International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 03 | Mar 2022 www.irjet.net p-ISSN: 2395-0072

PERFORMANCE EVALUATION OF DEEP EXCAVATION UNDER STATIC AND SEISMIC LOAD CONDITIONS

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Abstract - *Diaphragm wall supported by ground anchors also known as tie-back walls is one of the options to support deep excavation for the construction of basements in urban area having constraints of space due to nearby structures. In the present study numderical modelling and analysis is performed for a 12m deep vertical excavation supported by anchored diaphragm wall considering a surcharge uniformly distributed load of 50kPa over a length of 12m starting from the excavation line using a finite element based geotechnical software PLAXIS 2D. A parametric study is conducted by varying the anchor inclination angle to 0°, 15°, 30° and 45° and the behaviour of the soil body and forces generated in the diaphragm wall are compared for each case and it is found that the least horizontal displacement is noticed in the case of horizontal anchors but least bending moment in the diaphragm wall is noticed for 45° inclination case. The surcharge load is placed at different locations from the excavation line and the behaviour of the soil body is compared for those cases and found that when the surcharge is at 0m distance from excavation line the maximum displacement and the bending moment is observed, as the surcharge moves away from the excavation line the displacement, bending moment goes on decreasing and found that least displacement and bending moment is observed when the surcharge is at 5m distance. Also in this study an attempt is made to understand how the presence of water table affects the deep excavation.*

***Key Words*: Deep excavation, Collapse, Diaphragm wall, Ground anchors, PLAXIS 2D, Stratified soils.**

1.INTRODUCTION

A deep excavation is defined as any excavation that is deeper than 4.5m (15ft) [1, 2]. However, advances in construction technology and the use of computer programming allow for the analysis and design of excavation support systems at various depths while following to the same principles. The subsurface conditions, excavation depth, surrounding buildings, space inside the site for machinery, access to the site for machinery, and economics all play a role in the selection of an excavation support system. If the proposed excavation is deep and surrounded by existing structures, a diaphragm wall is one of the choices. It was used first time in the 1950s in Italy, after that it's use increased throughout the world [3].

Wall displacement is a critical safety parameter for the support system and neighbouring structures. In underground construction, horizontal displacement of the wall up to 2% of the final depth of excavation is common [5,6]. This horizontal displacement range, however, is not suitable for situations when shoring is near to a neighbouring building/structure. G.B Liu,P.Huang, J.W Shi [7] discovered that the greatest lateral wall displacement was roughly 0.2 percent of excavation depth based on case histories. Using the finite element approach, Bose and Som [8] investigated the influence of excavation depth on wall-soil deformation (FEM). The numerical investigation was carried out in order to investigate the effect of excavation on ground displacement, and a method for predicting ground displacement was presented [9]. Bin-Chen Benson [10] studied the ground and structural behaviour iduced by the deep excavation in loose sands. Case studies on the performance of diaphragm walls with tie-back anchors and struts were done, demonstrating the benefit of numerical simulation for an efficient design in various parts of the world. As the subsurface conditions, adjacent structures, foundation details of adjacent structures and excavation depth vary from location to location; therefore, case studies always provide a guide to designers to enhance their designing approach for future works. [12,13].

In the present study numderical modelling and analysis is performed for a 12m deep vertical excavation supported by anchored diaphragm wall considering a surcharge load of 50kPa over a length of 12m starting from the excavation line using a finite element based geotechnical software PLAXIS 2D. A parametric study is conducted to understand how soil body and the retaining structure bahaves for the deep excavation in the layered soil stratum.

1.1 Ground anchors and anchored systems

A prestressed grouted ground anchor is a structural element installed in soil or rock that is used to transmit an applied tensile load into the ground. Grouted ground anchors, referenced simply as ground anchors, are installed in grout filled drill holes. Grouted ground anchors are also referred to as "tiebacks". The basic components of a grouted ground anchor include the: (1) anchorage; (2) free stressing (unbonded) length; and (3) bond length. Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

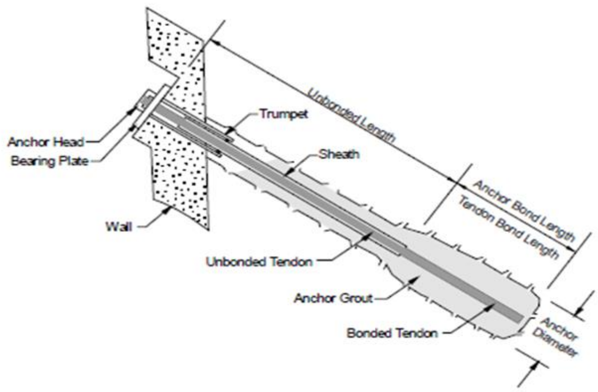

Fig -Error! No text of specified style in document.: Components of ground anchor (FHWA-IF-99-015, 1999)

2. PROBLEM DEFINATION

12m vertical deep excavation in a non-homogeneous soil strata using diaphragm wall and ground anchors. Taking surcharge of uniformly distributed load 50kPa along the excavation line.

Table -1: Soil properties

Parameter	Name	Layer 1	Layer 2	Layer 3	Layer 4
Material model	Model	M C model	M C model	M C model	M C model
Type of material behaviour	Type	Drained	Drained	Drained	Drained
Soil dry unit weight (kN/m^3)	Ɣuns at	17	17	18	24
Soil saturated unit weight (kN/m^3)	Ɣsat	20	20	21	25
Horizontal permeabilty (m/day)	Kx	0.1	0.5	0.5	$1*10^{-9}$
Vertical permeability (m/day)	Ky	0.1	0.5	0.5	$1*10^{-9}$
Young's modulus (kN/m^2)	E ref	25000	42000	144000	184800
Poisson's ratio	v	0.4	0.3	0.5	0.25
Cohesion (kN/m^2)	C ref	12	15	0	0
Friction angle	Φ	25	30	35	43
Dilatency angle	Ψ	0	0	0	0
Interface reduction factor	R inter	0.65	0.65	0.70	Rigid

Table -2: Properties of diaphragm wall

Parameter	Name	Value
Type of behaviour	Material type	Elastic
Normal stiffness (kN/m)	EA	$12*10^6$
Flexural rigidity (kNm^2/m)	EI	$0.12*10^6$
Equivalent thickness (m)	d	0.346
Weight (kN/m/m)	w	8.3
Poisson's ratio	v	0.15

Table -3: Properties of anchor rod

Parameter	Name	Value
Type of behaviour	Material type	Elastic
Normal stiffness (kN/m)	EA	$6.43*10^5$
Spacing out of plane (m)	Ls	2.5

Table -4: Properties of grout material

Parameter	Name	Value
Type of behaviour	Material type	Elastic
Normal stiffness (kN/m)	EA	$1*10^5$

The deep excavation is analysed for various cases by varying the parameters of the diaphragm wall, ground anchors and other properties of the soil, thee parameters for which the analysis is performed are listed below.

a) Embedment depth of diaphragm wall.
b) Inclination of ground anchors.
c) Position of surcharge from excavation line

d) With and without water table.

e) Static and dynamic analysis.

The forces acting on the anchors varies as the inclination of the anchor changes, therefore the length and the pre-stressing to be applied to anchor bar also changes with change in inclination.

Table -5: Top anchor length and prestress force

Anchor inclination (°)	Unbonded length (m)	Bonded length (m)	Pre-stress force(kN/m)
0	7	6	150
15	6.7	6	170
30	6.5	6	195
45	6.6	6	230

Table -6: Bottom anchor length and prestress force

Anchor inclination (°)	Unbonded length (m)	Bonded length (m)	Pre-stress force(kN/m)
0	**7**	**6**	**200**
15	**4.5**	**6**	**260**
30	**4.5**	**6**	**310**
45	**4.5**	**6**	**365**

2.1 Procedure for numerical modeling

Plaxis version 8.6 is used for the simulation of 12m deep vertical cut in soil using staged construction of anchored diaphragm wall and analyzing the response of anchored diaphragm wall under static and seismic condition. Numerical modelling is carried out taking the plane strain state of stresses. The 15-node triangular element with finer mesh density are used for the finite element discretization. The in-situ soil is simulated as Mohr-coulomb (MC) material for the static and dynamic analysis. For dynamic analysis, strong motion record of upland earthquake respectively is used. Ground anchors and diaphragm wall are simulated as the linear elastic material. Plate element is used to model the diaphragm wall and node to node anchor is used to model the ground anchors and geogrid element is used to model grout material. Excavation sequences are simulated as the staged excavation with 2-m excavation lift in each stage. The analysis is carried out in the sequence indicated below.

1. Starting a new project.

2. Creating soil stratigraphy using the geometry line feature, as shown below.

3. Defining standard earthquake boundaries.

4. Creating and assigning of material data sets for soil for each layer (MC model).

5. Creating and assigning of material data sets for soil for each layer (MC model).

6. Creating and assigning of material data sets for ground anchors.

7. Creating and assigning of material data sets for grout material.

8. Assigning a distributed load to model the surcharge load.

9. Generation of mesh.

10. Staged excavation calculation.

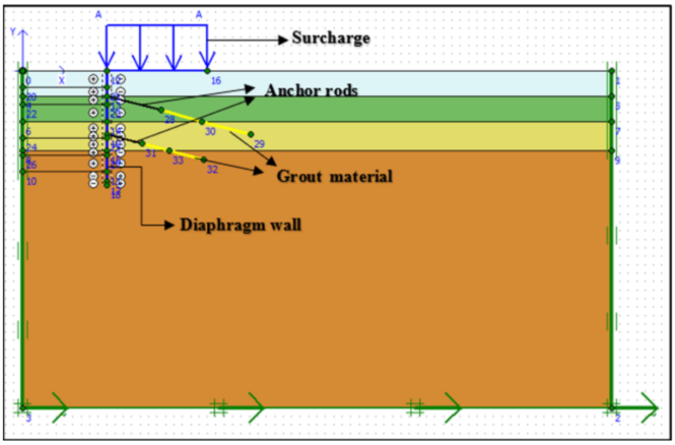

Fig -2: Geometric model showing the anchored diaphragm wall system

Fig 2 shows the geometric model of the layered soil strata and the support system provided for the proposed excavation, the geometric model is prepared using numerical modeling tool PLAXIS 2D.

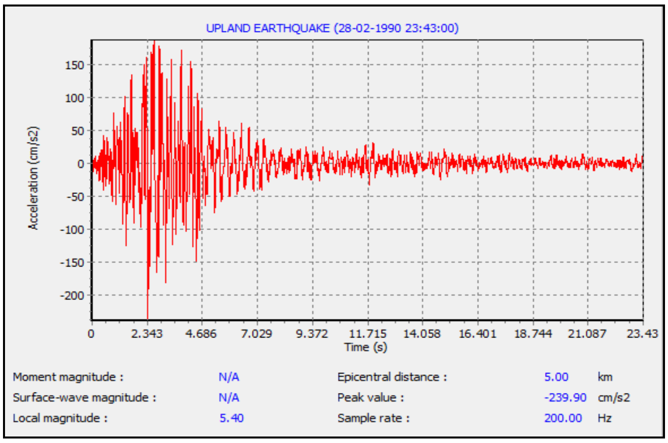

Fig -3: Strong ground motion record of Upland earthquake.

Dynamic analysis is performed using Upland earthquake (occurred during 20th feb 1990 at 3.44 pm in South California) of peak acceleration of 0.245g (0.24 m/s^2).

After all calculation phases have been defined, some points for load-displacement curves should be selected (for example top and bottom of the diaphragm wall).

2.2 Output

The deformed mesh shows the magnified image of how the soil body deforms after the excavation of 12m deep is made using the diaphragm wall and grouted ground anchors.The diphragm wall deflects due to the earth pressure and the surcharge, bottom heave is observed at the final excavation level.

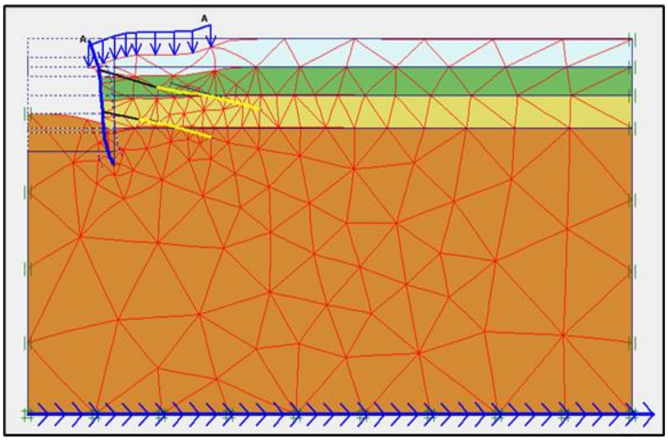

Fig -4: Deformed mesh (Static analysis)

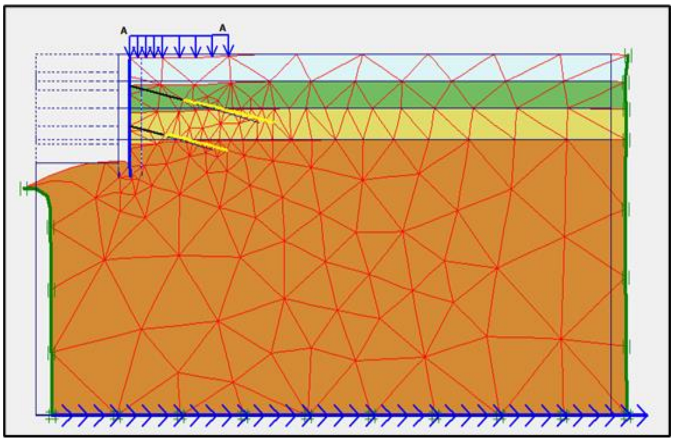

Fig -5: Deformed mesh (Dynamic analysis)

2.3 Results and discussion

Diaphragm wall anchorage system is analysed for different cases, varying the configuration of the system such as the embedment length of the wall and inclination of the anchors. The different cases were also analysed by varying the surcharge load location and water table. These all cases were analysed by both Static and Dynamic conditions. In Static conditions the forces acting on the system such as the lateral earth pressure is calculated and the system is made such that it resists all the forces acting on the system. In Dynamic condition the time history is defined in the programme and the forces generated due to the dynamic acceleration were calculated and the system is made such that it resists the forces effectively without any failure. The various parameters that were varied during analysis are as follows

1. Embedment depth of the wall
2. Anchor inclination with respect to horizontal
3. Surcharge load location.
4. Water table and.
5. Type of Analysis.

Static analysis:

In static analysis the loads which are acting on the system is constant with respect to time. So at every instance of time the magnitude of the forces acting on the Anchor wall system is constant. To perform static analysis in finite element analysis programme the geometry of the problem is defined, the anchor wall system is modelled and the analysis is carried out in stage manner.

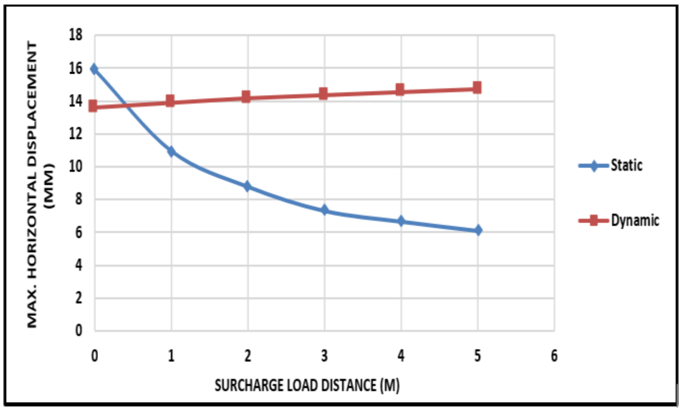

Chart -1: Load distance vs Maximum horizontal displacement

Chart 1 is the plot of Surcharge load distance from excavation line and the corresponding Maximum horizontal displacement in the wall after the final stage of excavation. From the graph we can see that the horizontal displacement is maximum when the Surcharge load is placed at the excavation line (i.e., at 0m) and it will goes on decreasing as the surcharge load is placed away from the excavation line. As we keep on moving the surcharge away from the excavation line the variation of bending moment will almost beccome constant(i.e., at 5m). The horizontal displacement is maximum in the case of Dynamic analysis when compared to Static analysis.

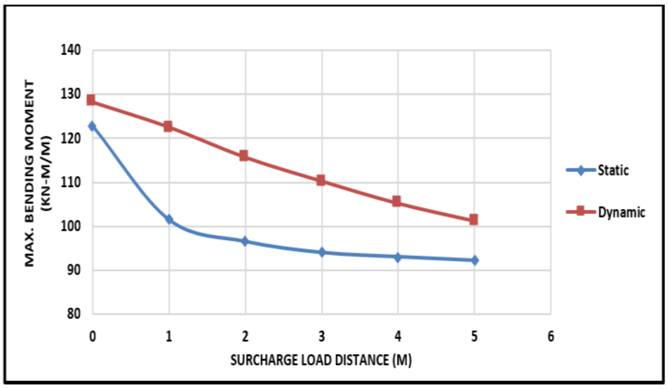

Chart -2: Load distance vs Maximum bending moment

Chart 2 is the plot of Surcharge load distance from excavation line and the corresponding Maximum bending moment in the wall after the final stage of excavation. From the graph we can see that the bendning moment is maximum when the Surcharge load is placed at the excavation line (i.e., at 0m) and it will goes on decreasing as the surcharge load is placed away from the excavation line. As we keep on moving the surcharge away from the excavation line the variation of bending moment will almost beccome constant(i.e., at 5m). The bending moment in the wall is maximum in the case of Dynamic analysis when compared to Static analysis.

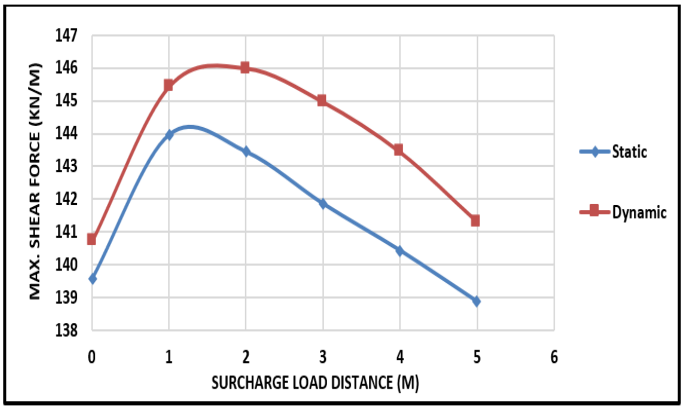

Chart -3: Load distance vs Maximum Shear force

Chart 3 is the plot of Surcharge load distance from excavation line and the corresponding Maximum shear force in the wall after the final stage of excavation. From the graph we can see that the shear force is not maximum when the Surcharge load is placed at the excavation line but it is maximum when the surcharge is placed at 1m from the excavation line in the case of Static analysis and is maximum when the load is placed at 2m from the excavation line in the case of Dynamic analysis. When the surcharge placed further away from the excavation line the shear force keeps decreasing and the variation seen is very less after the distance 5m and above from the excavation line.

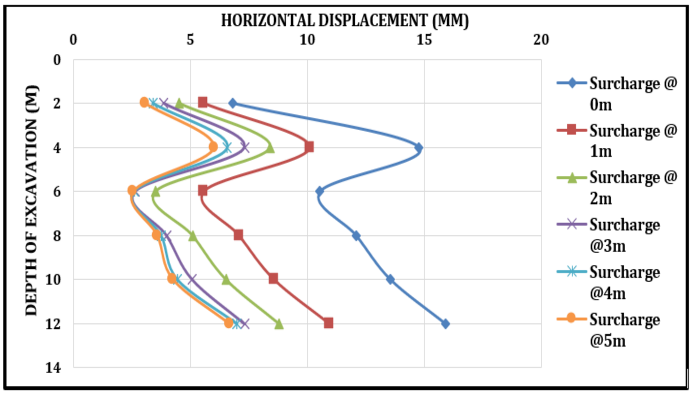

Chart -4: Depth of excavation vs Horizontal displacement

Chart 4 is the plot drawn for the comparison of the horizontal displacement at every stage of excavation (i.e., at 2m intervals) and for all the cases of surcharge at different locations from the excavation line. From graph it is seen that the horizontal displacement initially it will be minimum and goes on increasing as the depth of excavation increases and is maximum at the final stage of excavation i.e., at 12m. The maximum horizontal displacement is in the case of when surcharge is at 0m from excavation line, and least when the surcharge is at 5m distance from the excavation line.

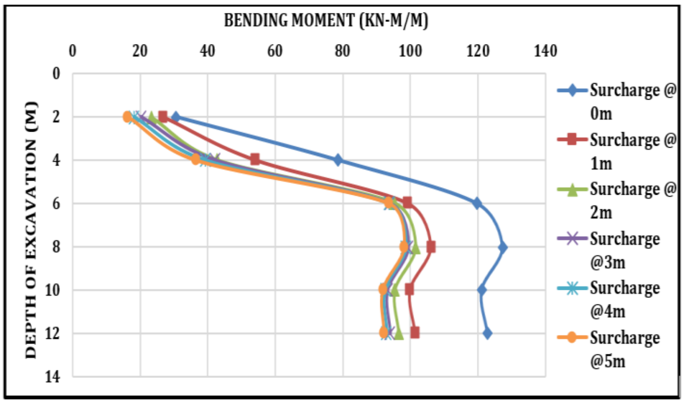

Chart -5: Depth of excavation vs Bending moment

Chart 5 is the plot drawn for the comparison of the bending momemt in the wall at every stage of excavation (i.e., at 2m intervals) and for all the cases of surcharge at different locations from the excavation line. From graph it is seen that the bending moment initially will be minimum and goes on increasing as the depth of excavation increases and it will be maximum at the final stage of excavation i.e., at 12m. The bending moment will be maximum when the surcharge load is at the excavation line i.e., at 0m and it will be least when the surcharge is at 5m from the excavation line.

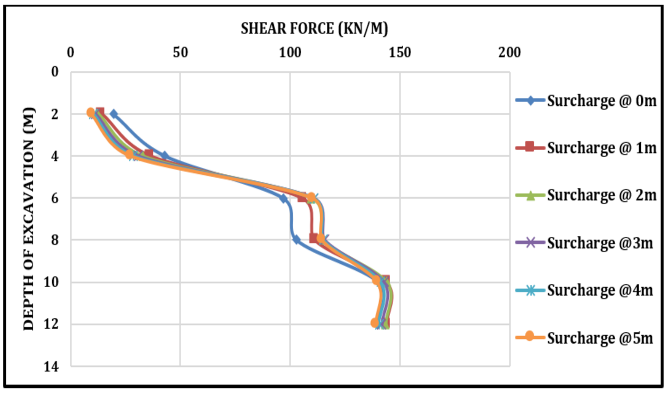

Chart -6: Depth of excavation vs Shear force

Chart 6 is the plot drawn for the comparison of the Shear force in the wall at every stage of excavation (i.e., at 2m intervals) and for all the cases of surcharge at different locations from the excavation line. From graph it is seen that the shear force initially will be minimum and goes on increasing as the depth of excavation increases and it will be maximum at the final stage of excavation i.e., at 12m.

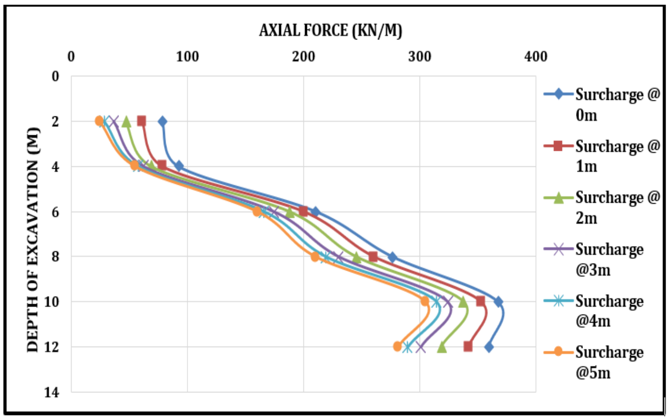

Chart -7: Depth of excavation vs Axial force

Chart 7 is the plot drawn for the comparison of the Axial force in the wall at every stage of excavation (i.e., at 2m intervals) and for all the cases of surcharge at different locations from the excavation line. From graph it is seen that the axial force initially will be minimum and goes on increasing as the depth of excavation increases and it will be maximum at the final stage of excavation i.e., at 12m. The axial force will be maximum when the surcharge load is at the excavation line i.e., at 0m and it will be least when the surcharge is at 5m from the excavation line.

Dynamic analysis:

In dynamic analysis the loads which are acting on the system are not constant but they vary with respect to time. So at every instance of time the magnitude of the forces acting on the Anchor wall system is not constant. Dynamic analysis is studied to asses whether the structural system so provided is safe in natural calamities such as earthquake. In Plaxis the system is put to the same ground acceleration which were recorded at the time of earthquakes. To perform the dynamic analysis in finite element analysis programme the geometry of the problem is defined, and the time-history analysis is done using the strong ground motion data file which is available in the PLAXIS 2D programme files.

The dynamic analysis is performed for those cases where the soil body is safe in the static analysis, and for those cases in which soil body is collapsing during the excavation stage itself, which is while performing the static analysis the dynamic analysis is not performed.

1. Embedment depth of diaphragm wall is taken as 3 times thickness of diaphragm wall and anhors are horizontal.

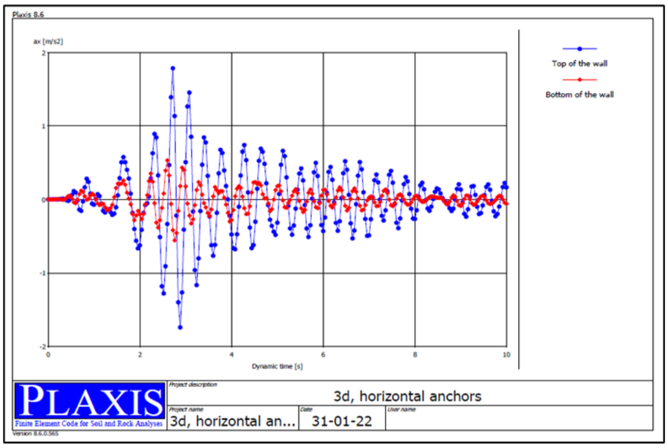

Chart -8: Time-Acceleration curve at top and bottom of the wall

Chart 8 is the Dynamic time - Acceleration curve generated by the curves tool available in software. The accelerations at the top and bottom of the wall are compared in the above graph and it is observed that the maximum horizontal acceleration is obtained at the top of the diaphragm wall. At dynamic time interval t = 2.72s, step 120 and the maximum horizontal acceleration value is ax = 1.78m/s².

2. Embedment depth of diaphragm wall is taken as 3 times thickness of diaphragm wall and anhors are inclined at 15º to the horizontal.

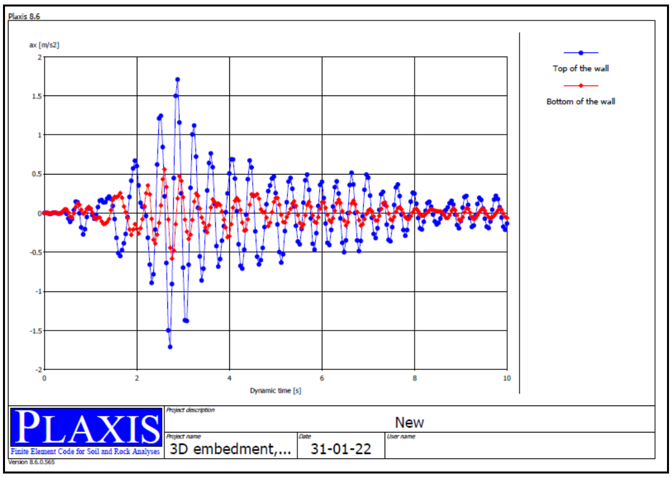

Chart -9: Time-Acceleration curve at top and bottom of the wall

Chart 9 is the Dynamic time - Acceleration curve generated by the curves tool available in software. The accelerations at the top and bottom of the wall are compared in the above graph and it is observed that the maximum horizontal acceleration is obtained at the top of the diaphragm wall. At dynamic time interval t = 2.88s, step 112 and the maximum horizontal acceleration value is ax = 1.70m/s².

3. Embedment depth of diaphragm wall is taken as 3 times thickness of diaphragm wall and anhors are inclined at 30º to the horizontal.

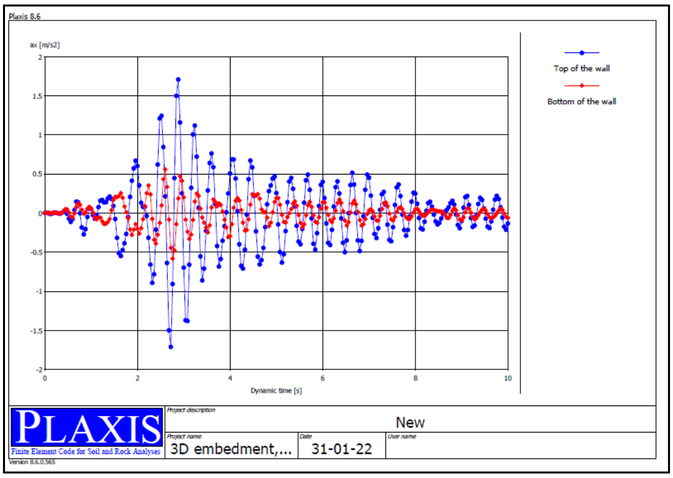

Chart -10: Time-Acceleration curve at top and bottom of the wall

Chart 10 is the Dynamic time - Acceleration curve generated by the curves tool available in software. The accelerations at the top and bottom of the wall are compared in the above graph and it is observed that the maximum horizontal acceleration is obtained at the top of the diaphragm wall. At dynamic time interval t = 2.88s, step 112 and the maximum horizontal acceleration value is ax = 1.70m/s².

4. Embedment depth of diaphragm wall is taken as 3 times thickness of diaphragm wall and anhors are inclined at 45º to the horizontal.

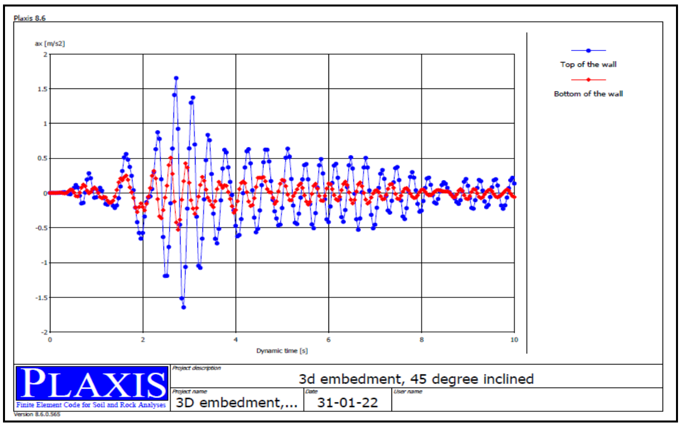

Chart -11: Time-Acceleration curve at top and bottom of the wall

Chart 11 is the Dynamic time - Acceleration curve generated by the curves tool available in software. The accelerations at the top and bottom of the wall are compared in the above graph and it is observed that the maximum horizontal acceleration is obtained at the top of the diaphragm wall. At dynamic time interval t = 2.72s, step 128 and the maximum horizontal acceleration value is ax = 1.75m/s^2.

5. Surcharge at different locations from excavation line.

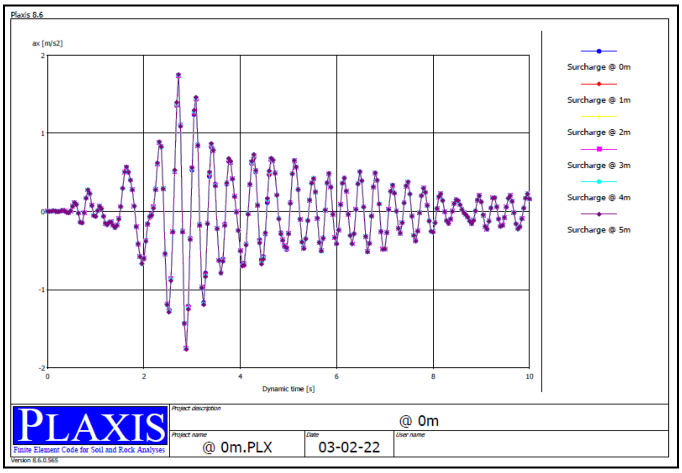

Chart -12: Time-Acceleration curve for all the cases of surcharge at different locations

Chart 12 is the Dynamic time - Acceleration curve generated by the curves tool available in software. The accelerations are compared for all the cases of surcharge at different locations and it is found that the maximum acceleration is same in all the cases and the plot obtained is also in the same trend.

3. CONCLUSIONS

The following conclusions can be drawn after the detailed parametric analysis on the deep excavation supported by diaphragm wall and ground anchors.

i. For a deep excavation supported by diaphragm wall and ground anchors a sufficient amount of embedment depth of the diaphragm wall has to be provided to keep the soil body safe. In the present study an embedment depth of 3 times thickness of diaphragm wall is found to be safe to retain a 12m deep excavation.

ii. The subsurface conditions and nearby existing structures generally decide whether the diaphragm wall will be supported by horizontal anchors or inclined anchors. By performing the numerical anlysis for different inclination angles it is found that the minimum horizontal displacements is observed for the case of horizontal anchors and the minimum bending moments in the diaphragm wall are observed in the case of 450 inclined anchors case.

iii. The diaphragm wall support system provided which is safe in the case when water table is not considered is analysed by considering a water table at a depth of 3m below the ground level and found that the soil body is collapsing due to the presence of water table.

iv. To make the excavation safe even when the water table is encountered, analysis is performed by increasing the embedment depth of diaphragm wall, by increasing the length of ground anchors and also the pre-stressing force, the excavation became safe when we provided diaphragm wall embedment depth of 4m, and also 3 rows of ground anchors which were 2 rows previously.

v. The effect of surcharge on the excavation is studied by varying the surcharge location from the excavation line, and it is found that closer the surcharge to the excavation area greater will be the displacements caused and vice-versa.

vi. In dynamic analysis the displacements and the forces in the diaphragm wall observed are more when compared to static analysis and it is found that the soil body along with the supports system provided displaces in the horizontal direction, and the soil body remains safe for the dynamic loads as well.

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