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Research Article
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Parametric Study on Analysis and Design of Permanently Anchored Secant Pile Wall for Earth Quake Loading

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Abstract

Due to space limitations in urban areas, deep excavation in to the ground has become a common practice worldwide. Deep excavations are supported by conventional retaining walls: sheet pile walls, braced walls, diaphragm walls and secant pile walls. An advantage of secant pile wall compared with other excavation supporting systems is that they are the most economical methods of creating an effective water control barriers for building structural walls. The analysis of these deep excavations requires considerations of; nonlinear, dynamic and involves consideration of soil parameters, deformation, interaction of soil and retaining configuration. Thus, in order to accurately describe the behaviour of the anchored secant pile for earthquake loading, 3D finite element simulation was applied. The study considering earth pressure, plastic analysis, and soil deformation was carried out. The analysis indicated that for 20 m excavation step in fourth stage, incremental lateral displacement was 55.2 mm and total displacement was 110.4 mm. The analysis indicated that the deeper the foundation, the larger the deformation. The real accelerogram of Loma Prieta earthquake at Del Valle Dam Station with moment magnitude 7.1 occurring at epicentral distance 66 (18 Oct, 1989) was used in the study. In order to accurately study the response of the anchored secant pile to earthquake loading; it is suggested to carry out the relevant tests to determine the right stiffness parameters. Further investigation on parameters (density and shear modulus) and other conditions that affect seismic analysis.

Keywords: Secant; Pile wall; Earthquake loading; Plaxis

Introduction

The New Headquarter Building of Commercial Bank of Ethiopia high-rise office tower complex consisting of 46 storey tower multi-functional and a 5 level underground basement. The tower is a box structure, measuring 186.4 m in height above the ground. The basement area is approximately 50500 m with 20.0 m below the ground. Most multi-storey buildings at the city centers lack adequate space for packing. Thus, creating the need for deep excavation (Figure 1).

Among researchers who have studied in this field are [1] summarized information from case histories on ground settlements adjacent to excavations and showed that settlements next to deep excavations are correlated to soil types. Clough et al. [2] showed the pattern of settlements next to excavation is influenced by soil type. Moormann [3] carried out extensive empirical studies by taking 530 case histories of retaining wall and ground movement due to excavation in soft soil (cu<75 kPa). The variation of normalized maximum horizontal displacements [4] with system stiffness are compared with [3] in the previous studies [5] the effect of excavation geometry; wall stiffness and embedment depth. The use of non-linear elastro plastic model have been used to incorporate the small strain behavior involved in deep excavation [6]. The application of a finite element analysis for modelling the top down construction of a seven-storey, underground parking garage at post office square in Boston. Predictions were evaluated through comparison with extensive field data, including settlement, wall deflection, and piezometric elevation. The results were consistent and adequate characterization of engineering properties for entire soil profile was emphasized [7]. Numerical experiments, using the advanced finite element analyses as an attempt to investigate the effect of wall depth and support conditions was conducted by Hashash and Whittle [8]. The parametric studies to investigate how predictions of excavations-induced ground movement are related to parameters such as excavation geometry, soil mass, and stress history [9]. Finite element software (PLAXIS3D) was employed to model the excavation of the anchored and shotcrete system (actual wall behaviour) and predict the displacements. The numerical modelling of shotcrete system has been compared with anchored secant pile wall which is the preferred option and parametric studies were conducted for anchored system.

Seismic test

Seismic test are conventionally classified in to borehole and surface methods. These methods enable one to determine the velocity of body waves compressional (p) and shear waves(s) and surface waves [Rayleigh] respectively which induce very small strain levels in to soil i.e. $\varepsilon_{ij} < 0.001\%$. The analysis of foundation vibrations and geotechnical earthquake engineering problems in civil engineering requires characterization of the dynamic soil properties using geophysical methods (Figure 2) [10].

Methods and Materials

This section presents the proper characterization of the soil types to the investigation depth and the material properties used as input parameters to the model. The results of the investigation helped to determine the soil properties used for modelling (HS-Model). The soil types were sorted in to categories as the borehole data. The p-wave refraction results along the weaker profile Figures 2 and 3 was used to determine the seismic properties used in the modelling (HS-Small strain model). The seismic data for borehole (Figures 2 and 3).

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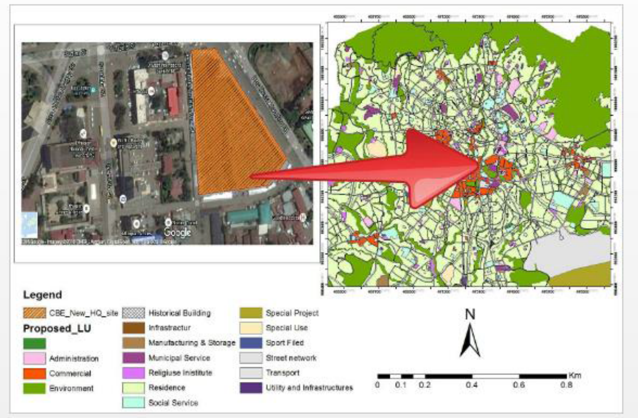


Figure 1: Site location plan.

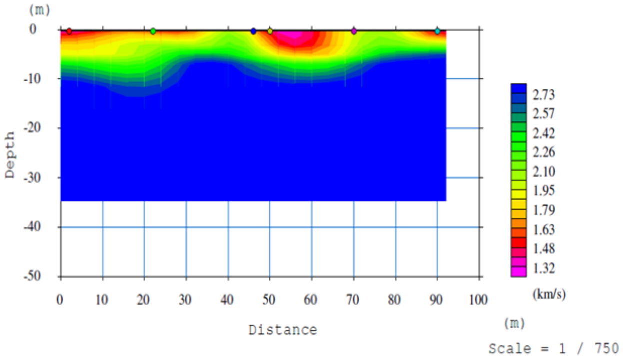


Figure 2: P-wave refraction result along profile 1 which clearly shows indentation with relatively low velocity in the middle for the CBE New Building Site.

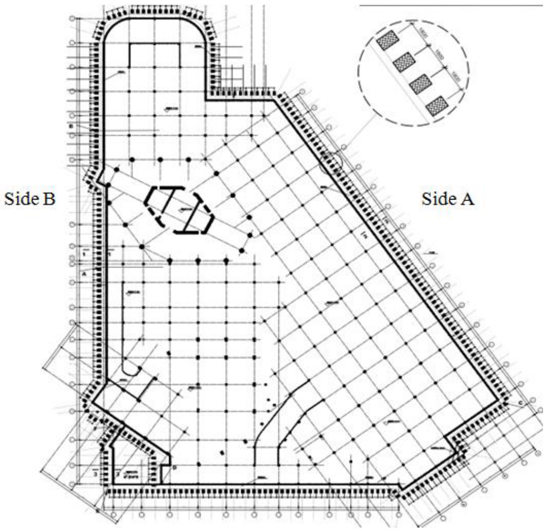


Figure 3: Site layout for the CBE New headquarters building.

There are many internationally recognized codes of practice related to the design and construction of the excavation and lateral support works. Stability of excavation is the major criterion in order to avoid collapse of the excavation. Stability analysis involves the distribution of the earth pressure.

This section presents the Finite Element Method (FEM) analyses with PLAXIS3D software.

PLAXIS” is a three-dimensional element computer program used to perform deformation and stability analysis for various types of geotechnical applications.

This program allows different soil types to be modelled along with structural and interface elements for realistic representation of soil structure interaction effects.

The numerical modelling was performed by "PLAXIS" 3D Finite Element Method in order to carry out parametric studies, since it allows for modelling complicated nonlinear soil behaviour and various interface conditions with different geometries and soil properties.

Other material parameters required for modelling were determined as per the material used and the modelling was according to the site dimensions.

Model geometry

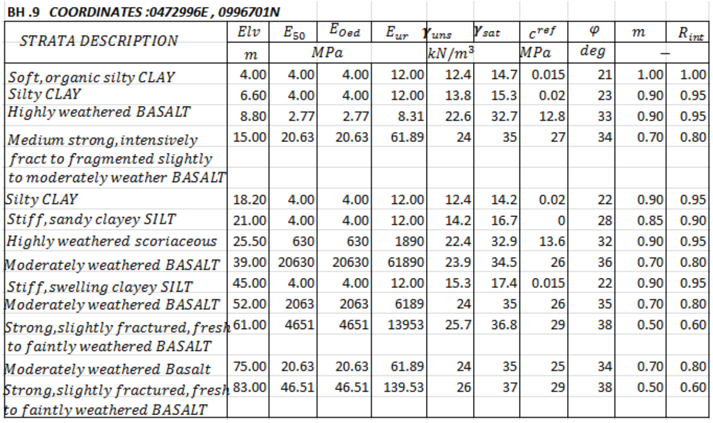
Model geometry is shown in Figures 3-5.

Model parameters

Model Parameters are given in Figures 4-7.

Loading

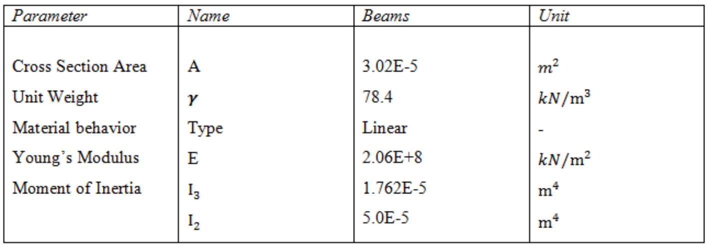
Due to the existence of several buildings around the excavation and the associated traffic. The large surcharge load is expected to take care of the adjoining structures and the traffic loading. The applied overload of 150 kPa 36 was used in the modelling. This load was used in 3D finite element analysis of a deep excavation for the Odeon project in Monaco. The project consisted of the construction of a high-rise building (160 m), the tallest building in Monaco with approximately 10 basement levels, located on a steep slope hillside. TERRASOL was the geotechnical consultant to carry out soil testing, foundation and 3D finite element model to analyze the influence of excavations on surrounding buildings.



BH .9 COORDINATES :0472996E , 0996701N

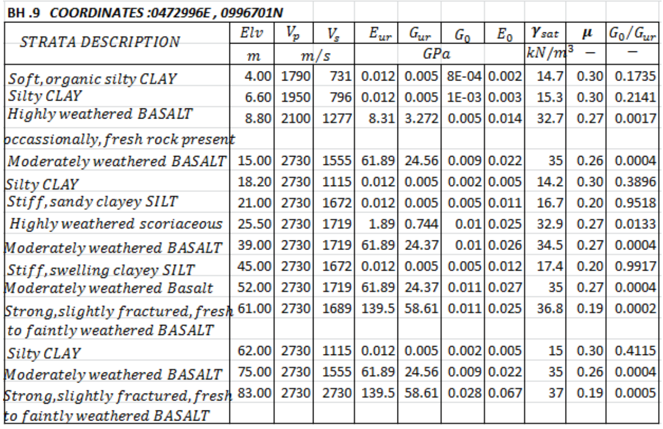
STRATA DESCRIPTION	Elv	E_{50}	E_{Oed}	E_{ur}	γ_{uns}	γ_{sat}	c^{ref}	φ	m	R_{int}
	m	MPa			kN/m^3		MPa	deg	–	
Soft, organic silty CLAY	4.00	4.00	4.00	12.00	12.4	14.7	0.015	21	1.00	1.00
Silty CLAY	6.60	4.00	4.00	12.00	13.8	15.3	0.02	23	0.90	0.95
Highly weathered BASALT	8.80	2.77	2.77	8.31	22.6	32.7	12.8	33	0.90	0.95
Medium strong, intensively fract to fragmented slightly to moderately weather BASALT	15.00	20.63	20.63	61.89	24	35	27	34	0.70	0.80
Silty CLAY	18.20	4.00	4.00	12.00	12.4	14.2	0.02	22	0.90	0.95
Stiff, sandy clayey SILT	21.00	4.00	4.00	12.00	14.2	16.7	0	28	0.85	0.90
Highly weathered scoriaceous	25.50	630	630	1890	22.4	32.9	13.6	32	0.90	0.95
Moderately weathered BASALT	39.00	20630	20630	61890	23.9	34.5	26	36	0.70	0.80
Stiff, swelling clayey SILT	45.00	4.00	4.00	12.00	15.3	17.4	0.015	22	0.90	0.95
Moderately weathered BASALT	52.00	2063	2063	6189	24	35	26	35	0.70	0.80
Strong, slightly fractured, fresh to faintly weathered BASALT	61.00	4651	4651	13953	25.7	36.8	29	38	0.50	0.60
Moderately weathered Basalt	75.00	20.63	20.63	61.89	24	35	25	34	0.70	0.80
Strong, slightly fractured, fresh to faintly weathered BASALT	83.00	46.51	46.51	139.53	26	37	29	38	0.50	0.60

Figure 4: Summary of ground conditions encountered in borehole(BH9).



Parameter	*Name*	*Beams*	*Unit*
Cross Section Area	A	3.02E-5	m^2
Unit Weight	γ	78.4	kN/m^3
Material behavior	Type	Linear	-
Young's Modulus	E	2.06E+8	kN/m^2
Moment of Inertia	I_3	1.762E-5	m^4
	I_2	5.0E-5	m^4

Figure 5: Material properties of beam(C-Plain purlins).



BH .9 COORDINATES :0472996E , 0996701N

STRATA DESCRIPTION	Elv	V_p	V_s	E_{ur}	G_{ur}	G_0	E_0	γ_{sat}	μ	G_0/G_{ur}
	m	m/s			GPa			kN/m^3	–	–
Soft, organic silty CLAY	4.00	1790	731	0.012	0.005	8E-04	0.002	14.7	0.30	0.1735
Silty CLAY	6.60	1950	796	0.012	0.005	1E-03	0.003	15.3	0.30	0.2141
Highly weathered BASALT	8.80	2100	1277	8.31	3.272	0.005	0.014	32.7	0.27	0.0017
occassionally, fresh rock present										
Moderately weathered BASALT	15.00	2730	1555	61.89	24.56	0.009	0.022	35	0.26	0.0004
Silty CLAY	18.20	2730	1115	0.012	0.005	0.002	0.005	14.2	0.30	0.3896
Stiff, sandy clayey SILT	21.00	2730	1672	0.012	0.005	0.005	0.011	16.7	0.20	0.9518
Highly weathered scoriaceous	25.50	2730	1719	1.89	0.744	0.01	0.025	32.9	0.27	0.0133
Moderately weathered BASALT	39.00	2730	1719	61.89	24.37	0.01	0.026	34.5	0.27	0.0004
Stiff, swelling clayey SILT	45.00	2730	1672	0.012	0.005	0.005	0.012	17.4	0.20	0.9917
Moderately weathered Basalt	52.00	2730	1719	61.89	24.37	0.011	0.027	35	0.27	0.0004
Strong, slightly fractured, fresh to faintly weathered BASALT	61.00	2730	1689	139.5	58.61	0.011	0.025	36.8	0.19	0.0002
Silty CLAY	62.00	2730	1115	0.012	0.005	0.002	0.005	15	0.30	0.4115
Moderately weathered BASALT	75.00	2730	1555	61.89	24.56	0.009	0.022	35	0.26	0.0004
Strong, slightly fractured, fresh to faintly weathered BASALT	83.00	2730	2730	139.5	58.61	0.028	0.067	37	0.19	0.0005

Figure 6: Summary of Seismic properties encountered in borehole(BH9).

Dynamic loading

In 3D plaxis non option is selected, it is assumed that the base of the model is rigid and the seismic signal is trapped within the soil deposit and cannot escape through the bottom boundary (Figures 8-10).

Comparison for models

The comparison was made between the secant and the shotcrete model. The soil material parameters and the loading conditions are the same in both models. The basic difference between the two models is the stiffness parameter which influences the results of the modeling. At the maximum excavation depth of 20 m the two models were subjected to deformation analysis and conclusions were drawn (Figure 11).

Models comparison and conclusion

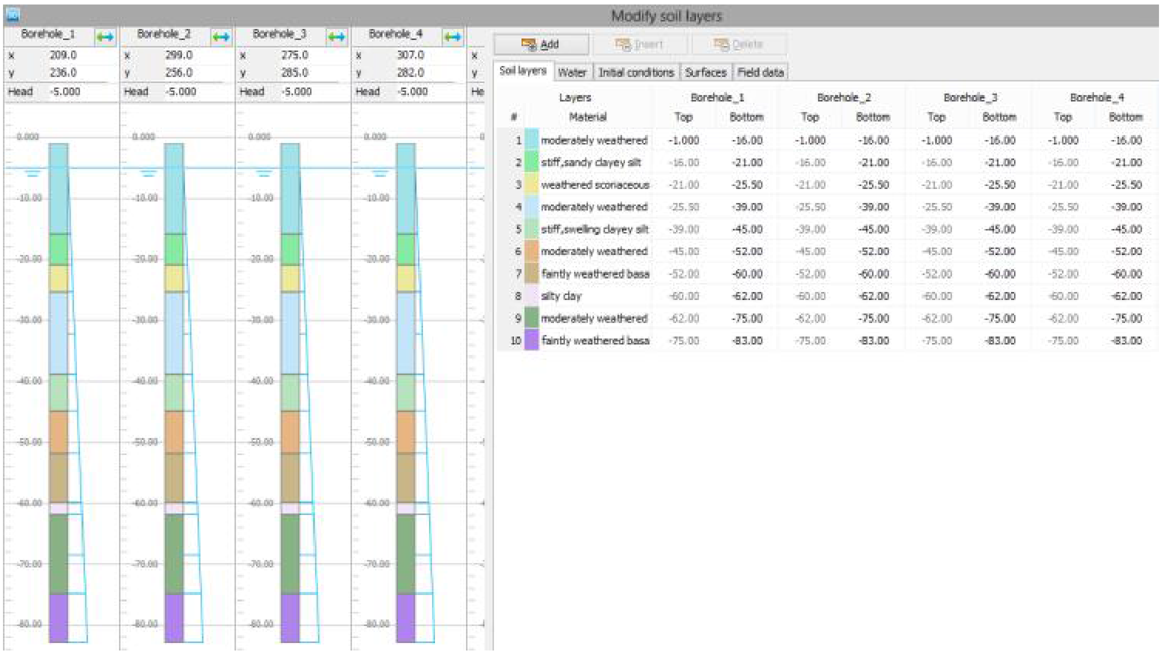
Comparing the maximum results of the displacements, contact stresses and other important parameters between shotcrete and secant pile model the following can be concluded:

The displacements in both models are acceptable and must apparently be regarded as unavoidable, even if a typical shotcrete shoring and shear wall system are currently used as the retaining structure in the New Commercial Bank building. Secant pile wall or a sheet pile might fare just well if it were correctly braced or anchored.

The unloading and reloading modulus is larger, thus stiffness is built up in the foundation. The stiffer the foundation the larger structural stiffness and hence the smaller the displacement and the more the time

Parameter	*Name*	*Node-to-Node*	*Unit*
Material Type	Type	Elastic	-
Axial Stiffness	EA	3.09E+3	*kN*

Figure 7: Material Properties for node to node Anchors.



	Borehole_1	Borehole_2	Borehole_3	Borehole_4
x	209.0	299.0	275.0	307.0
y	236.0	256.0	285.0	282.0
Head	-5.000	-5.000	-5.000	-5.000

	Layers	Borehole_1		Borehole_2		Borehole_3		Borehole_4	
#	Material	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
1	moderately weathered	-1.000	-16.00	-1.000	-16.00	-1.000	-16.00	-1.000	-16.00
2	stiff,sandy clayey silt	-16.00	-21.00	-16.00	-21.00	-16.00	-21.00	-16.00	-21.00
3	weathered scoriaceous	-21.00	-25.50	-21.00	-25.50	-21.00	-25.50	-21.00	-25.50
4	moderately weathered	-25.50	-39.00	-25.50	-39.00	-25.50	-39.00	-25.50	-39.00
5	stiff,swelling clayey silt	-39.00	-45.00	-39.00	-45.00	-39.00	-45.00	-39.00	-45.00
6	moderately weathered	-45.00	-52.00	-45.00	-52.00	-45.00	-52.00	-45.00	-52.00
7	faintly weathered basa	-52.00	-60.00	-52.00	-60.00	-52.00	-60.00	-52.00	-60.00
8	silty clay	-60.00	-62.00	-60.00	-62.00	-60.00	-62.00	-60.00	-62.00
9	moderately weathered	-62.00	-75.00	-62.00	-75.00	-62.00	-75.00	-62.00	-75.00
10	faintly weathered basa	-75.00	-83.00	-75.00	-83.00	-75.00	-83.00	-75.00	-83.00

Figure 8: Soil profile in Plaxis 3D Model.

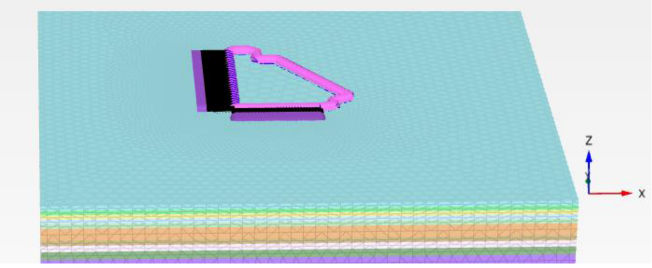


Figure 9: Overview of mesh set up for model B in Plaxis 3D model.

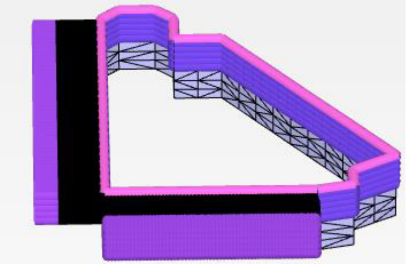


Figure 10: Overview of model B and ground Anchors in Plaxis 3D model.

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required for the analysis in plaxis due to the larger matrix generated. This was also observed in the result.

The secant pile model is the preferred model to increase the wall stiffness compared to the equivalent stiffness of the shotcrete model.

The new Commercial Bank building site is filled with cobbles/boulders and the water table is relatively high 5.0 m (field investigation report by Design and Share Company). Therefore, the secant pile model can fare well in difficult ground conditions without excessive dewatering.

Another alternative structural design philosophy would be to accept the wall displacement and to create a well-integrated structure with a wall that was as thin as shotcrete shoring (50-80 mm) to minimize bending strains. Other constrains such as connections to support, water tightness can be taken in to account.

Parametric studies

Among the different output results that can be obtained from plaxis, such as deformation of geotechnical and structural elements, steady pore pressure and plastic state parameters. The most important parameter of concern is displacements due to excavation, in addition since the excavation has taken place in short period of time plastic analysis is only performed rather than consolidation analysis and all results due to consolidation process from the plaxis simulations are considered not relevant to this project.

Parameter analysis

In order to evaluate the impact of some input parameters on the deformation analysis, a parameter analysis is performed. In this analysis various important parameters are analyzed by changing the values of each of them according to the typical values for the specific parameter.

Stage excavation, height of the pile wall, strength mobilization of shear, geometry of excavation model etc. are the parameters evaluated in this research.

Effect of stage excavation

The excavation steps used in modeling the effect of stage construction are in intervals of 5 m depth. This is the conservative design, which leads to more calculation steps and more calculation time. The excavation steps considered are: 5 m, 10 m, 15 m, and 20 m the surfaces are added to stimulate each single excavation step and number of calculation steps.

Due to the different excavation steps the distribution of the lateral displacements of the secant pile wall changes dramatically Figure 4 shows the displacement of the secant pile at 20 m deep (Figures 12 and 13).

The small excavation step 5 m requires more calculation steps and more time. While the large excavation step results to high lateral displacement (Figure 14).

Height of the Pile Wall

The parametric study in varying the height of the wall and the deformation obtain from plaxis output. The height of the wall used is 30 m in these parametric study walls of 24, 27, 30, 33 and 36 m were used. The Figures 4 and 8-16. Shows the results from Plaxis Analysis and the pile wall lateral deflection is normalized σ h / H e in% and the normalized depth of the pile h/H w, where σ h the lateral deflection along the wall and h is the depth below the ground surface. The maximum excavation depth He for the project is 20 m commencing

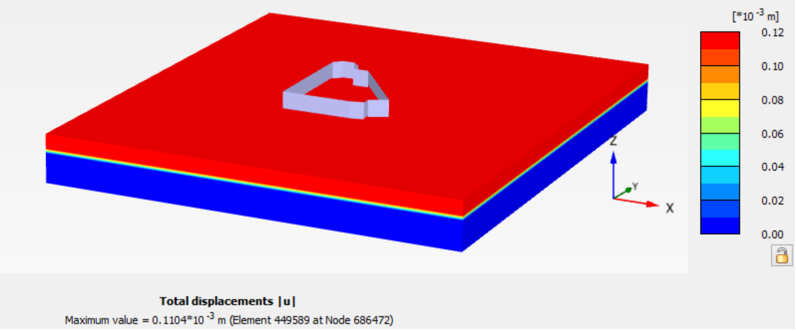

Figure 11: Deformed mesh for model A- total displacement.

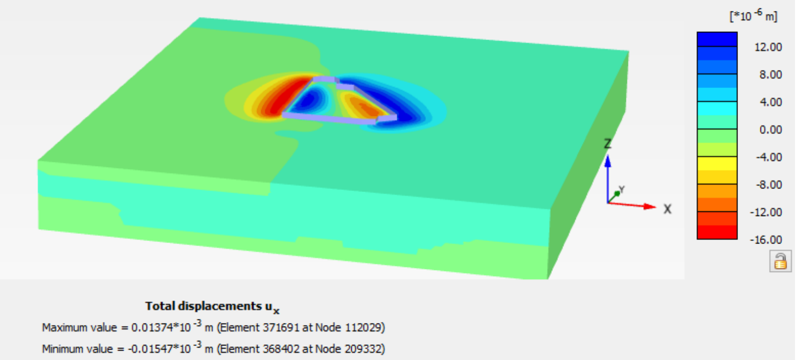

Figure 12: Stage excavation 5 m – horizontal displacement.

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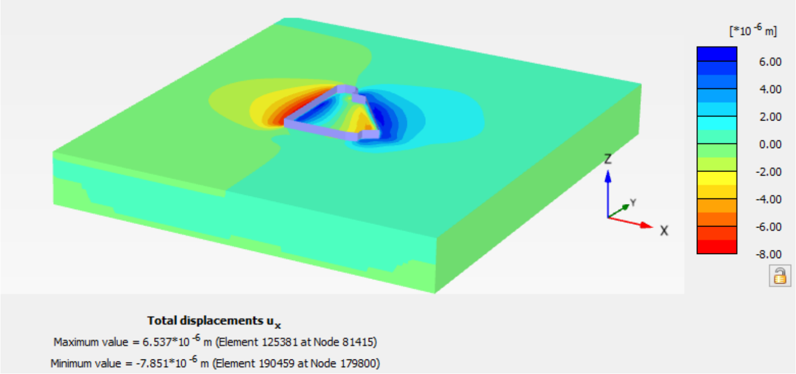

Figure 13: Stage excavation 10m – horizontal displacement.

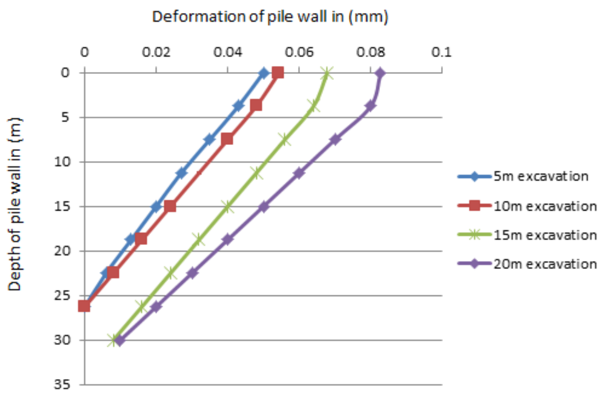

Figure 14: Effect of stage excavation on deformation of the pile wall.

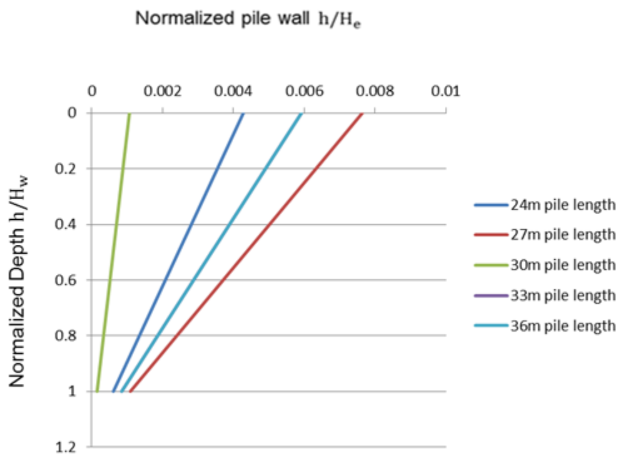

Figure 15: Effect of length of pile on lateral deformation of pile wall.

from the natural ground level. The wall length H_w is 25 m (Figure 15).

Effect of Shape on the Model

The geometry of the excavation has also an impact on the results obtained from plaxis. The parameters in the geometry such as the angle of slop' has a direct impact on the deformation results. A steeper slope will lead to higher horizontal displacement and vice versa therefore, increasing the accuracy of the geometry model of the excavated area in plaxis will give better and realistic results (Figures 16-19).

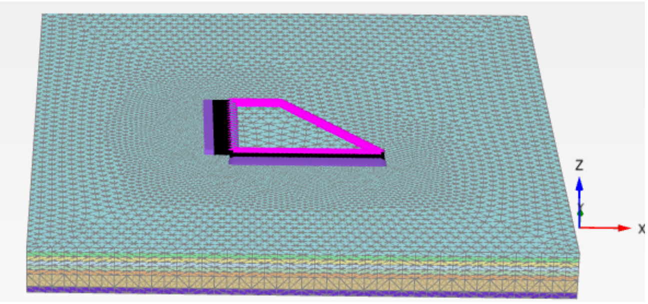

Figure 16: regularly shaped model.

Mobilization of Shear Strength

At different excavation levels the mobilization of soil strength at locations around an excavation. It is observed that significant rate of mobilization with excavation depths for soil elements at different depth supported by Figures 4 and 8-25 a stiff structural system (Figures 20-23).

The Effect of Power for Stress Level, m on Settlement

In the settlement comparison it is revealed that the m-factor has significant influence on the settlement. The m has different values for different soil types. The influence the m has on the displacement of the foundation Figures 4-27. It is observed that as m increases the displacement U_z decreases (Figures 23-25).

Parametric Studies on the Seismic Response

Accelerations

The seismic body and surface waves create inertia forces with in the building. When the building starts shaking it is subjected to inertia forces. Thus, responding to Newton's second law of motion.

Acceleration or the rate of change of velocity of the waves setting the structure mass or weight in motion. The acceleration is measured in terms of the acceleration due to gravity or 'g' which is the change of velocity of the freely falling body in space (Figure 26).

Site response spectrum

A site response spectrum is a graph that plots the maximum response values acceleration velocity, and displacement against the period and frequency. The spectrum shows on vertical ordinate the acceleration, velocities and displacements that may be expected at varying periods on the horizontal ordinate. The building response

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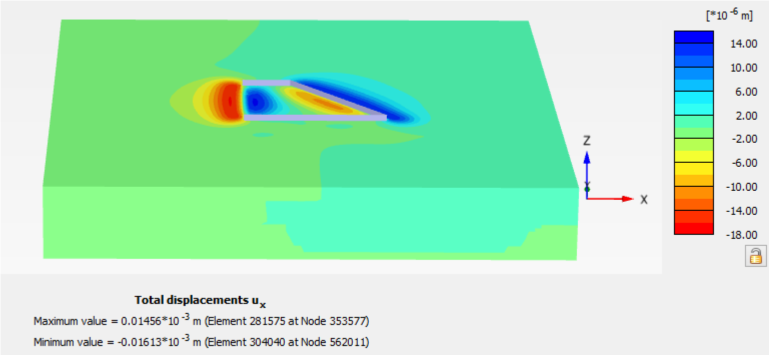
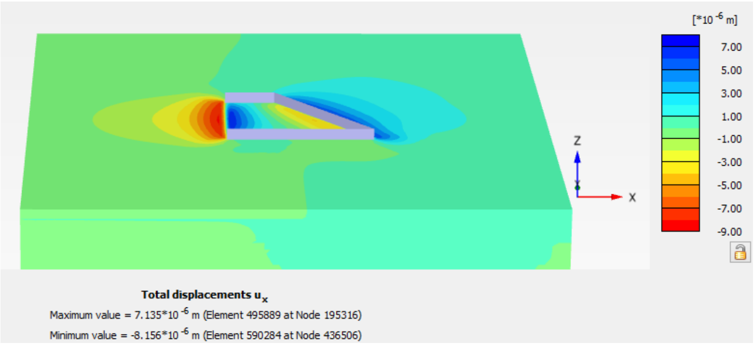


Total displacements u_x

Maximum value = $0.01456*10^{-3}$ m (Element 281575 at Node 353577)

Minimum value = $-0.01613*10^{-3}$ m (Element 304040 at Node 562011)

Figure 17: Stage excavation 5m for regular model total displacements horizontal direction.



Total displacements u_x

Maximum value = $7.135*10^{-6}$ m (Element 495889 at Node 195316)

Minimum value = $-8.156*10^{-6}$ m (Element 590284 at Node 436506)

Figure 18: Stage excavation 10m for regular model total displacements horizontal direction.

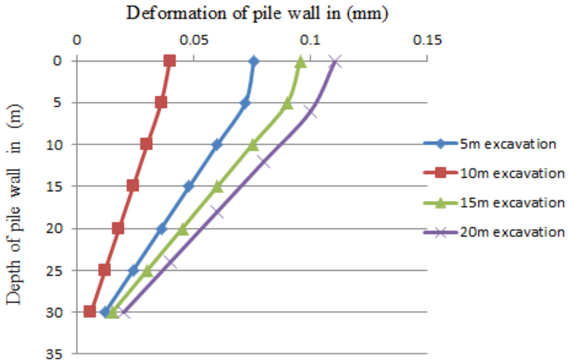
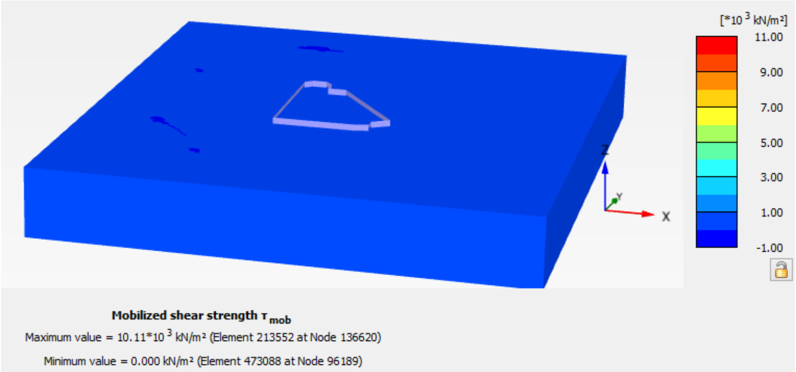


Figure 19: Stage wise excavation for regularly shaped model.



Mobilized shear strength τ_{mob}

Maximum value = $10.11*10^3$ kN/m² (Element 213552 at Node 136620)

Minimum value = 0.000 kN/m² (Element 473088 at Node 96189)

Figure 20: Mobilized shear strength at 5m excavation.

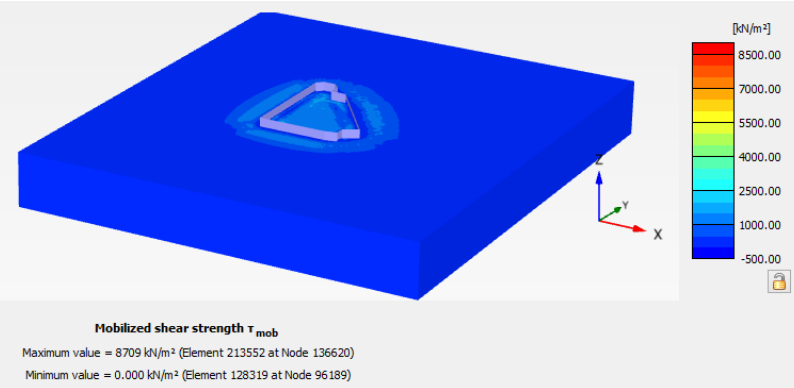


Figure 21: Mobilized shear strength at 10m excavation.

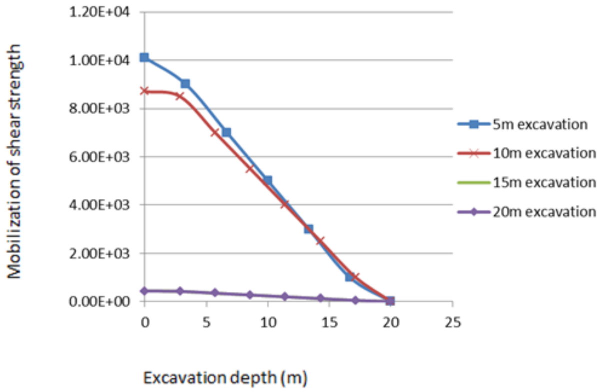


Figure 22: Mobilization of undrained shear strength.

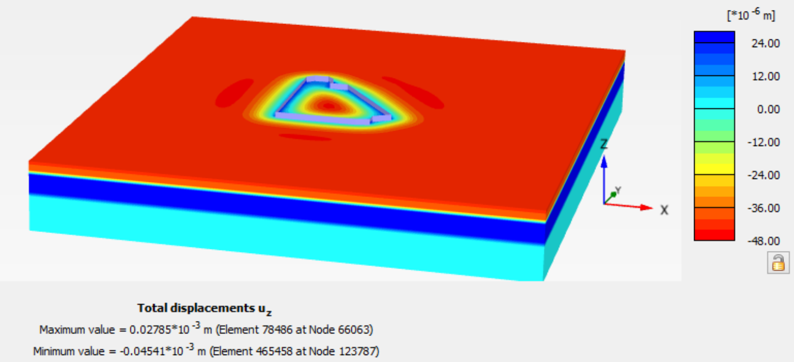


Figure 23: Total displacement U_z at 5m excavation.

varies with building period; as the period lengthens (moving towards the right of the horizontal axis of the spectrum), accelerations decrease and displacement increases (Figure 27).

Velocities: The velocity of motion on the ground caused by seismic wave is quite slow. This is because large quantities of earth and the rock are moved. As a result the motion of the structure is slow and the displacements are very low (Figure 28).

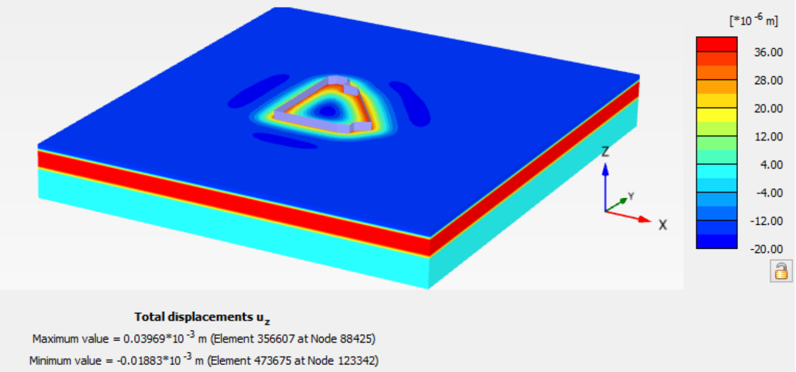
Ground amplification: Earthquake shaking is initiated by a fault slippage in the underlying rock. As the shaking propagates to the surface, it may be amplified depending on the intensity of shaking, the surface soil and depth of the layers and the nature of the rock.

Weaker layers of soft soil may results in to higher amplification factor over the rock shaking. The amplification factor 1.0 indicates the soils are firm. The amplification also tends to decrease as the level of shaking is increased. The earthquake damage tends to be more severe in areas of soft soils (Figure 29).

Results and Discussion

In order to stimulate field conditions in the numerical modelling the initial stresses were calculated before loading. The k_0 pressure remained the same throughout the calculation.

The analysis also indicated that the maximum total displacement



Total displacements u_z

Maximum value = $0.03969*10^{-3}$ m (Element 356607 at Node 88425)

Minimum value = $-0.01883*10^{-3}$ m (Element 473675 at Node 123342)

Figure 24: Total displacement U_z at 10m excavation.

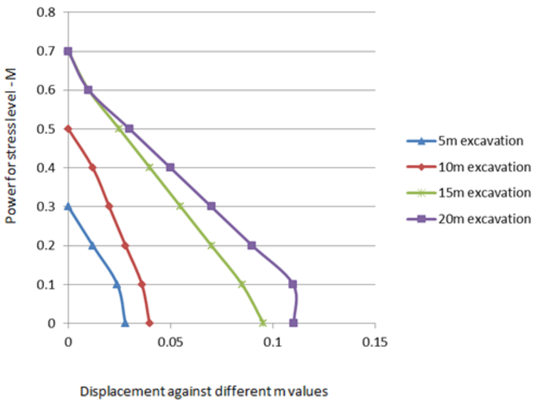


Figure 25: Effect of power for stress levels.

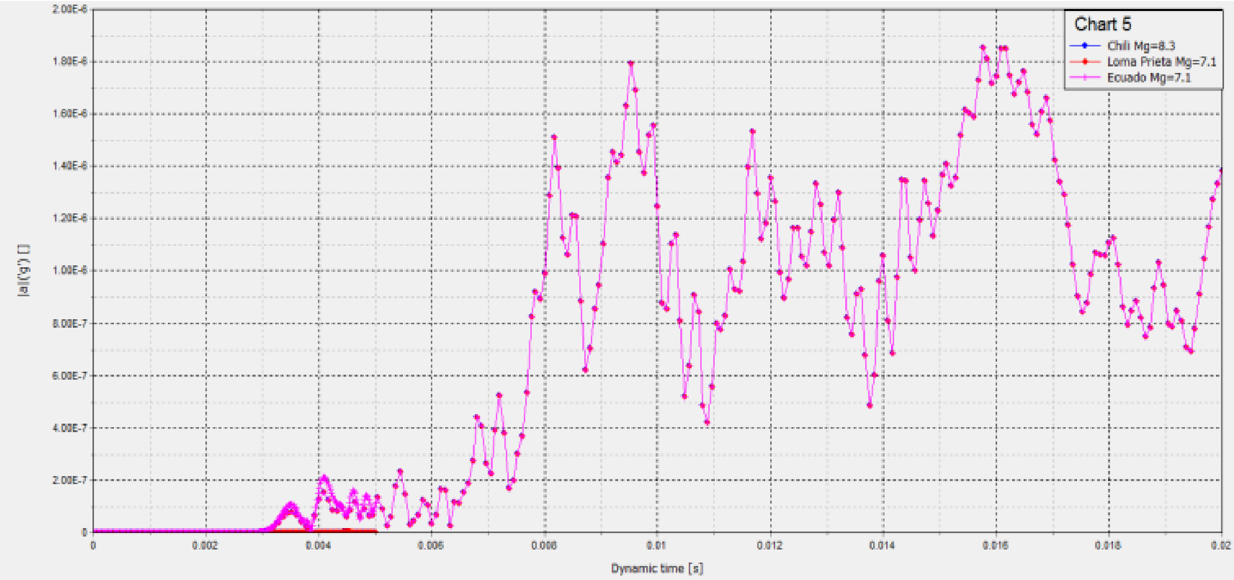


Figure 26: Magnitude of acceleration in 'g'.

for 20 m excavation was 110.4 mm and in general, small step excavation take longer time in calculating results and small displacement while large step excavation takes small time and larger displacements recorded. The deeper the foundation excavation was, the larger the surface settlement.

The parametric studies in varying the height of the wall, the values of height of the wall were 24, 27, 30, 33 and 36 m. The maximum excavation depth was 20 m. It was observed that as the height of the wall is increased from 24 m to 27 m the deformation of the pile was

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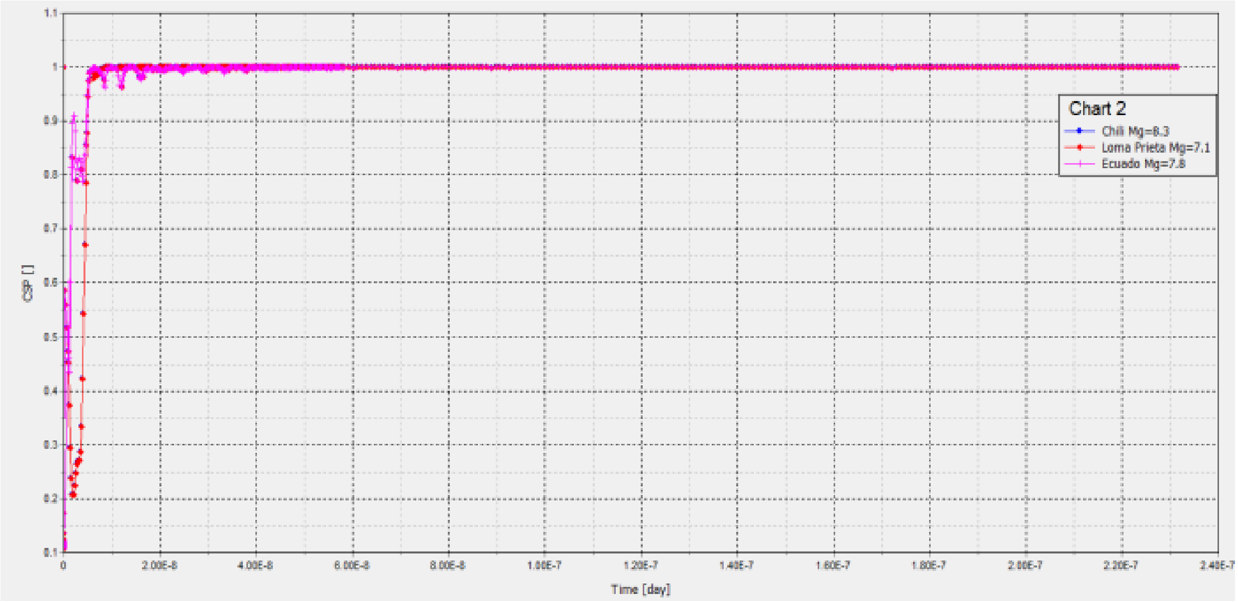

Figure 27: Site Response Spectrum.

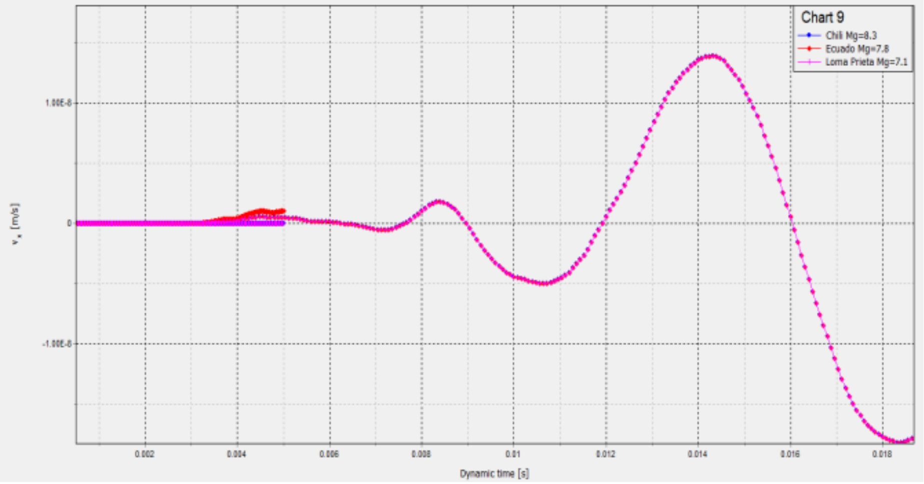

Figure 28: Velocity in horizontal direction.

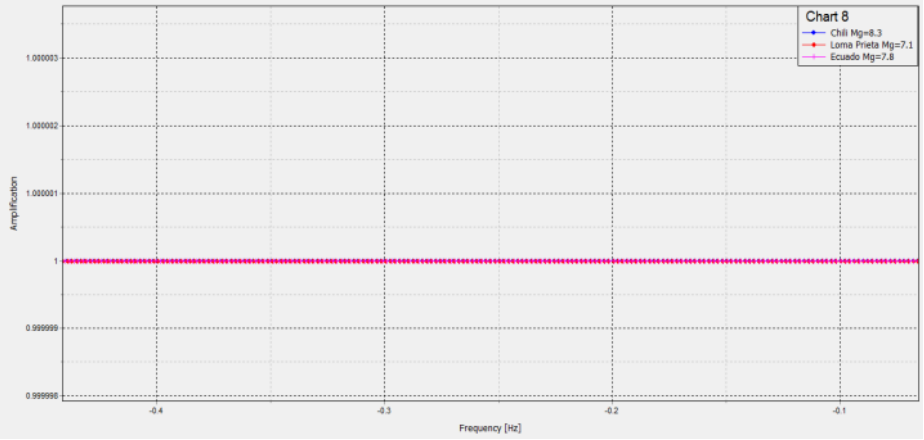

Figure 29: Ground Amplification.

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reduced. Further increase in height to 30, 33 and 36 m resulted to significant decrease in total and horizontal displacements.

The distinct failure plane of the system can be achieved by reducing the mesh size. The incremental shear strains were observed by refining the mesh size. The coarser mesh take short time to calculate with higher values of deformations and the smaller mesh takes long calculation time with small deformations.

The stress distribution in the soil plays a role when determining the settlement of foundation. The stresses in the soil closely beneath the foundation slab will almost be the same as the stress acting on the foundation. This stresses will however decrease in large depth of the soil Figures 4 and 8-20. It is clearly seen that the depth increases with reduction in shear strength in the mobilization of undrained shear strength.

Conclusions and Recommendations

The finite element program Plaxis 3D was used to model the secant pile wall. Two different constitutive models in plaxis (Hardening soil model and Hardening small strain model) were used to stimulate the structure and soil behavior.

Parametric studies for the geometry were evaluated based on the deformation analysis that was conducted. The test results showed that the dimensions of the excavation may have great influence over the response of the secant pile wall.

The parametric study on the mesh set up indicate the results especially the distribution of forces varied due to different mesh set up. Precisely, coarse mesh leads to forces distributed to limited number of nodes and some nodes receive extra force than the actual condition. In plaxis 3D model the degree of refinement of mesh is essential. The use of coarse mesh discretization was due to expectation of high gradients of stresses near corners or sharply curved edges. The time required for the calculation is long and depends on the matrices size generated. The larger the matrice the more the time required for the calculation.

The excavation step used in the excavation model range from 5 m to 20 m. The result from normal stage excavation model and sequential model with 5 m excavation set the boundaries for all results. In general, longer excavation step results in less calculation time and higher deflection. The whole soil model was stimulated and the stage construction was conducted by deactivated the soil layers in the phase.

With increase in height of pile wall from 24 m to 27 m, there is decrease in deformation of pile wall. Further increase in the wall height to 30, 33 and 36 m resulted to significant decrease in total and horizontal wall displacements.

During progress in excavation on stage construction, the ground deformations increase and the settlement value increases as the excavation depth is increased.

The effect of mesh size was studied by generating a finer mesh and re-running the analysis. A more distinct failure plane of the system was observed by reducing the mesh size.

A sample earthquake recorded by the USGS is used for the analysis. Water pressure is neglected. The total displacement after the seismic event resulted to less displacements.

The final results were totally satisfying and for complexity excavation projects of this nature plaxis3D gives stimulations close to reality.

Recommendations

The deformation analysis due to excavation was performed through the plaxis simulations. It was complex to model the real behavior of the soil due to unloading in the plaxis simulations. Therefore, increasing the accuracy of the investigation of important soil parameters and other conditions will make plaxis simulations simple and accurate results would be obtained.

Usually the unloading modulus is determined by performing unloading and reloading test in the Oedometer laboratory test. For this simulations the results used were not obtained from the Ondometer test but default value as suggested by plaxis of thrice the tangent modulus.

Further investigations on parameters and other conditions that affect the deformation analysis like liquid limit, density and swelling parameters of clay, the field deformation measurements and influence of structural elements on the deformation near the excavation area shall be carried out in order to increase the accuracy of the deformation analysis and decrease the possible error.

Further investigations on parameters and other conditions that affect seismic analysis like density and shear modulus and p-waves and S-waves are calculated from those parameters soil.

Using different earthquake input in order to investigate the effect of seismic characteristics such as magnitude, frequency etc. and performing the analysis with the use of structures with different geometries.

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