

1. Caltabiano S., Cascone E. and Maugeri M., Seismic stability of retaining walls with surcharge, *Soil Dynamics and Earthquake Engineering*, **20(5-8)**, 469-476 **(2000)**

2. Callisto L. and Soccodato F.M., Seismic design of flexible cantilevered retaining walls, *Journal of Geotechnical and Geoenvironmental Engineering*, **136(2)**, 344-354 **(2010)**

3. Chan S.F. and Yap T.F., Effects of construction of a diaphragm wall very close to a masonry building, *Slurry Walls: Design, Construction and Quality Control*, **4**, 128 **(1992)**

4. Chowdhury S.S., Deb K. and Sengupta A., Behavior of underground strutted retaining structure under seismic condition, *Earthquakes and Structures*, **8(5)**, 1147-1170 **(2015)**

5. Conti R., de Sanctis L. and Viggiani G.M., Numerical modelling of installation effects for diaphragm walls in sand, *Acta Geotechnica*, **7**, 219-237 **(2012)**

6. Dibiagio E. and Myrvoll F., Full scale field test of a slurry trench excavation in soft clay, In Fifth Eur Conf On Soil Proc/Sp/, no. Conf Paper (**1972**)

7. Farmer I.W. and Attewell P.B., Ground movements caused by a betonite-supported excavation in London Clay, *Geotechnique*, **23(4)**, 576-581 **(1973)**

8. Gazetas G., Psarropoulos P.N., Anastasopoulos I. and Gerolymos N., Seismic behaviour of flexible retaining systems subjected to short-duration moderately strong excitation, *Soil Dynamics and Earthquake Engineering*, **24(7)**, 537-550 **(2004)**

9. Gourvenec S.M. and Powrie W., Three-dimensional finite-element analysis of diaphragm wall installation, *Geotechnique*, **49(6)**, 801-823 **(1999)**

10. IS 1893 Part 1 Criteria for earthquake resistant design of structures, Bureau of Indian Standards, New Delhi, India **(2016)**

11. Jasmine Nisha J. and Muttharam M., Deep excavation supported by diaphragm wall: A case study, *Indian Geotechnical Journal*, **47**, 373-383 **(2017)**

12. Konai S., Sengupta A. and Deb K., Behavior of braced excavation in sand under a seismic condition: experimental and numerical studies, *Earthquake Engineering and Engineering Vibration*, **17**, 311-324 **(2018)**

13. Madabhushi S.P.G. and Zeng X., Seismic response of gravity quay walls. II: Numerical modeling, *Journal of Geotechnical and Geoenvironmental Engineering*, **124(5)**, 418-427 **(1998)**

14. Masuda T., Einstein H.H. and Mitachi T., Prediction of lateral deflection of diaphragm wall in deep excavations, *Doboku Gakkai Ronbunshu*, **505**, 19-29 **(1994)**

15. Nam N.H. and Dung N.V., Effect of deep excavation on deformation of diaphragm wall and adjacent structures, Geotechnics for Sustainable Infrastructure Development, Springer Singapore 337-344 **(2020)**

16. Ou C.Y., Chiou D.C. and Wu T.S., Three-dimensional finite element analysis of deep excavations, *Journal of Geotechnical Engineering*, **122(5)**, 337-345 **(1996)**

17. Psarropoulos P.N., Klonaris G. and Gazetas G., Seismic earth pressures on rigid and flexible retaining walls, *Soil Dynamics and Earthquake Engineering*, **25(7-10)**, 795-809 **(2005)**

18. Puri N., Jain A., Nikitas G., Dammala P.K. and Bhattacharya S., Dynamic soil properties and seismic ground response analysis for North Indian seismic belt subjected to the great Himalayan earthquakes, *Natural Hazards*, **103**, 447-478 **(2020)**

19. Sneha S., Abbas S.M. and Sahu A.K., Numerical Analysis of Diaphragm Wall Supporting Deep Excavation, Recent Advances in Civil Engineering, CRC Press, 115-120 **(2024)**

20. Tamano T., Fukui S., Suzuki H. and Ueshita K., Stability of slurry trench excavation in soft clay, *Soils and Foundations*, **36(2)**, 101-110 **(1996)**

21. Tedd P., Chard B.M., Charles J.A. and Symons I.F., Behaviour of a propped embedded retaining wall in stiff clay at Bell Common Tunnel, *Géotechnique*, **34(4)**, 513-532 **(1984)**

22. Wartman J., Rondinel-Oviedo E.A. and Rodriguez-Marek A., Performance and analyses of mechanically stabilized earth walls in the Tecoman, Mexico earthquake, *Journal of Performance of Constructed Facilities*, **20(3)**, 287-299 **(2006)**.

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