

Parametric Study on Analysis and Design of Permanently Anchored Secant Pile Wall for Earthquake 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. Among the conventional retaining support systems, this study is focused on secant pile walls. The secant pile methodology comprised the formation of overlapping concrete piles. The overlap between the piles is achieved to prevent soil and ground water ingress. The analysis of these deep excavations involved consideration of soil parameters, deformation, interaction of soil and retaining configuration. It is difficult to precisely describe the nonlinear system using traditional analysis. Thus, in order to accurately describe the behavior of the anchored secant pile for earthquake loading, 3D finite element simulation was applied. The analysis for 20m excavation step in the fourth stage, showed incremental lateral displacement was $0.0552E-3m$ and total displacement was $0.114E-3m$. The analysis indicated that the displacement induced in the ground increased with excavation depth. As the excavation depth increased, the unbalanced forces increased resulting to increase in stresses and displacement. Increase in pile diameter reduced displacement of the pile and with 1400mm pile diameter, the maximum displacement occurs at the wall; zero displacement, this was due to increase in structural stiffness. In addition, the modulus of deformability of the soil has great importance in the settlement of the soil. It is visible that when the thickness of the wall increases, the horizontal and vertical displacement near the wall increases. Decreasing the horizontal and vertical spacing of the anchors increased stiffness of the anchor per unit width. With high anchor stiffness, displacement occurs near the excavation surface thus, reducing the displacement of the wall.

Keywords: secant. pile wall. earthquake loading. plaxis.

I. INTRODUCTION

The Commercial Bank of Ethiopia new building headquarter project is currently under construction. The building comprises of five basement levels and 46 floors above ground level. The geotechnical investigation was conducted by Design and Share Company Limited. The ground water was encountered at 5m below the natural ground level (NGL) during testing. The detailed design for the lateral support and foundation was conducted by China State Engineering Corporation and included but not limited to; soldier piles and shotcrete lagging techniques which retained the soil. The soldier piles were driven at intervals of 1800mm along the planned excavation perimeter. The lagging consisting of steel mesh was inserted behind the front pile flanges as the excavation proceeded and concrete of grade C-20 was sprayed to the lagging. The wall was designed to receive additional support from the anchors of different free and bonded length placed in layers. This study is to investigate the shoring of the commercial bank of Ethiopia project using the secant pile wall as an alternative support scheme.

Secant pile model

Secant piles are innovative way of constructing retaining walls and are formed by a series of interlocking bored concrete piles. Secant piles can be constructed either with conventional drilling methods or through the use of Continuous Flight Auger (CFA) techniques computer monitoring of the pile installation process is essential for quality assurance. Secant pile walls typically include both reinforced secondary (male) and unreinforced primary piles (female). The secondary piles overlap the primary piles, with the primary piles essentially acting as concrete lagging Figure 1. The reinforcement in the secondary piles generally consists of rebar cages or steel beams. Secant pile wall formed by the primary and secondary piles by drilling the piles to the specified diameter and required depth. The secondary piles are positioned between the primary piles and secant with the primary piles in order to form the interlocking joint [7].

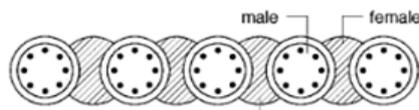


Figure 1: Typical secant pile wall arrangement with female (primary) and male (secondary) piles forming hard/soft walls after Suckling et al. (2005)

Secant pile –merits and demerits

The main advantages of secant pile walls are: Increased construction alignment flexibility, increased wall stiffness compared with sheet piles, can be installed in difficult ground (cobble/boulders), they are primarily used in unsuitable ground conditions or where there is a high water table conditions without excessive dewatering. Secant walls can also be used to form a continuous water tight wall which can be an added benefit for the construction of basements and underground car parks. Secant pile walls are used as permanent or temporary elements in foundation, excavations, slope stabilization, retaining walls or hydraulic barriers. However the disadvantages of secant pile walls include: verticality tolerances may be hard to achieve for deep piles, total waterproofing is very difficult to obtain in joints, increased cost compared to sheet pile walls if depth is less than 12.2m deep, noise and vibration are generated, if casing is driven in lieu of hydraulically pushed and retrieved casings [2].

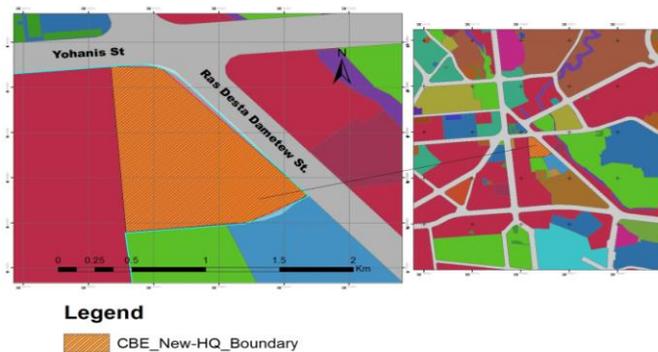


Figure 2: Site location plan

Among researchers who have studied in this field are:

Perk, summarized information from case histories on ground settlements adjacent to excavations the results indicated that settlements next to deep excavations are correlated to soil types. The results further, indicated that wall movement for excavation in sand and gravel or very stiff to hard clay are usually less than 0.4 percent of the excavation depth. Peck also noted that ground next to deep excavations in stiff over consolidated clay might rise instead of settling [12].

Clough and O'Rourke observed that the pattern of settlements next to excavations is influenced by the soil type .Further movements in the anchorage zone for tie back walls could occur in over consolidated clays with high lateral stresses [4].

Moormann, had carried out extensive empirical studies by taking 530case histories of retaining wall and ground movement due to excavation in soft soil ($C_u < 75kPa$) . It was concluded that the ground conditions and excavation depth H are found to be the most influential parameters for deformation due to excavation [10].

Ng, reported field measurements of a 10m excavation in over-consolidated stiff-fissured gault clay lion yard, Cambridge. The field results revealed that due to construction of diaphragm wall, significant reduction of lateral total earth pressure at the soil wall interface is resulted [11].

Hashash andWhite (1996) carried out a series of two dimensional numerical parametric studies to study effects of wall embedment depth and prop spacing on ground deformations due to multi-propped excavation. The research at the Massachusetts Institute of Technology(MIT) ,has developed a series of generalized rate independent models for clay based on the theory of incremental linear elasto-plasticity.Constitutive model(MIT-E3)adopted in the numerical analyses is capable of considering anisotropic stress-strain relationship, stress path dependency and strain dependency of clay. Computed results indicated that wall length has minimal effect on the pre-failure deformation for excavations in deep layers of clay. Use of very deep walls can improve base stability. However, large bending movements can be resulted and may cause flexure failure of the retaining wall [6].

Jen,(1998) carried out numerical parametric studies to study effects of excavation geometry, retaining system and stress history of clay on ground deformations due to excavation. The computed results revealed that

distribution of ground deformation is significantly affected by depth and hard stratum below soft clay. Depth of the rock was found to be the key parameter affecting the distribution of ground movements, excavation width, excavation depth and uncertainties in the stress history and were major factors contributing to the magnitude of displacement [8].

Mana and Clough carried out parametric studies on the effect of wall stiffness and strut spacing, the effect of strut stiffness, and the effect of excavation geometry such as excavation width and depth of the underlying firm layer, the effect of strut preloading and calculation of elastic soil stiffness on the excavation induced deformation. Increasing the wall bending stiffness or decreasing strut spacing decreases movement [9].

Chang, (2006) several in-situ support systems have been deployed for containing deep excavations. The criteria for the selection of these systems are excavation depth, ground conditions, ground water level, allowable vertical and horizontal displacements of adjacent ground, availability of construction know-how, cost factors, subsequent construction methodology, working space limitations etc. One of the key governing factors is the requirement of water tightness of the retaining structure. Secant piles are innovative way of constructing retaining walls and are formed by a series of interlocking bored concrete piles. The exact spacing is determined by the construction tolerances which can be achieved. The intermediate piles are placed through a heavy casing whose cutting edge is toothed and enables the casing to cut into the concrete of the initial piles on either side. Subsequent concreting results in a continuous wall [3].

Erin Leung and Charles, (1992). Soil properties and wall stiffness affect the performance of excavations. The overall stiffness of the support system is calculated in terms of an effective stiffness of the system. Secant pile walls are considered stiff on the basis of rigidity of the wall element. The soil conditions, wall installation methods, and effective stiffness of the excavation support system are specific factors that influence the magnitude of movements of the support system [5].

Response Spectrum

Response spectra are curves plotted between maximum response of Single Degree of Freedom (SDOF) system subjected to specified earthquake ground motion and its time period (or frequency).

Response spectrum can be interpreted as the locus of maximum response of a SDOF system for a given damping ratio. Response spectra helps in obtaining the peak structural response under linear range, which can be used for obtaining lateral forces developed in structure due to earthquake thus, facilitates in earthquake resistant design structure.

Final plot with system time period on x-axis and response quantity on y-axis is the required response spectra pertaining to specified damping ratio and input ground motion Figure 3. Same process is carried out with different damping ratios to obtain overall response spectra.

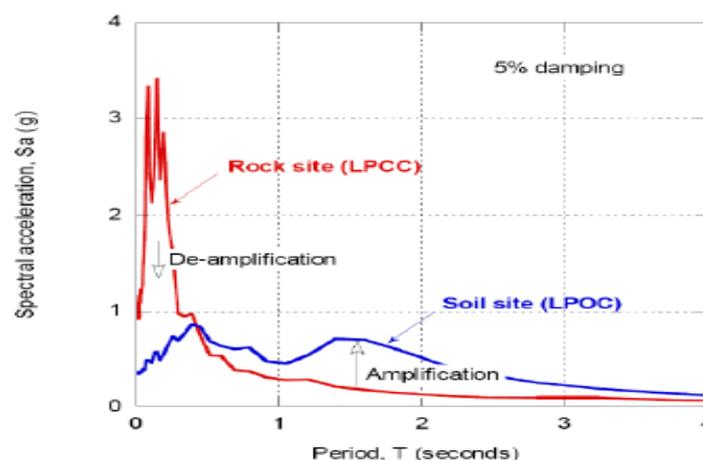


Figure 3: Acceleration response spectra during the 22 February 2011 Christchurch earthquake (Cubrinovski and McMahan 2011).

Seismic refraction

The seismic refraction method is non-invasive test method, used for determination of the p-wave velocity of the different subsurface layers and thickness of each layer. These waves(s) induce very small strain levels in to soil i.e $\epsilon_{ij} < 0.001\%$. The analysis of foundation vibrations requires characterization of the dynamic soil properties using geophysical methods. Figure 4 shows P-wave refraction result along profiles.

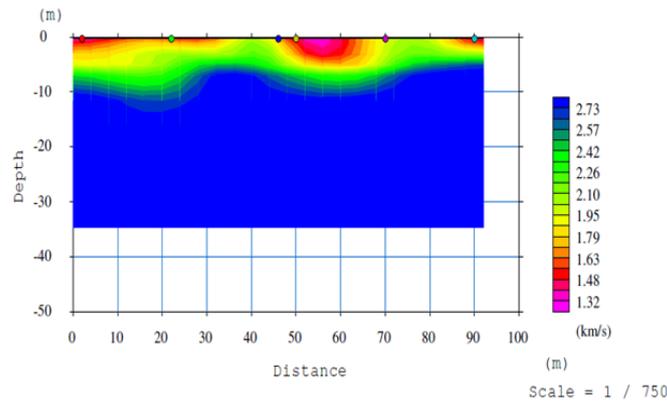


Figure 4: P-wave refraction result along profile 1 which clearly shows indentation with relatively low velocity in the middle for the CBE New Building Site [1].

II. METHODS AND MATERIALS

Characterization of the soil to determine the input soil parameters used for modeling (HS-Model). The p-wave refraction results along the weaker profile was used to determine the seismic properties used in dynamic modelling (HS-Small strain model).

For dynamic analysis of the retaining structure, the earthquakes are important loads on the ground. This is uncontrolled and unexpected phenomenon of nature. The advice given in the FHWA manual was applied during the modelling. In accordance with FHWA, ten observations of seismic performance of anchored walls have been made when California earthquake of 1987 occurred. The observations indicated overall good performance of anchored wall systems. The same conclusion was drawn following a survey of the performance of anchored walls conducted following the 1994 Northridge earthquake. The earthquake considered in this study is the upland earthquake of 18 Oct, 1989 of real accelerogram at Del Valle Dam Station. The Finite Element analysis with PLAXIS3D software was applied. Figure 5-7 shows material parameters used in modelling.

STRATA DESCRIPTION	Elv m	E_{50} MPa	E_{Oed} MPa	E_{ur}	γ_{uns} kN/m ³	γ_{sat}	c^{ref} MPa	ϕ deg	m	R_{int}
Soft, organic silty CLAY	4.00	4.00	4.00	12.00	12.4	14.7	0.015	13	1.00	1.00
Silty CLAY	6.60	4.00	4.00	12.00	13.8	15.3	0.02	17	0.90	0.95
Highly weathered BASALT	8.80	2770	2770	8310	22.6	32.7	7.8	33	0.90	0.95
Medium strong, intensively fract to fragmented slightly to moderately weather BASALT	15.00	20630	20630	61890	24	35	18	34	0.70	0.80
Silty CLAY	18.20	4.00	4.00	12.00	12.4	14.2	0.02	17	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	46510	46510	139530	25.7	36.8	29	38	0.50	0.60
Moderately weathered Basalt	75.00	20630	20630	61890	24	35	25	34	0.70	0.80
Strong, slightly fractured, fresh to faintly weathered BASALT	83.00	46510	46510	139530	26	37	29	38	0.50	0.60

Figure 5: Summary of ground conditions encountered in borehole

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 6: Material properties of beam(C-Plain purlins)

STRATA DESCRIPTION	Elv m	V_p m/s	V_s m/s	E_{ur}	G_{ur}	G_0	E_0	γ_{sat} kN/m ³	μ	G_0/G_{ur}
					GPa					
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
occasionally, 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 7: Summary of Seismic properties encountered in borehole

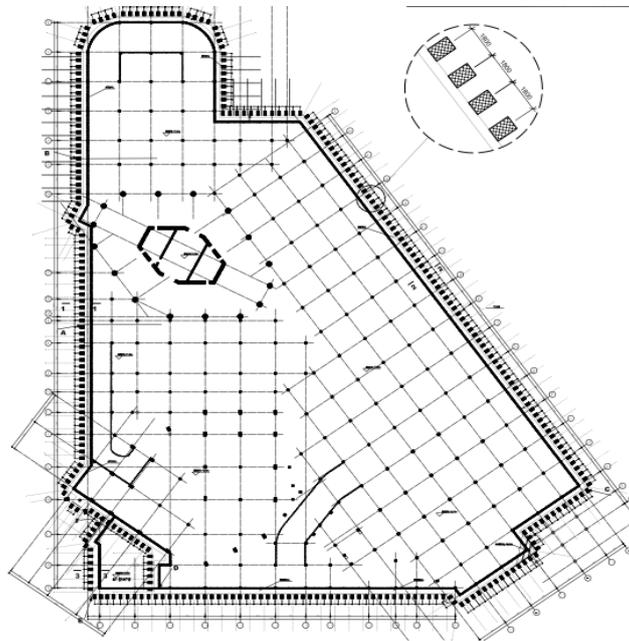


Figure 8: Site layout for the existing wall scheme

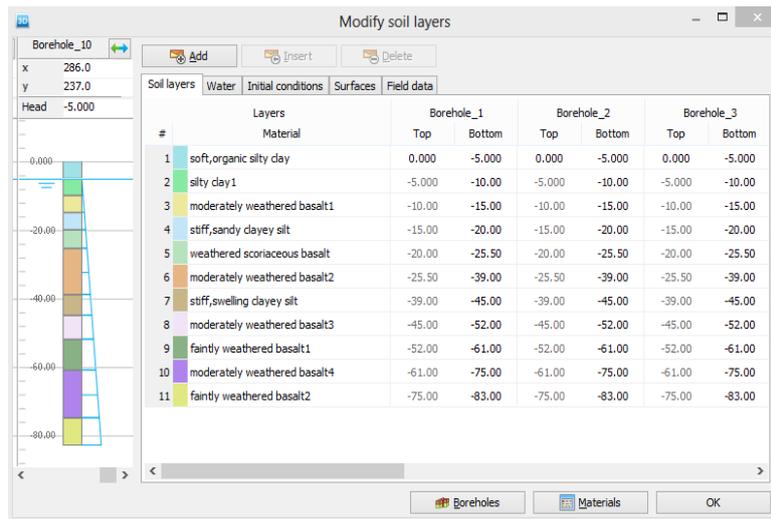


Figure 9: Soil profile in plaxis3D

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. Since the existing site surcharge could not be estimated accurately, the applied overload of 150kPa was used in the modelling. This load was also used in 3D finite element analysis of a deep excavation for the Odeon project in Monaco [13].Figure 11 shows the loading condition.

Earthquake Analysis

The earthquake considered in this study was the upland earthquake of 18 Oct, 1989 of realaccelerogram at Del ValleDam Station. The Finite Element analysis with PLAXIS 3D software was applied. The real accelerogram of strong motion was assigned as dynamic multiplier and the generated spectrum was adjusted to the acceleration of 0.12g for the case of Addis Ababa area. An earthquake modelling is by means of horizontal displacements. The selection of standard earthquake boundaries in the loads is followed by the definition of horizontal displacement component by Plaxis. Figure 10 shows the real time acceleration of Loma Prieta Earthquake.

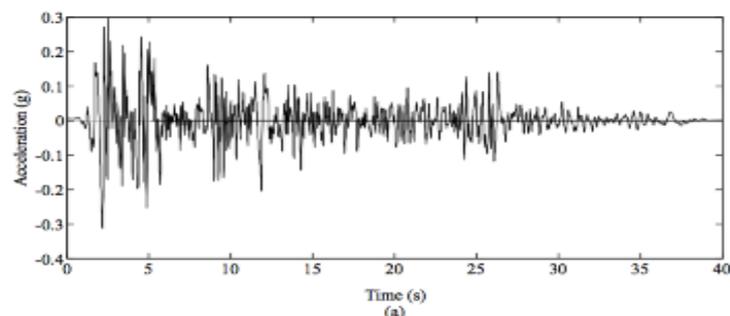


Figure 10: Real time accelerogram of Loma Prieta Earthquake

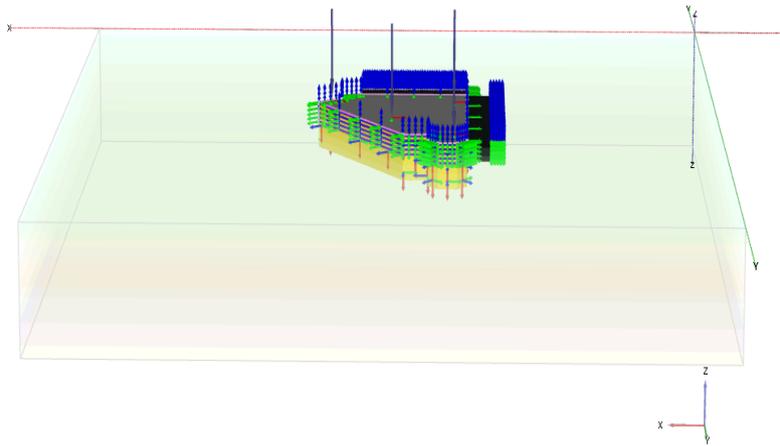


Figure 11: Static loading

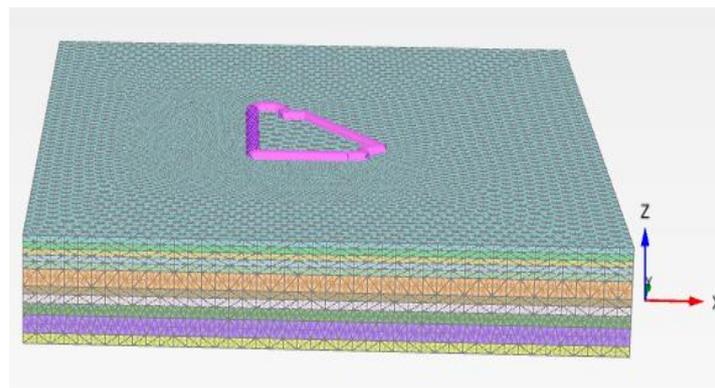


Figure 12: Overview of mesh set up for model in Plaxis 3D

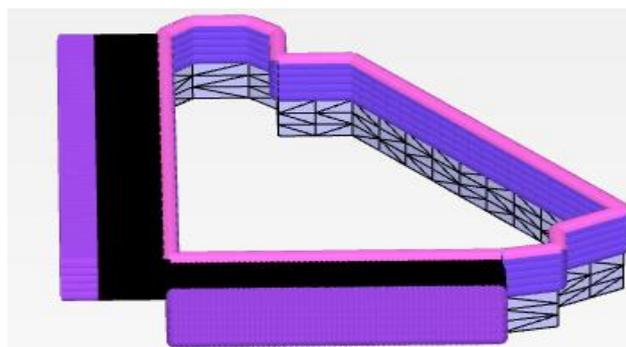


Figure 13: Model and ground Anchors in Plaxis 3D

PARAMETRIC STUDIES

The purpose for this study was to study the parameters due to the anchored secant pile wall by varying; length of the piles, anchor spacing and pile diameter under static and dynamic load condition. The analysis was performed on the model with the same characteristics (except pile length, anchor spacing and pile diameter). The plastic analysis using plaxis 3D Anniversary Edition was performed because the excavation process takes short period of time. Stage construction was also considered in the analysis. In this analysis some important parameters; pile length, anchored spacing and pile diameter were analyzed by changing the values of each of them according to the specific parameter. Figure 12 and 13 shows resulting finite element model and global mesh refinement.

Effect of stage excavation

The excavation steps used in modelling the effect of stage construction were in intervals of 5m deep. Due to the different excavation steps the distribution of the displacement of the secant pile wall changes dramatically. Figure 16 shows the displacement of secant pile wall at 20m excavation. Figure 14 and 15 show the total displacement output at 5m and 10m respectively. The small excavation step 5m requires more calculation steps

and more time and yields less deformations. While the large excavation step 20m takes short time and results to high lateral displacement.

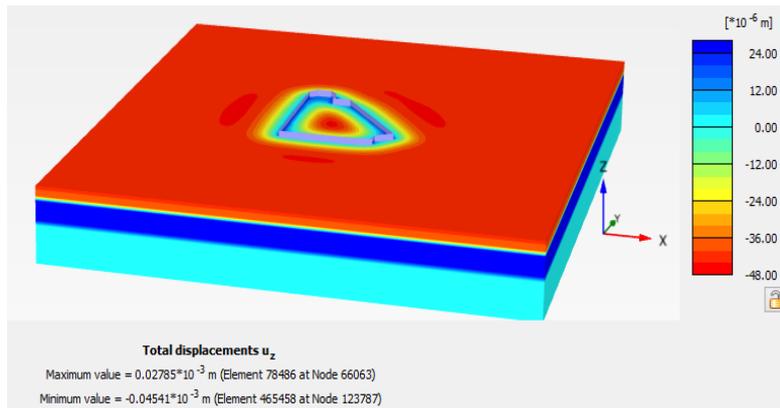


Figure 14: Stage excavation 5m – horizontal displacement

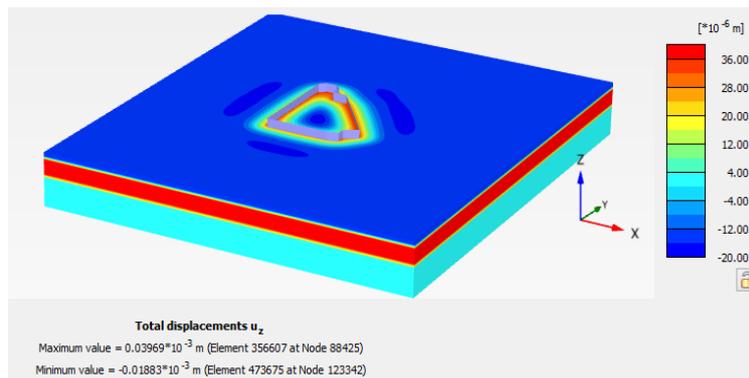


Figure 15: Stage excavation 10m – horizontal displacement

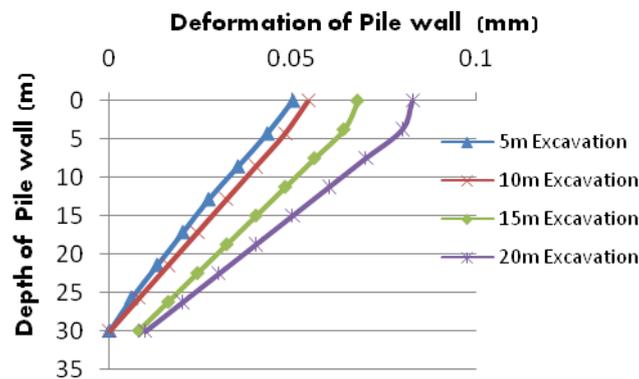


Figure 16: Effect of stage excavation on deformation of the pile wall

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 30m. This parameter was varied for different wall length of 24, 27, 30, 33 and 36m in the study. Figure 17 shows the results obtained from Plaxis Analysis. The pile wall lateral deflection and pile wall depth below the ground are normalized. The maximum excavation depth H_e for the project is 20m commencing from the natural ground level.

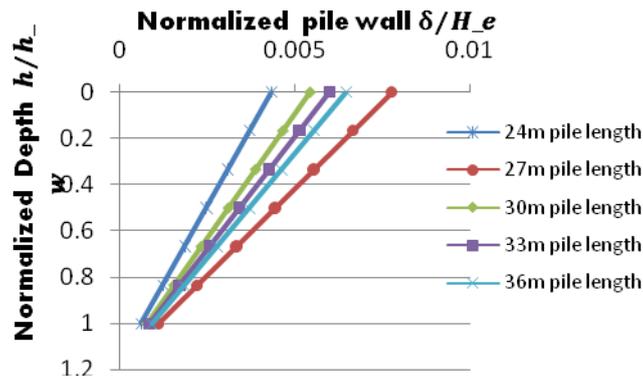


Figure 17: Effect of length of pile on lateral deformation of pile wall

Diameter of Pile wall

The diameter of pile wall was increased from 650mm to 1400mm. There is change in structural stiffness. In Plaxis 3D the pile wall was modelled with diameter of pile 650mm, 900mm, 1150mm and 1400mm. Increase in diameter of pile wall increased the deformation near the surface of the wall in horizontal and vertical directions. Figure 18.

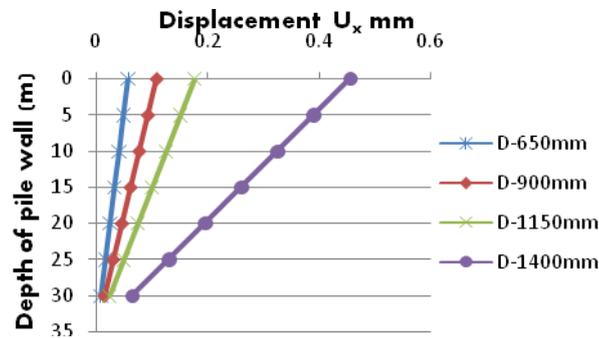


Figure 18: Effect of Diameter of Pile on deformation

Anchor spacing

Horizontal and vertical spacing of anchors. The analysis was conducted with horizontal spacing of 2m, 3m, 4m, and 5m and vertical spacing was also varied; 3m, 4m and 5m. One level of ground anchors was spaced at 2m in the horizontal direction and installed at an inclination of angle of 15° below the horizontal direction (left to right). The anchors were also spaced at 3m in the vertical direction (top to bottom).

Decreasing the horizontal spacing can increase the stiffness of the anchor per unit width. With high anchor stiffness, the compression of the anchor will be quite small, and the maximum deformation occurs near the excavation surface. Figure 19 shows the results obtained from plaxis analysis.

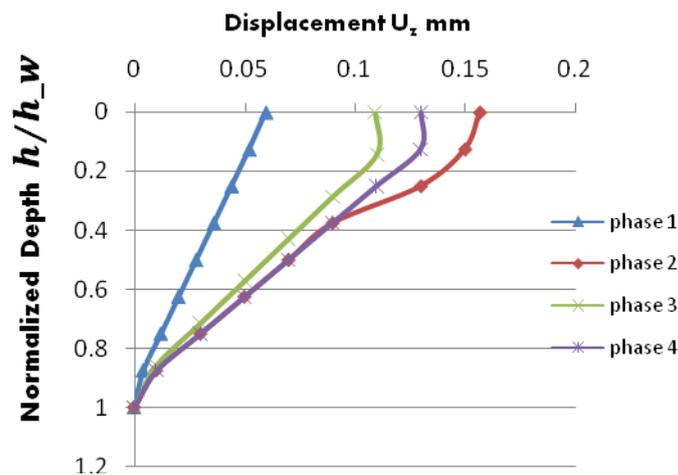


Figure19: Effect of Anchor spacing on deformation

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 a stiff structural system Figure 20.

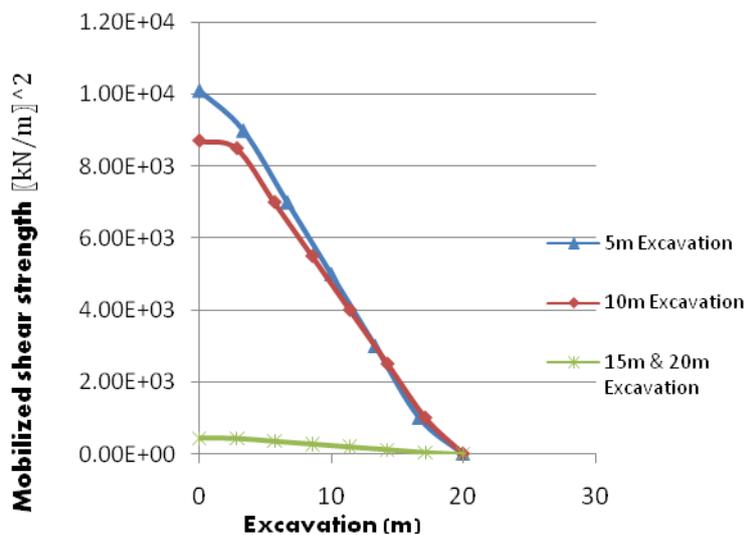


Figure 20: Mobilized shear strength at 10m excavation

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 Figure 21. It is observed that as m increases the displacement decreases.

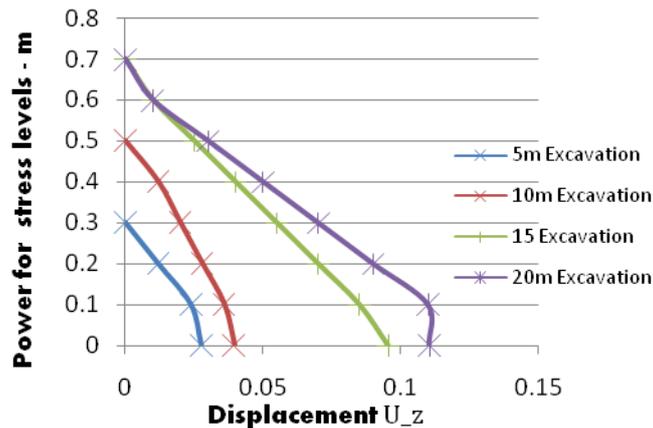


Figure 21: Effect of power for stress levels

SEISMIC SITE RESPONSE

The influence of local geologic and soil conditions on the intensity of ground shaking and earthquake damage has been recognized for many years. Local site conditions can profoundly influence all of the important characteristics of strong ground motion: amplitude, frequency content and duration. The effect of their influence depends on the geometry and material properties of the subsurface materials on the site topography, and on the characteristics of the input motion. Based on the seismic damage data for the 1906 San Francisco California, earthquake, Wood argued that the local site conditions emerge a dominant factor controlling the amplification of damage during the earthquakes (Woods, 1916). The Northridge (1994), and Loma Prieta (1989) earthquake have predicted the role of local site conditions in modifying the characteristics of strong motions.

Damage patterns in Mexico City after the 1985 Michoacán earthquake demonstrates conclusively the significant effect of the local site conditions on the seismic ground response. Thus understanding of local site effects of the strong ground motion is of particular importance for the mitigation of earthquake disasters as well as well as aiding the earthquake resistant design. In order to estimate the behavior of the ground during an earthquake, this study considers site condition as one of the most important ground motion parameters for engineering design and it is often characterized by a set of simplified parameters such as site predominant period, ground amplification.

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. Figure 22 shows the magnitude of acceleration of earthquake.

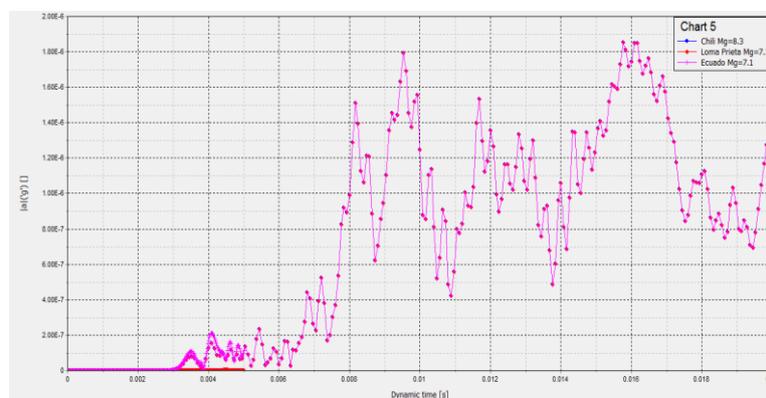


Figure 22: Magnitude of acceleration in ‘g’

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 23 shows horizontal velocity during the earthquake shaking.

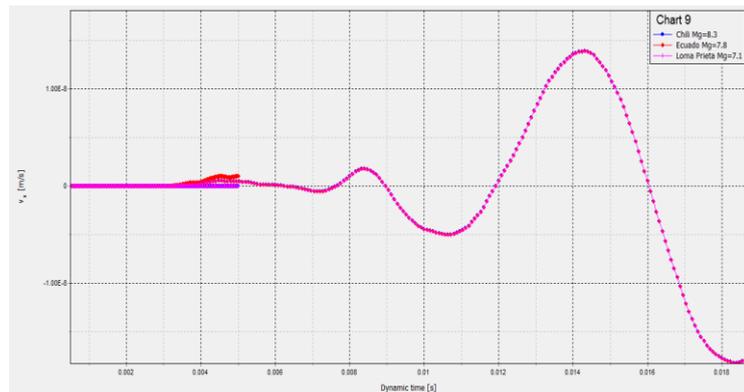


Figure 23: Velocity in horizontal direction

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 result 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 24 shows the site amplification factor.

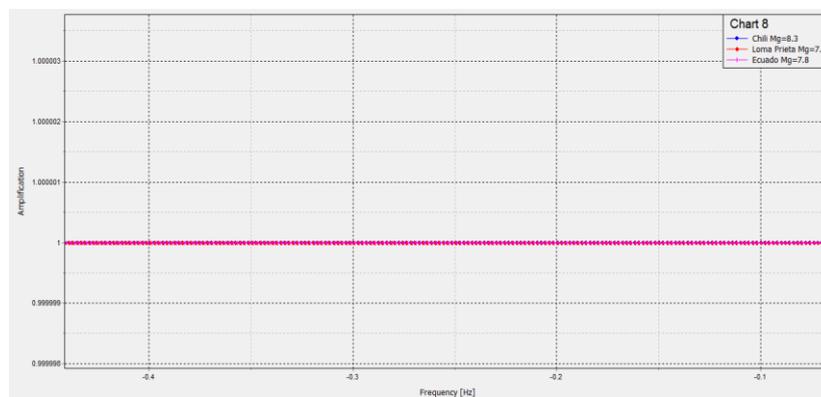


Figure 24: Ground Amplification

III. RESULTS AND DISCUSSION

The analyses for stage excavation indicate that the maximum displacement (U_z) for 20m stage excavation was $0.1104E-3$ m and 5m stage excavation was $0.02785E-3$ for static condition. The dynamic analysis also resulted to displacements (U_z) for 20m and 5m excavation depths as respectively $0.1104E-3$ and $0.04542E-3$. The formation of water filled cracks which remain open was observed in the greater depth in clay. This analysis reveals that the deeper the foundation excavation was, the larger the deformation. Since the excavation width is very wide, it also follows that the wider the excavation, the larger the deformation. As a matter of fact, for a typical excavation the wider the excavation, the larger are the unbalanced forces, the larger the unbalanced forces, the greater is the wall deformation. The magnitude of wall movement is determined by the excavation-induced unbalanced forces. The unbalanced forces are as results of factors such as excavation width, excavation depth and the preload. The stresses and deformation caused by excavation arise from their unbalanced forces.

The effect of wall height. The modelling and analysis was performed to investigate the effect of wall height (H) with increasing wall penetration depth (D) on the secant pile wall. The maximum excavation depth (H_c) was 20m and the modelling was as per the site conditions. This parametric study was conducted for 24, 27, 30, 33 and 36 m high wall. The soil parameters as in the investigation presented the effect of this parametric study on the wall behavior. The analysis results in terms of wall displacements for soil parameter studied in the modelling were obtained. It was observed that as the height of the wall increased from 24m to 27m the displacement U_z of the wall increased. Further increase in height from 27m to 30m observed was the decrease in displacement U_z of the wall and 33m to 36m resulted to significant increase in displacement. The high unusual displacement at wall

height 27m would be the basalt failure produced due to weak, highly weathered scoriaceous basalt material thus, rapid increase in displacement.

IV. DISCUSSION

The material of the interface element was defined by creating a new material, specific for the interface element. The interface element could also be used to smoothen the mesh around the areas with high stress and strain gradients (eg. sharp edges, stiff material). Standard volume elements have difficulties to produce physical stress oscillation in such areas. Smoothening is created by applying interfaces around the area and activating them during mesh generation and deactivating during calculation.

As the spacing between the anchors is increased, implying the stiffness of the anchors has been reduced, the compression of the anchor increases. There will be large wall displacement around the contact point during the second phase of excavation.

The uniformly distributed load (UDL) is applied across the site, and this gives the better estimate on the change of horizontal soil stresses due to surcharge application. The application of the UDL modifies both active and passive limits of the underlying soil. Initial stresses are built up in the calculation step and in the initial step in the calculations, by setting values of K_0 and over consolidation ratio. The ground water level was set to 5m below the ground surface. Plastic analysis was selected as calculation type due to that no time effect is considered on deformation analysis.

V. CONCLUSIONS AND RECOMMENDATIONS

According to the parametric analysis; changing the stiffness modulus and varying the pile diameter, pile length and anchor spacing in plaxis affects the deformation analysis. Special care is taken when choosing the value and condition of these parameters most especially, the stiffness modulus of the soil. The following conclusions have been drawn from the analysis.

Effect of stage excavation. The analyses for stage excavation showed that the deformations increased as the excavation depth increased. This was due to increase in the magnitude of the unbalanced forces as result of increase in depth of excavation, thus increasing stresses and deformations.

Effect of wall height. The analysis was performed to investigate the effect of wall height with increasing wall penetration depth on the secant pile wall. It was observed that as the height of the wall increased from 24m to 27m, the deformation U_z of the wall increased rapidly. Further increase in the height from 27m to 30m showed decrease in deformation of the wall and 33m to 36m resulted to significant increase in deformation. The erratic increase in deformation at wall height 27m would be the basalt failure produced as result of highly weathered scoriaceous basalt at that depth.

Decreasing the horizontal and vertical spacing of the anchors increased stiffness of the anchor per unit width. With high anchor stiffness, displacement occurs near the excavation surface.

The modulus of deformability of the soil has great importance in the settlement of the soil. It is visible that when the thickness of the wall increases, the horizontal and vertical displacement near the wall increases.

The flexibility of the wall is the most important parameter studied, because when it increases, the wall tends to move as rigid body. When the wall has 1.4m of thickness the maximum displacement occurs at the wall.

The displacement at the base of the wall was very small; this is because the wall has the tendency to insert in the soil.

The mobilized shear before the occurrence of earthquake is the same as that at the end of the earthquake.

Recommendations

There is need to consider the anticipated responses of the adjacent buildings during construction. This will require the design professional to survey the condition of the adjacent properties to understand their present condition and fragility, establish acceptable limits, conduct soil-structure analyses of various support systems and develop limits on their respective movements, and develop a monitoring strategy.

Monitoring information is compared with anticipated behavior predicted by analysis to evaluate performance and provide information that can be used to understand adjacent building responses.

In addition measurement of vibrations to evaluate the likelihood of the damage and capture the source vibrations at the foundation level and understand how those source vibrations attenuate or amplify through the structure.

Further investigations on parameters and other conditions that affect seismic analysis like density and shear modulus thus, compressional (p) waves and shear (s) waves can be calculated from those soil parameters for each layer and result can be compared with those from seismic refraction test.

APPENDIX

Parameter	Name	Secant pile(Composite)	Unit
Thickness	d	0.9	m
Unit Weight	γ	2.2	kN/m ³
Material behaviour	Type	Linear,Non-Isotropic	-
Young's Modulus	E ₁	10.06E+3	MPa
	E ₂	0.76E+3	MPa
Poisson's ratio	V ₁₂	0.25	-
Shear Modulus	G ₁₂	3.04E+3	MPa
	G ₁₃	3.04E+3	MPa
	G ₂₃	1.96E+2	MPa

Figure 25: Material properties of composite secant pile walls with different diameters

Manufacturer Trade Name	Steel grade	Yield strength(MPa)	Tensile Strength(MPa)	Poisson's Ratio
TIANJIN STEEL CO.LTD	PSB 500	500	6300	0.3

Figure 26: Material properties of rebar anchor

Equation	Concrete grade	Young's Modulus(GPa)	Shear Modulus(GPa)	Poisson's Ratio
$E_c = 4700\sqrt{f'_c}$	C 35	27.81	12.09	0.15

Figure 27: Material properties of Concrete

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

Figure 28: Material Properties for node to node Anchors

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 29: Material properties of beam(C-Plain purlins)

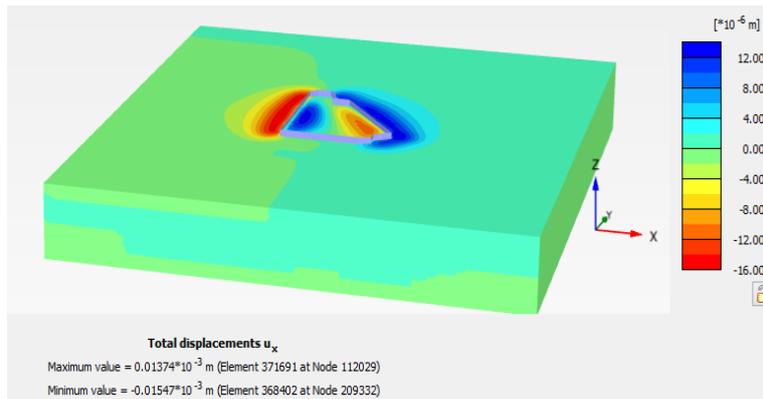


Figure 30: Stage excavation 5m – horizontal displacement

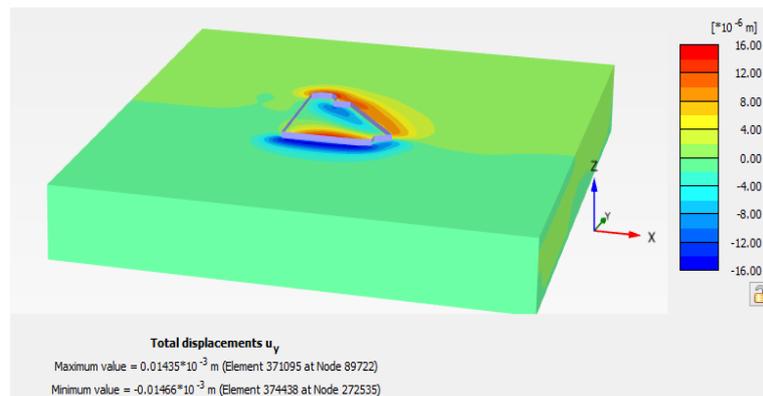


Figure 31: Stage excavation 5m – vertical displacement

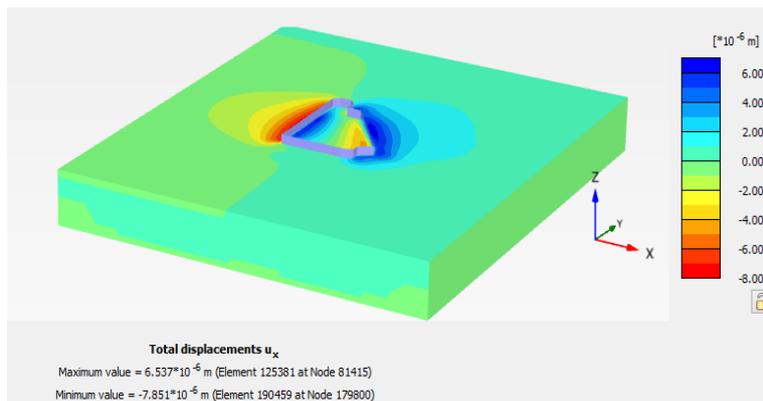


Figure 32: Stage excavation 10m – horizontal displacement

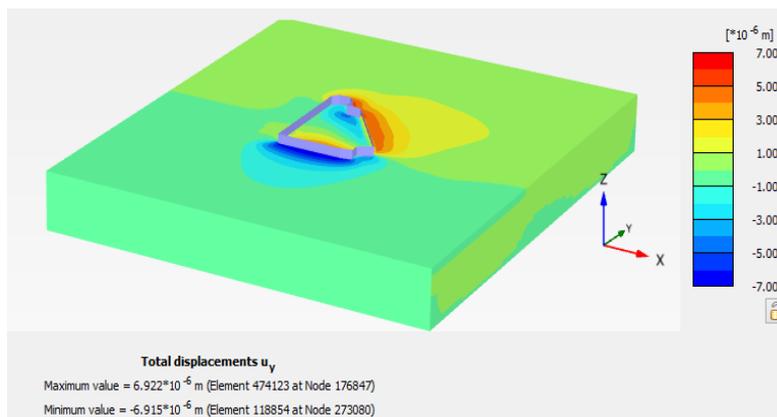


Figure 33: Stage excavation 10m – vertical displacement

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