Numerical Analysis of Diaphragm wall on the context of Dhaka City

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A THESIS SUBMITTED FOR THE DEGREE OF BACHELOR OF SCIENCE IN CIVIL ENGINEERING (GEOTECH)

Department of Civil and Environmental Engineering
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2022

APPROVAL

This is to certify that the dissertation entitled “**Numerical Analysis of Diaphragm wall on the context of Dhaka City”**, by Md. Ashraful Abedin, Inzamam Ul Kabir Priom, Imam Hussain Arif, and Abdullah Al Fahad has been approved fulfilling the requirements for the Bachelor of Science Degree in Civil & Environmental Engineering.

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DECLARATION

We declare that the undergraduate research work reported in this thesis has been performed by us under the adept supervision of Istiakur Rahman. We have taken appropriate precautions to ensure that the work is original. We can corroborate that the work has not been plagiarized. We can also make sure that the work has not been published for any other purpose (except for publication).

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ACKNOWLEDGEMENT

"In the name of Allah, the Most Gracious, the Most Merciful."

All praises belong to the Almighty Allah (SWT) for giving us the strength and courage to successfully complete our Undergraduate Thesis. We would like to extend our special gratitude to our parents for being the constant source of inspiration and support.

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DEDICATION

Our Combined Thesis work is dedicated to our respective parents, family and friends. We also express our heartiest gratitude to our respected supervisor Istiakur Rahman. It is a small token of appreciation towards all those who supported us through our endeavor and encouraged us to continue our work until the end.

ABSTRACT

Diaphragm walls are constructed with structural concrete, usually in deep excavations, either cast on location or using precast components. The construction of diaphragm walls is primarily concerned with supporting walls, heavy foundations, combined retaining walls and foundations, and deep basements. In the past, geotechnical engineers predicted excavation performance using conventional soil mechanics and empirical data. Deep excavations, however, were not easily predicted using these methods. The thickness of the diaphragm walls isconsidered 0.5m, 1m, 1.265m & 1.5m. Mohr Coulomb model and Hardening soil models are usedto calculate the maximum wall displacement and ground settlement for each thickness. Also, theground settlement and wall displacements are measured in both adjacent load and non-adjacentload conditions. The maximum allowable deflections are compared with other researches to validate the study.

In this study Diaphragm walls have shown fewer bulging effects. In general, hardening soil model shows less displacement and ground settlement compared to Mohr coulomb model. Ground settlement and wall displacements show harmony with the available literature. The maximum lateral deflection of Diaphragm wall towards the excavation measured is generally within 0.2% of excavation depth. And ground settlement should be 0.3% of excavation depth. From this study it is conclusive that Diaphragm wall with thickness of 0.5m of single basement is most cost efficient and satisfactory. Diaphragm wall is recommended as the retaining structure in Bangladesh for future projects.

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1. INTRODUCTION

1.1 General

In recent times with the ever-growing urbanization, lots of big infrastructures are being made. For these structures massive excavations are taking place, a lot of which have been subject to soil failures. To prevent this, we are conducting a numerical model analysis to find feasible solutions to these failures with the use of Retaining walls.

In Modern times rapid industrialization is leaving us with inadequate land for development within the populated areas. In the construction of these underground projects,deep excavation is required in deplorable soil conditions and not very far away from surrounding structures. These deep excavations can induce excessive ground deformations which can inevitably harm the encompassing nearby buildings.

If for some reason the soil failures are not kept in check, this can result in catastrophic consequences. Special care must be taken so that in no circumstance, the situation can be let to go in that direction.

However, in most cases, the soil performance is very important and significant efforts have been made by engineers to grasp the failures due to excavation, wall and support systems were designed using available construction methods. As the excavation becomes deeper and a lot larger in scale and if done in problematic soil condition, new challenges arise for the analysis, design and construction of these wall and support systems. Therefore, the performance of soil in deep excavations ought to be understood better through refined processes ex- timely field observation and numerical predictions.

The bottom condition (e.g., initial stress states, stiffness and strength properties and groundwater regime) of the soil mainly effects ground movements and deep excavations.

1.2 Background Study

Deep Excavation is very common projects in many urban areas all around the world nowadays. In the above model the soil is retained byhorizontal struts and anchors. There are some steps to measure and analyze the deep excavationsupport system. These are: To calculate the wall displacements, ground settlement, adjacentstructure load, force acting on the structure. A numerical analysis is performed to analyze thosedata. Retaining walls must be built completely by calculating the stability and safety factor of thesoil and the wall itself, and this can be done manually or using software programs such as Oasis,Plaxis, Geo 5, etc. Programs such as Plaxis are used to solve various geotechnical problems, suchas analyzing stability issues and designing foundations and retaining walls. Plaxis 2D is used toanalyze 2D finite element models of various wall configurations in this project.

1.3 Objectives:

The followings are the main objective of the research:

1) To perform a numerical analysis of diaphragm wall for a single and two basement system to obtain ground settlement and lateral wall displacement.
2) Compare the numerical method with physical data.
3) To find of the feasibility of diaphragm in the context of Dhaka.

2. LITERATURE REVIEW

This Chapter will discuss about the use case scenario of Diaphragm walls and the studies related to the topic.

2.1 Introduction

As a result of the installation of the diaphragm walls, the surrounding soil undergoes deformation and stress changes. The already existing piled foundation nearby may have an effect given the construction procedure. As there happens to be very little data regarding the direct effects surrounding slurry trenching on piled foundations, the given chapter elaborates a generalized characteristic of the exiting pile under normal circumstances following the effect of the variations of construction activities on the slurry trench's level of stability and the curiosity which has piqued many researcher's interests in trying to understand the stress mechanism of the surrounding trench in hopes of being able to develop an understanding of such a mechanism which may help to seek out the effects regarding a slurry trench on piles. Deep excavations of deep deposits of soft clay can result in excessive levels of shifting positions of the ground and in turn, may result in adverse effects on the soil causing damage to adjacent buildings.

The overall in-depth explanation of predicting wall deflection has been elaborated in section 2.2. Given in section 2.3 and 2.4, we discuss the Numerical Modelling approach we have taken and our Model details. Further sections elaborate on more related topics regarding deep foundation, vertical loads and soil deformation. In the given last section of 2.13, there is a vast yet summarized portion of the chapter.

2.2 Predicting wall deflection

According to Kung (2009) [1], the lateral movements account for nearly 0.2% of excavation depth. Kung (2009) evaluated the effect of excavation methods from the top-down (TDM) and bottom-up (BUM) on diaphragm wall deflection. According to the study, in general, wall deflections of BUM cases are smaller than those of TDM cases.

When anchors are used, the displacements at the anchor level are limited, according to Andzio (1998). While the wall can bend between these two positions, the total displacement will be much smaller than that of a similar height cantilever wall.

A semi-empirical method was developed by Clough and O'Rourke (1990) [3] to estimate excavation deformations in soft clays.The stiffness of thesystem can greatly affect the movement of the soil, according to Clough and O'Rourke.

The data collected by Peck (1969) [4] was normalized by excavation depth to measure ground surface settlement. This leads to sizeable settlements, which may have an extent up to 0.2 percent of the excavation next to a supporting wall and also settle 4x the depth from side to side compared to the wall. In general, the maximum settlements are expected to be smaller when a stiffer retaining wall is used.

Table 2.2.1: Predicting wall Deflection

Study Reference	Criterion	Literary Info	Year
Bentler [5]	Lateral Displacement	Maximum lateral ground settlement should be 0.22% - For sand andhard clay Maximum Lateral diaphragm wall ground settlement should be 0.55% of groundsettlement - For soft to stiff soil.	1998
Konstantakos [7]	Lateral Displacement	Maximum Lateral diaphragm wall ground settlement should be 0.2-0.4% ofexcavation depth.	2008
Moorman [2]	Lateral Displacement	Maximum Lateral diaphragm wall ground settlement should be 1.1% of excavationdepth.	2004
Clough and O'Rourke [3]	Lateral Displacement	Maximum Lateral diaphragm wall movement within point two percent.	1990
National Engineering Handbook	Lateral Displacement	Lateral displacements should be within 25mm-75mm	2007
El- Nahhas et al. And others [5]	Lateral Displacement	Lateral Movements are nearly 0.2% of excavation depth	2009
Kung [1]	Lateral Displacement	Max Movement exceed not point one percent.	2009

2.3 Numerical Modelling

The numerical modeling of soil structure mechanisms is a powerful method for studying them in deep excavations. It can provide the necessary data for outlining purposes. Here we depict a portion of the numerical modeling forms as well as an overview of early discoveries.

2.4 Model details

A large number of 2D simulations have been used in the design phase and for research due to the limited capabilities of software and computing resources available.

PLAXIS having been chosen for this project and we will be reviewing the constitutive soil models of PLAXIS. Only models associated with the chosen models will be reviewed. For more detailed information, consult PLAXIS manuals.

PLAXIS is an engineering soil simulation tool that uses numerical soil models to qualitatively represent soil behaviors and use parameters to quantitatively define soil characteristics. There are 7 variations of soil models included in PLAXIS.

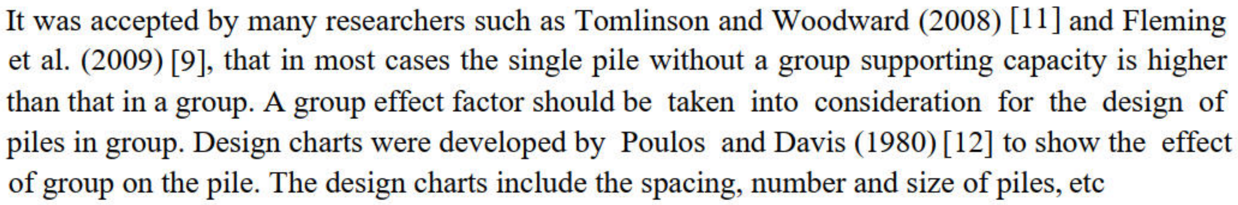
Hardening Soil (HS) is an advanced soil model thatgenerates more realistic soil responses, such as nonlinearity, stress dependence, and inelasticity.However, it suffers from the same problem as the MC model when determining undrained shearstrength using effective stress parameters c' and ϕ'. It is most likely that the HS model will replacethe MC model. The MC model as a quick and simple approximation can be followed by the HSmodel to provide a 'second opinion.' The LE model is mainly used to model piles, diaphragm walls,and other structural components. Models will all be evaluated by comparing their performances tomeasurements taken in the field.

Models that are not better than or not developed specifically for excavation analysis are not considered. Models such as SS and SSC are better suited to modeling loading behavior of very soft soils; MCC is better suited to modeling near-normally consolidated clayey soils, and NGI-ADP is less commonly used for excavation modeling. In the PLAXIS Material Models Manual, further details are given regarding their limitations to simulate excavation works.

2.5 Deep Foundation Stress and Strain Mechanism (Pile Foundation)

Models that are not better than or not developed specifically for excavation analysis are notconsidered.Models such as SS and SSC are better suited to modeling loading behavior of verysoft soils; MCC is better suited to modeling near-normallyconsolidated clayey soils, and NGI-ADP is less commonly used for excavation modeling.In the PLAXIS Material Models Manual,further details are given regarding their limitations to simulate excavation works.

2.6 Pile Group Under Vertical Load



It was accepted by many researchers such as Tomlinson and Woodward (2008) [11] and Fleming et al. (2009) [9], that in most cases the single pile without a group supporting capacity is higher than that in a group. A group effect factor should be taken into consideration for the design of piles in group. Design charts were developed by Poulos and Davis (1980) [12] to show the effect of group on the pile. The design charts include the spacing, number and size of piles, etc

2.7 A Theoretical Study on the Analysis of Diaphragm Wall

Diaphragm walls are deep retention systems used as a part of foundation. Building basements, urban spaces congested with people, metro train tunnels, river forts and marine structures typically require these types of structures. Construction procedure and equipment for diaphragm walls are described in Indian code IS 9556-1980. The code of practice for reinforcement concrete design IS 456-2000 is used for the analysis and design process. The aim of the paper is the theoretical study on the analysis procedure of diaphragm wall.

2.8 Soil deformation calculation using analytical solution

The lateral displacement of the earth can be calculated from Equation 2.8.1 which is based on Timoshenko, Goodier (1951) [13] for deep circular cut (Xanthakos, 1994). [14]

$$\delta h = 0.75(ko\gamma`-\gamma f`)2L/Ei \qquad \ldots 2.8.1$$

Where L is the length of the panel, Ei is the initial tangent modulus of the clay and ko is the at rest earth pressure.

Lei et al. (2001) [15] used the method of complex variables with a simplified conformal transformation function to transfer the exterior of rectangular section into the interior of the circle. In order to obtain an approximate elastic solution capable of calculating the stress distribution and deformation around a rectangle opening such as trench. Uniaxial stress was used. The finite element model was used to verify their method. Ng and Lei (2003) [16] came up with a two-dimensional elastic solution to solve biaxial stress problems as an improvement to the previous method. In addition to soil characteristics, geometric properties are also important in determining the solution. They provided calculation charts that could help to find empirically the soil deformation and stress during trenching. Lei et al. (2014) [17] approximately predicted the ground surface settlement due to the diaphragm wall construction along the centerline. The solution was based on applying the total earth pressure on the trench side walls and base. In the model, a homogeneous, isotropic, elastic soil was assumed. The settlement was calculated by applying the method of superposition with respect to maximum horizontal total earth pressure changes; soil undrained Young's modulus and trench length. This method was verified with finite element and field data.

2.9 Soil deformation calculation using numerical analysis

In the last few decades, the numerical solutions were widely used in engineering problems. Many researchers studied the diaphragm wall trenching using numerical analysis such as finite element or finite difference analysis.

Gunn and Clayton (1992) [18] discussed the change in stress during diaphragm wall installation and its effect on deformation. They showed that the limit equilibrium analysis did not take into consideration the change in stress and its effect on design. Accordingly, Gunn et al. (1993) [19] used two-dimensional finite element mish to simulate a full trenching process in order to estimate the lateral stress reduction. The soil was modeled using the Mohr-Coulomb model while the slurry was simulated with an equivalent hydrostatic pressure. Their intention was to find out the effect of wall installation on the final wall bending moment after excavation. The cantilever wall was not noticeably affected, while the propped wall was affected. The installation effect is low if the water level is high and vice versa.

2.11 Comparation Study of Stabilization Work using Sheet Piles made of Reinforced Concrete-Steel-Vinyl

The purpose of this paper is to compare the use of sheet piles to protect river embankments from scouring under normalization works. This study describes briefly how sheet piles can be used to reinforce embankments of rivers against landslides. This chapter describes how sheetpiles are used for stabilizing river embankments. After that, it is discussed the comparison of sheet piles used at several different locations in Batang Manggor and Batang Anai. Geotechnical and geographical characteristics of both sites are similar, so a comparative study is possible. Concrete, steel, and vinyl sheet piles make up the piles. After presenting a comparison of the three types of sheet pile in terms of materials cost and site workability, the study concluded.

From observations made during the construction, it seems that the installation of reinforced concrete sheet piles was more problematic than the other works. As a result of the large cross section of the concrete sheet pile tip contacting the ground when driven, this problem is generally experienced. Due to the relatively smaller cross section of steel and vinyl sheet piles compared to concrete sheet piles, installation is relatively simple. In addition, the vibratory machine used to drive the piles has a greater capacity than the others. A chainsaw can additionally be used to cut vinyl sheet pile neatly and easily. Cutting Steel and concrete sheet piles require greater amounts of effort.

As a construction option for riverbank stabilization, sheet piles can be used. The application must choose from the available types of sheet pile however. In addition to geotechnical and geographical data, the decision maker must also consider relevant nontechnical matters. In comparison to concrete and steel sheet piles, installing vinyl sheet piles is relatively easy and less expensive. Sheet pile implementation costs are mainly determined by the different material choices. Depending on the material selected, the budget incurred will be affected by variations in the costs of the material, installation, human resources, and other aspects of the project. This study compared the costs of river banks stabilization with steel sheet piling to concrete and vinyl sheet piling. We can conclude that the steel sheet piling is much more expensive than concrete and vinyl piles. A special maintenance program is required for steel materials after construction to prevent corrosion.

2.12 Parametric Study of Different types of Diaphragm Wall using Soil–Structure Interaction for Section Optimization

This paper presents a study of the effects of deep excavations with diaphragm wall in loose sandy soil, medium sandy soil and clay soil.

The objectives of this study are to investigate the effect of different parameters on the prediction of wall deformation by using STAADpro software. Study aims to find an optimal section for a differentdiaphragm wall considering variations in many of its design parameters to suit the soil conditionsand depth of excavation.

Results of these analyses were recorded in terms horizontal displacement of the diaphragm wall, steel consumption at the depth of 3m, 8m, 12m at Strutted Diaphragm Wall, Cantilevered Diaphragm Wall, Anchored Diaphragm Wall behind the diaphragm wall, and deflection induced in the diaphragm wall due to an adjacent deep excavation Using STAADPro Software.

The lateral earth pressure is of three types at rest, active and passive. By using Rankin's analysis, we can calculate the lateral earth pressure.

Type of diaphragm wall used for study

1- Cantilever Diaphragm wall
2- Anchored Diaphragm wall
3- Strutted Diaphragm Wall

IS2911 method has been considered for the calculation of the soil sub grade modulus and spring constants can be calculated from these subgrade reaction coefficients.

Modulus of subgrade reaction taken from Joseph E Bowles' Foundation analysis and design book's table 9-1 Range of modulus of subgrade Reaction Ks We assume the following values of K For sands and normally consolidated lays, modulus varies with depth (type 2 soils)

$$K=(hh)(z/B),p =hh(z/B)$$

Where, hh=coefficient of horizontal modulus variation (kN/m3) z= depth below G.L. B=width of shaft in meters.

For analyzing diaphragm wall, modeling has been done for different sections, such as cantilever, anchored and strutted section in STAADPRO software. For a particular depth of wall and for different models were made by changing soil condition such as loose sand, medium sand and clay soil.

Maximum horizontal Displacement is little higher in loose soil compare to medium and clay soil. By providing the different type of wall it is found that cantilever wall has maximum horizontal displacement Ø. At the height of 12m itis found that compare to all the cases of 3m and 8m ,12m wall height has maximum horizontal displacement. Ø Maximum Steel Consumption of different diaphragm wall. It is found that cantilever wall has little higher consumption of steel compare to the other wall and at the height of 12 m steel consumption is maximum for different type of wall.

2.13 Summary

Numerous aspects of deep excavations have been analyzed numerically, including wall though some parts of comprehension of deep excavation needed to be contributed to. With the advancement of hardware and software, 3D analysis is now entirely feasible even in deep

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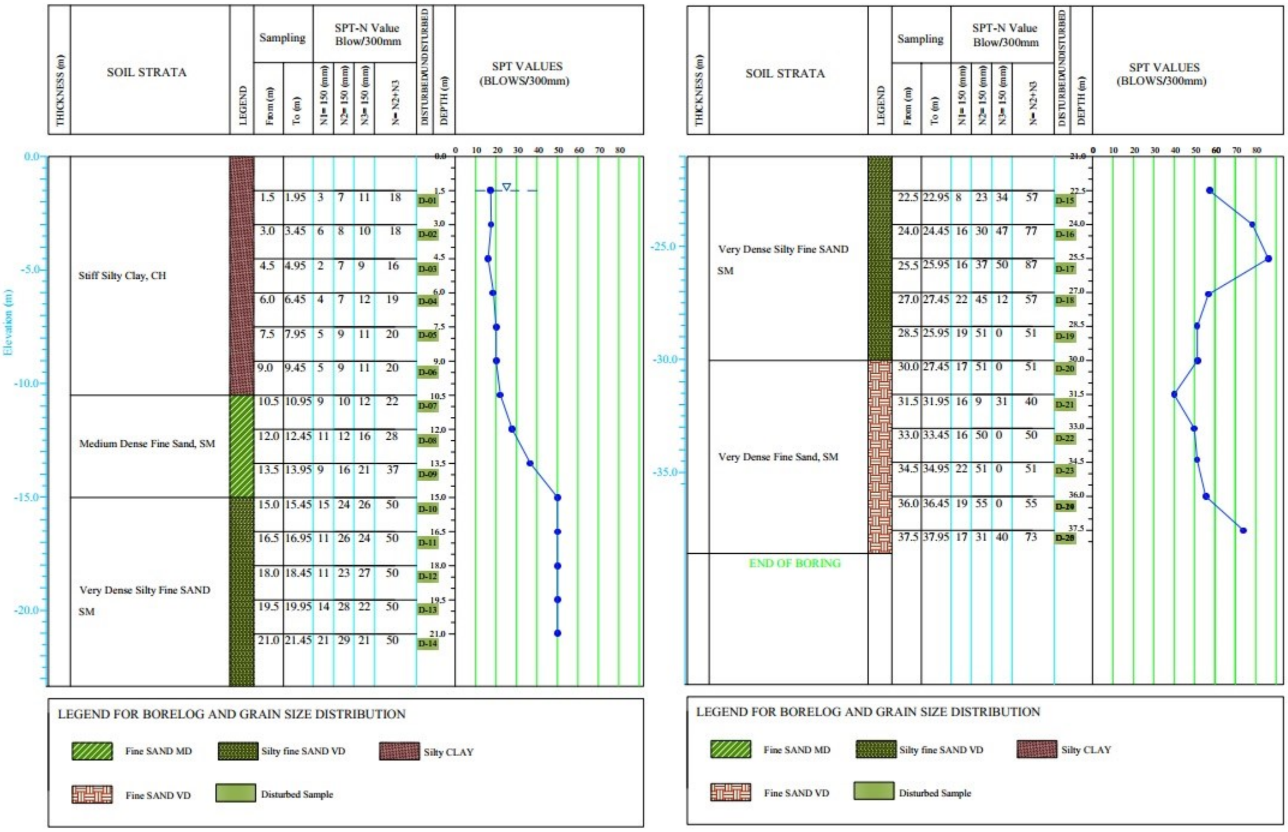
3. DATA COLLECTION AND VALIDATION

From the data obtained, it shall be compared to an existing data for validation.

3.1 Data Collection:

The test was conducted with soil samples collected from Dhaka and Chittagong. Field tests are also described here. In this chapter, a parametric study is conducted using an idealized excavation geometry. The findings and conclusions generated are useful for designing and work procedure of deep excavations.

A sub-soilinvestigation report of the project area served as the primary source of information.



From (m)	To (m)	N1= 150 (mm)	N2= 150 (mm)	N3= 150 (mm)	N= N2+N3	DISTURBED/UNDISTURBED	DEPTH (m)
1.5	1.95	3	7	11	18	D-01	1.5
3.0	3.45	6	8	10	18	D-02	3.0
4.5	4.95	2	7	9	16	D-03	4.5
6.0	6.45	4	7	12	19	D-04	6.0
7.5	7.95	5	9	11	20	D-05	7.5
9.0	9.45	5	9	11	20	D-06	9.0
10.5	10.95	9	10	12	22	D-07	10.5
12.0	12.45	11	12	16	28	D-08	12.0
13.5	13.95	9	16	21	37	D-09	13.5
15.0	15.45	15	24	26	50	D-10	15.0
16.5	16.95	11	26	24	50	D-11	16.5
18.0	18.45	11	23	27	50	D-12	18.0
19.5	19.95	14	28	22	50	D-13	19.5
21.0	21.45	21	29	21	50	D-14	21.0

From (m)	To (m)	N1= 150 (mm)	N2= 150 (mm)	N3= 150 (mm)	N= N2+N3	DISTURBED/UNDISTURBED	DEPTH (m)
22.5	22.95	8	23	34	57	D-15	22.5
24.0	24.45	16	30	47	77	D-16	24.0
25.5	25.95	16	37	50	87	D-17	25.5
27.0	27.45	22	45	12	57	D-18	27.0
28.5	25.95	19	51	0	51	D-19	28.5
30.0	27.45	17	51	0	51	D-20	30.0
31.5	31.95	16	9	31	40	D-21	31.5
33.0	33.45	16	50	0	50	D-22	33.0
34.5	34.95	22	51	0	51	D-23	34.5
36.0	36.45	19	55	0	55	D-29	36.0
37.5	37.95	17	31	40	73	D-28	37.5

Figure 3.1.1: Soil test report

3.2 Validation:

To validate our data we have taken a study by Hsiung, B. C., Dan, D. S., & Lum, C. W. (2016) [31]. With that as our reference, we used our data obtained from the field and compared them.

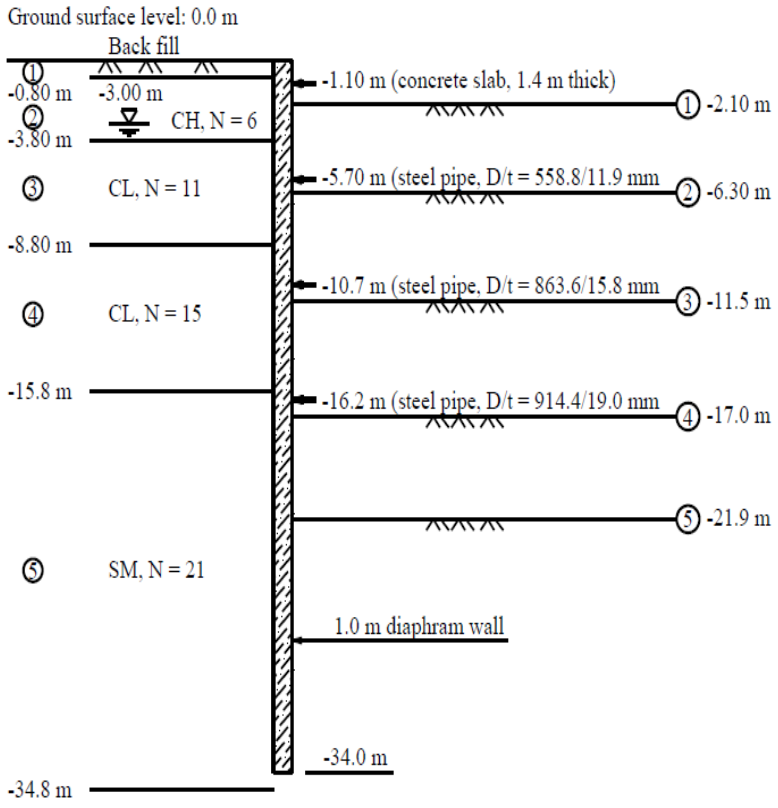


Figure 3.2.1: Evaluation of performance of diaphragm walls by wall deflection paths

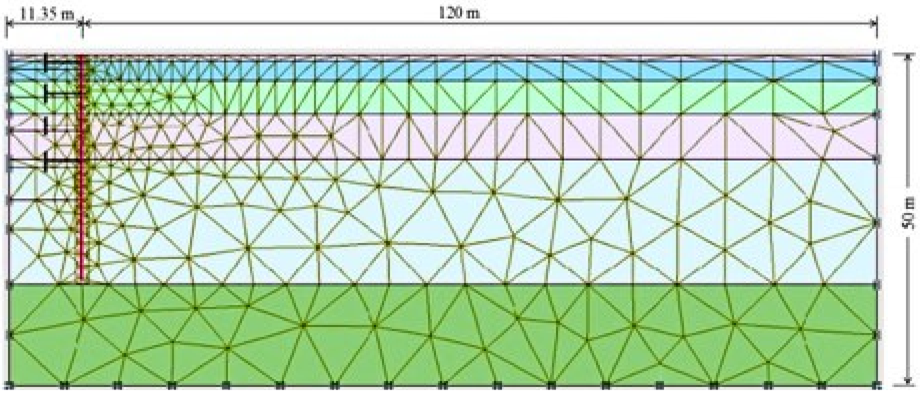


Figure 3.2.2: Mesh analysis

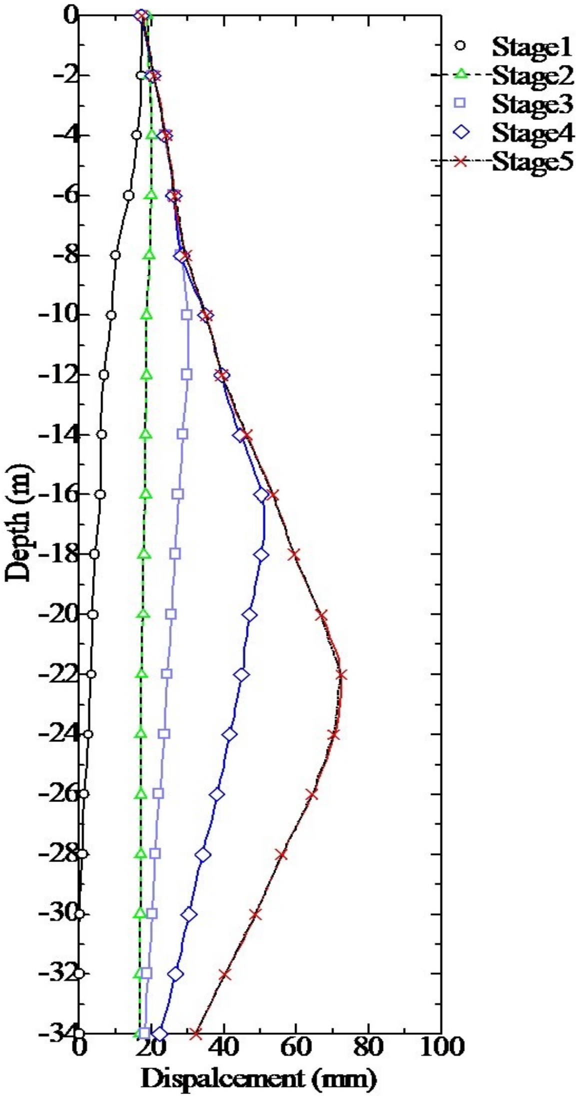


Figure 3.2.3: Graph from our model

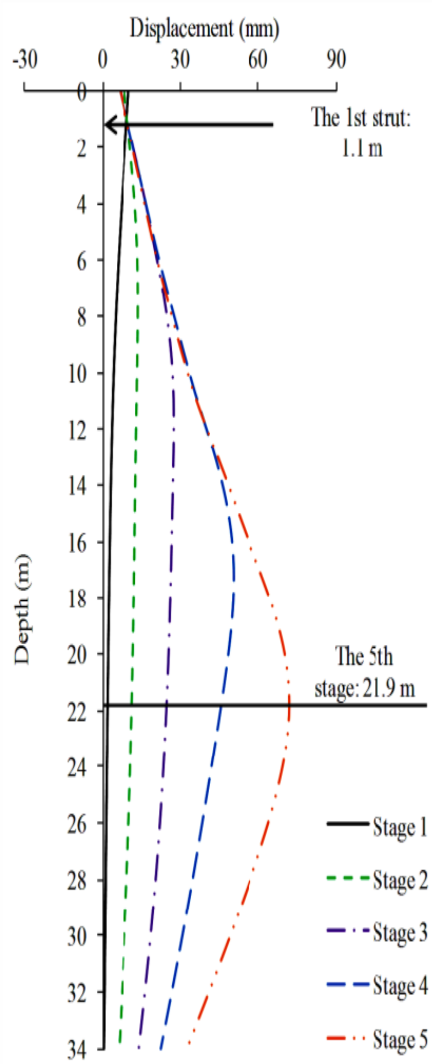


Figure 3.2.4: Graph from literature

We have compared the data obtained from our model with the data from the literature and found our results to be within acceptable margins..

PLAXIS 2D vs. Data from Literature

68.34mm	72.3mm (+5.79%)
Wall displacement of model by Researcher	Result from our model

PLAXIS 2D vs. Data from Literature

21.9m	22.5m (+2.74%)
Depth of maximum displacement from researcher's model	Result from our model

4. NUMERICAL MODELLING

This chapter will discuss about the various models and parameters we have rendered with computer aided software named PLAXIS 2D.

4.1 PLAXIS 2D:

PLAXIS 2D is a finite element software package for geotechnical engineering and rock mechanics that analyzes two-dimensional deformation and stability. Excavation, dams, embankments, and tunnels are some examples of geotechnical structures that can be modeled via the software. The software calculates 2D plane strain and axisymmetric deformations as well as soil stresses, water flow, and pressures, as well as structural and thermal forces. In order to account for the behavior of different soil types, such as clay, sand and rock, as well as the behavior of the soil when loaded, unloaded and reloaded, many different soil models are included. In addition to providing users with an environment that resembles a CAD system, PLAXIS 2D allows users to create models quickly and efficiently, allowing them to spend more time interpreting results.

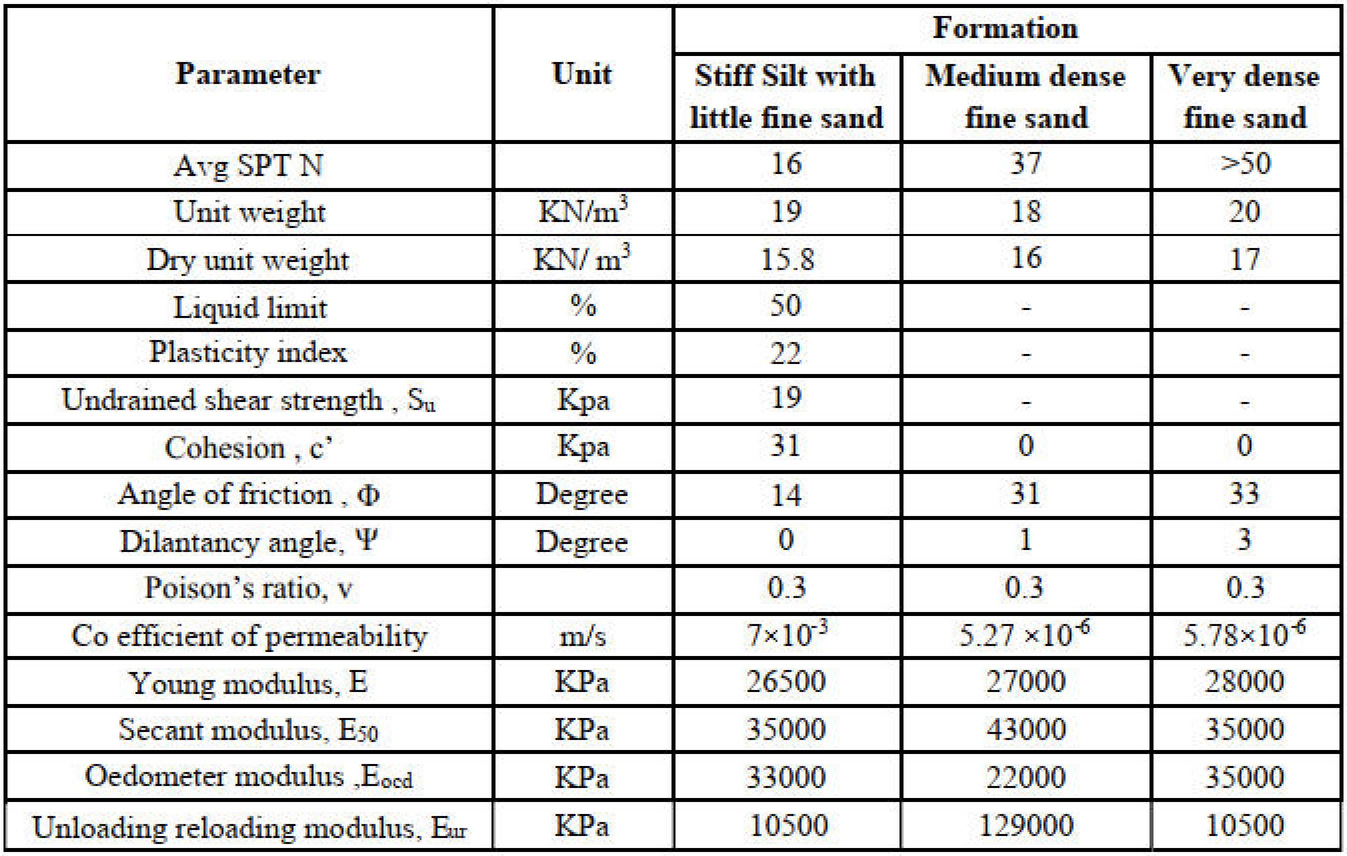
4.2 Soil Parameters:

The Tables below show the soil parameters we have used in our PLAXIS model. We have used both MC Model and HS Model.

MC Model:

Table 4.2.1 shows the soil parameters used for MC Model.

Table 4.2.1: MC model parameters

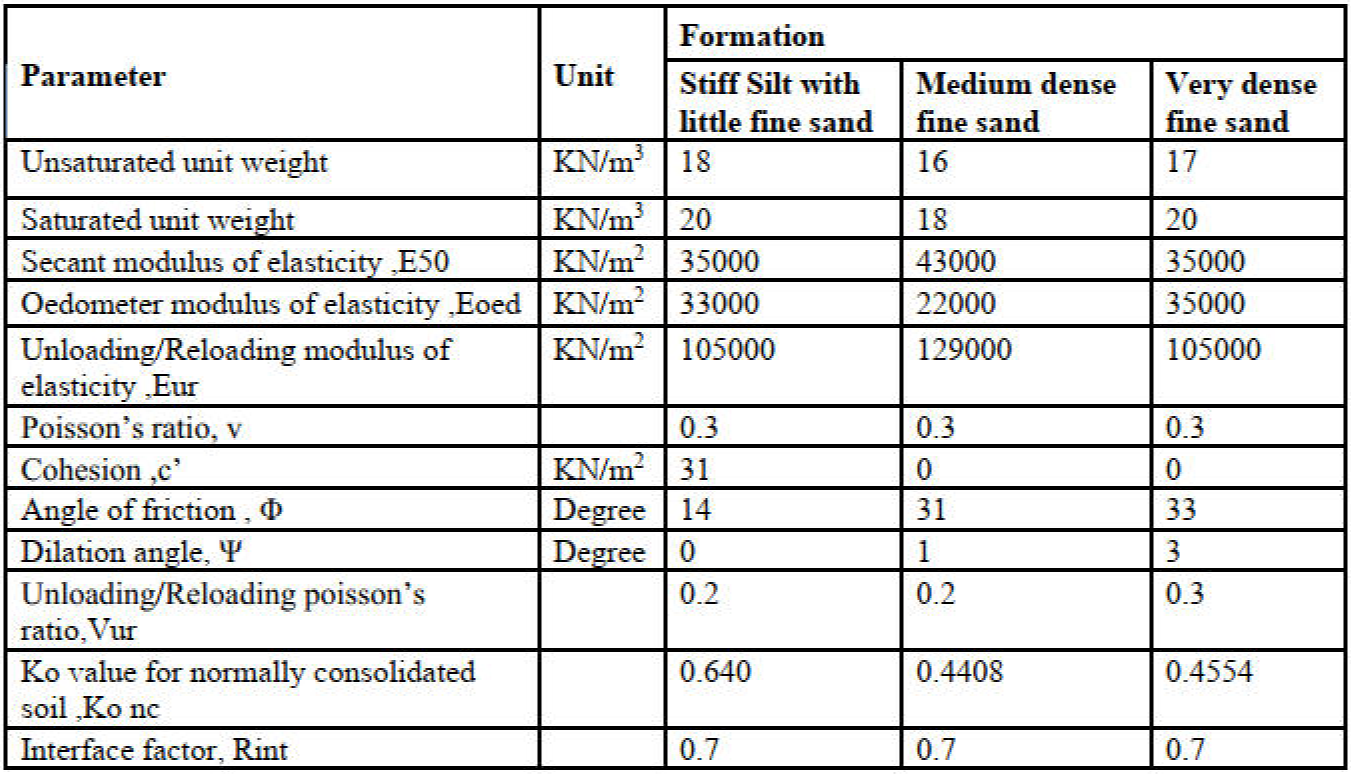


Parameter	Unit	Formation		
		Stiff Silt with little fine sand	**Medium dense fine sand**	**Very dense fine sand**
Avg SPT N		16	37	>50
Unit weight	KN/m^3	19	18	20
Dry unit weight	$KN/\ m^3$	15.8	16	17
Liquid limit	%	50	-	-
Plasticity index	%	22	-	-
Undrained shear strength , S_u	Kpa	19	-	-
Cohesion , c'	Kpa	31	0	0
Angle of friction , Φ	Degree	14	31	33
Dilantancy angle, Ψ	Degree	0	1	3
Poison's ratio, ν		0.3	0.3	0.3
Co efficient of permeability	m/s	7×10^{-3}	5.27×10^{-6}	5.78×10^{-6}
Young modulus, E	KPa	26500	27000	28000
Secant modulus, E_{50}	KPa	35000	43000	35000
Oedometer modulus ,E_{ocd}	KPa	33000	22000	35000
Unloading reloading modulus, E_{ur}	KPa	10500	129000	10500

HS Model:

Table 4.2.2 shows the soil parameters used for HS Model.

Table 4.2.2: Hardening soil parameters



Parameter	**Unit**	**Formation**		
		Stiff Silt with little fine sand	**Medium dense fine sand**	**Very dense fine sand**
Unsaturated unit weight	KN/m^3	18	16	17
Saturated unit weight	KN/m^3	20	18	20
Secant modulus of elasticity ,E50	KN/m^2	35000	43000	35000
Oedometer modulus of elasticity ,Eoed	KN/m^2	33000	22000	35000
Unloading/Reloading modulus of elasticity ,Eur	KN/m^2	105000	129000	105000
Poisson's ratio, v		0.3	0.3	0.3
Cohesion ,c'	KN/m^2	31	0	0
Angle of friction , Φ	Degree	14	31	33
Dilation angle, Ψ	Degree	0	1	3
Unloading/Reloading poisson's ratio,Vur		0.2	0.2	0.3
Ko value for normally consolidated soil ,Ko nc		0.640	0.4408	0.4554
Interface factor, Rint		0.7	0.7	0.7

4.3 2D Models used and their variations:

We have designed different 2D models in PLAXIS 2D. Both MC and HS models were used along with variations in basement levels, diaphragm wall thickness and presence of adjacent load.

❖ For MC Model Variation are:

- Double Basement with no adjacent load for 1.265m diaphragm wall.
- Double Basement with no adjacent load for 0.5m diaphragm wall.
- Double Basement with no adjacent load for 1m diaphragm wall.
- Double Basement with no adjacent load for 1.5m diaphragm wall.
- Single Basement with no adjacent load for 1.265m diaphragm wall.

- Double Basement with adjacent load for 1.265m diaphragm wall.
- Single Basement with adjacent load for 1.265m diaphragm wall.

❖ For HS model the variations are:

- Single Basement with no adjacent load for 1.265m diaphragm wall.
- Double Basement with no adjacent load and 0.5m diaphragm wall.
- Double Basement with no adjacent load and 1m diaphragm wall.
- Double Basement with no adjacent load and 1.5m diaphragm wall.
- Double Basement with adjacent load for 1.265m diaphragm wall.
- Double Basement with no adjacent load for 1.265m diaphragm wall.
- Single Basement with adjacent load for 1.265m diaphragm wall.

4.4 Diaphragm wall properties:

The Table below shows the properties of the Diaphragm walls of different thickenesses.

Table 4.4.1: Diaphragm wall properties

Parameter	Value	Unit
EA1	$48x10^6$	KN/m
EA2	$48x10^6$	KN/m
EI	$1x10^6$	KN m^2/m
D	0.5	m
W	10	KN/m/m
v	0.3	-

Parameter	Value	Unit
EA1	12x106	KN/m
EA2	12x106	KN/m
EI	1x106	KN m2/m
D	1	m
W	10	KN/m/m
v	0.3	-

Parameter	Value	Unit
EA1	7.5×10^6	KN/m
EA2	7.5×10^6	KN/m
EI	1×10^6	KN m^2/m
D	1.265	m
W	10	KN/m/m
v	0.3	-

Parameter	Value	Unit
EA1	5.3×10^6	KN/m
EA2	5.3×10^6	KN/m
EI	1×10^6	KN m^2/m
D	1.5	m
W	10	KN/m/m
v	0.3	-

4.5 Plan and Section view of the model:

Figures 4.5.1 and 4.5.2 show the PLAXIS 2D model's Plan view and Section view.

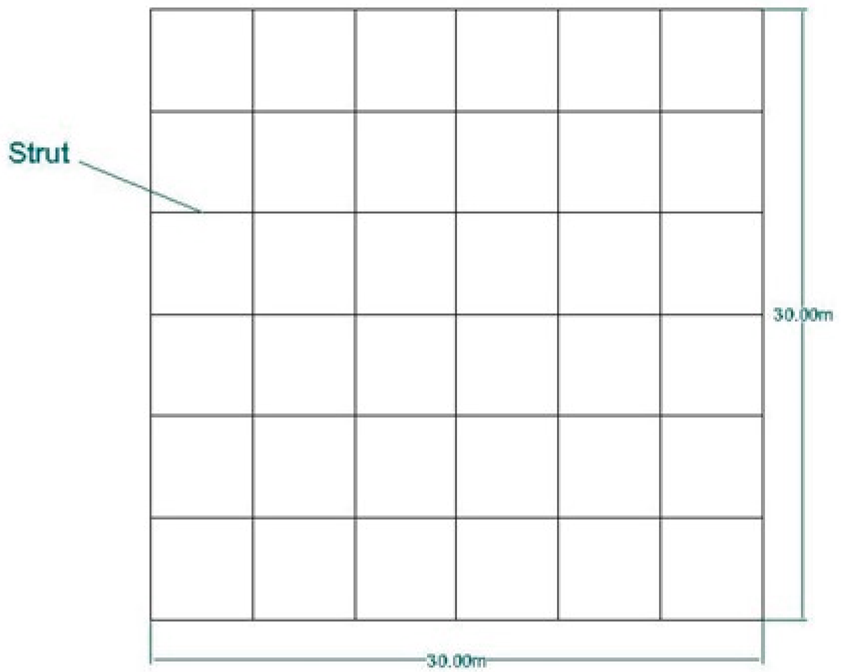


Figure 4.5.1: Plan view of the model

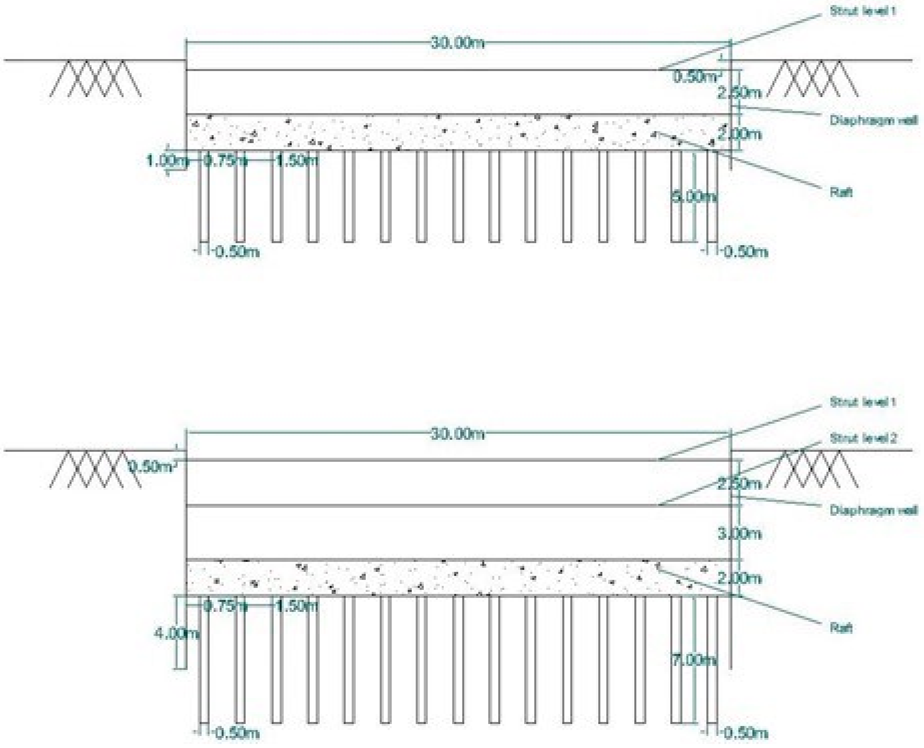


Figure 4.5.2: Section view of the model

4.6 Mesh Analysis:

Figures 4.6.1-4 shows the Mesh Analysis of our 2D model with variations in basement levels and presence of adjacent loads.

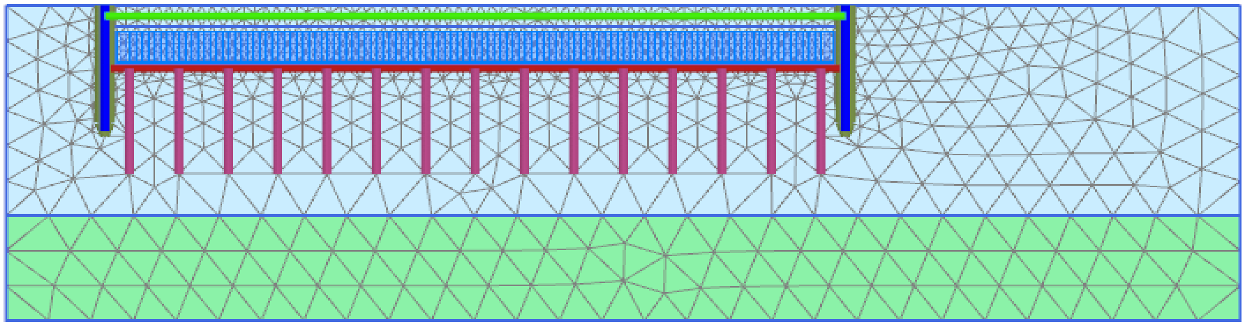


Figure 4.6.1: Diaphragm wall model with single basement

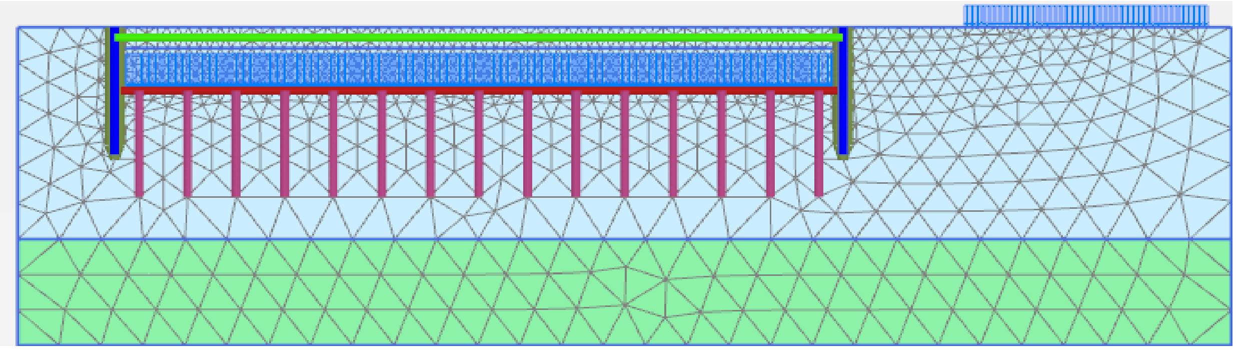


Figure 4.6.2: Diaphragm wall model with single basement with adjacent load

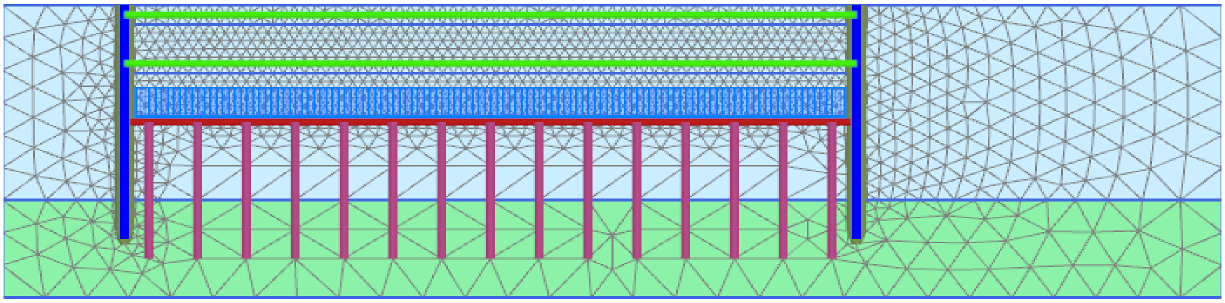


Figure 4.6.3: Diaphragm wall model with double basement

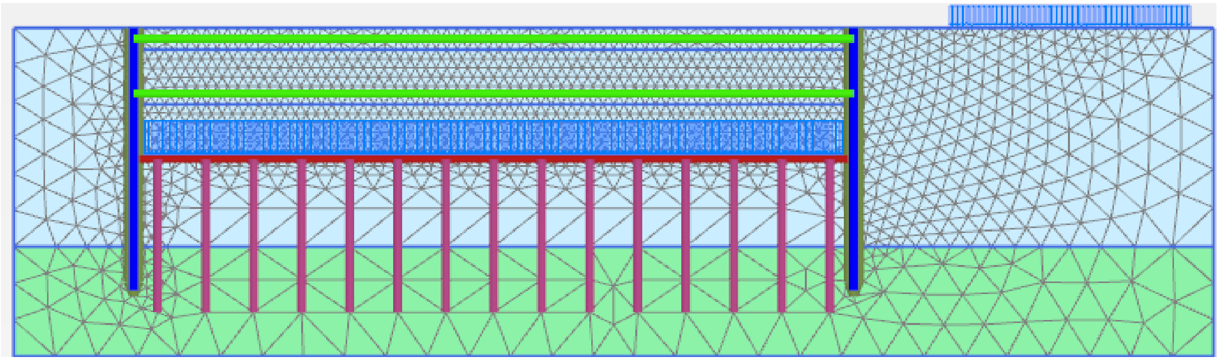


Figure 4.6.4: Diaphragm wall model with double basement with adjacent load

5. ANALYSIS & COMPARISON

With the data obtained from our PLAXIS 2D model, we plotted graphs for analysis and comparison based on different thickness of diaphragm wall, basement levels and adjacent load.

5.1 Depth Vs Displacement graph for Diaphragm wall

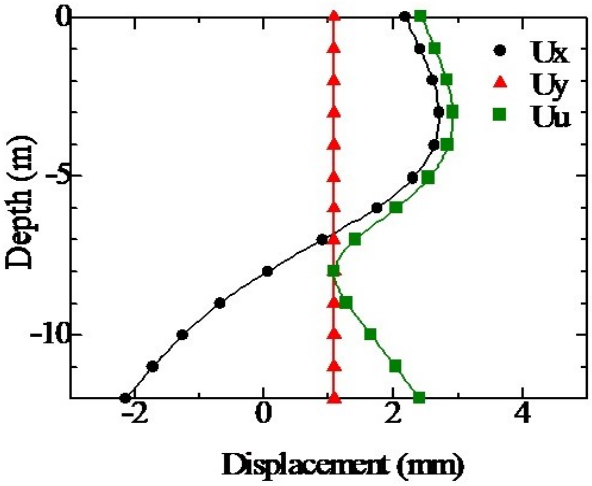


Figure 5.1.1: HS model Left wall (thickness 0.5m)

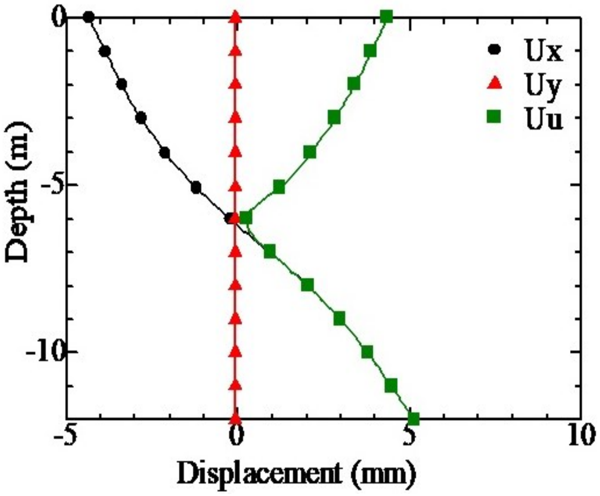


Figure 5.1.2: HS Model Right wall (thickness 0.5m)

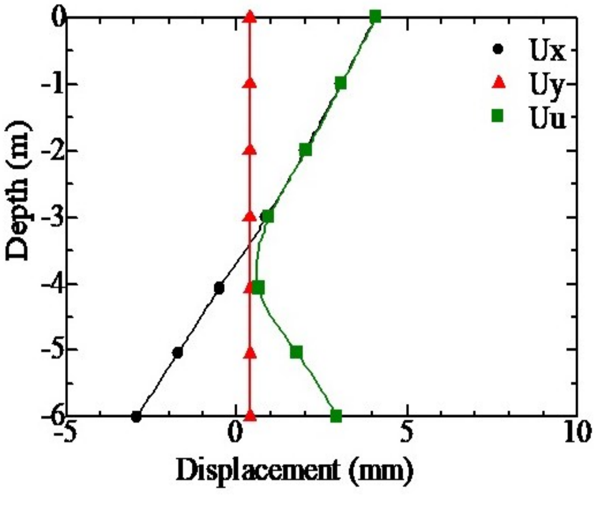


Figure 5.1.3: Single Basement HS Model Left wall

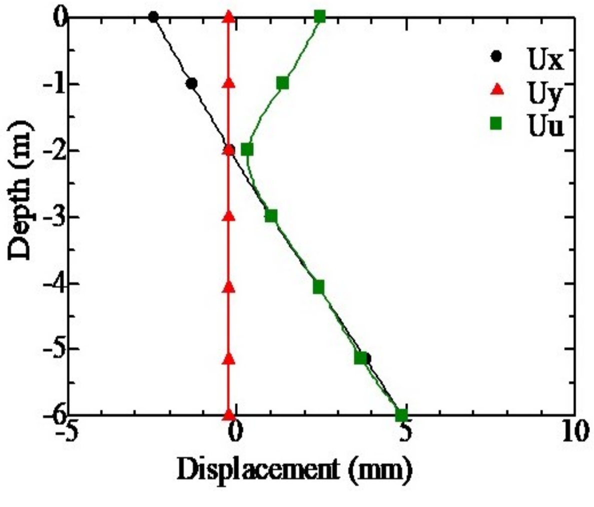


Figure 5.1.4: Single Basement HS Model Right wall

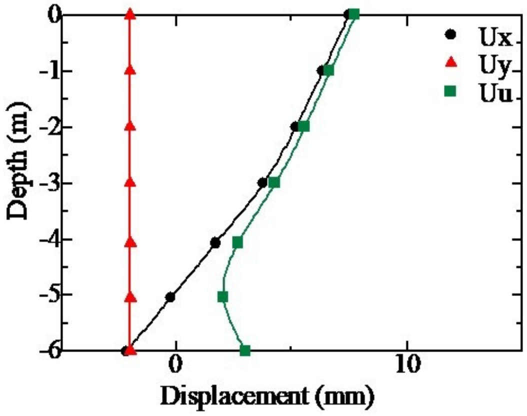


Figure 5.1.5: Single Basement MC model left wall (thickness 1.265m)

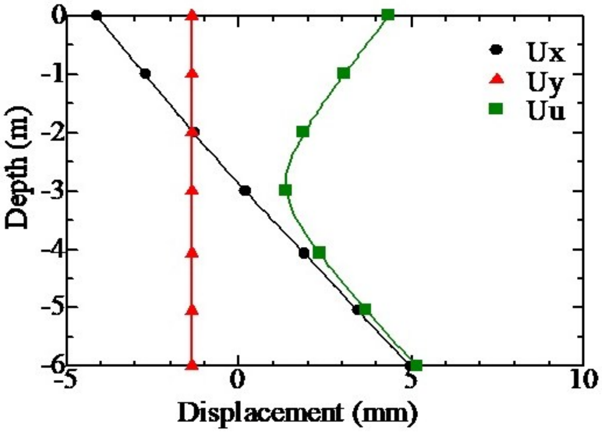


Figure 5.1.6: Single Basement MC model right wall (thickness 1m)

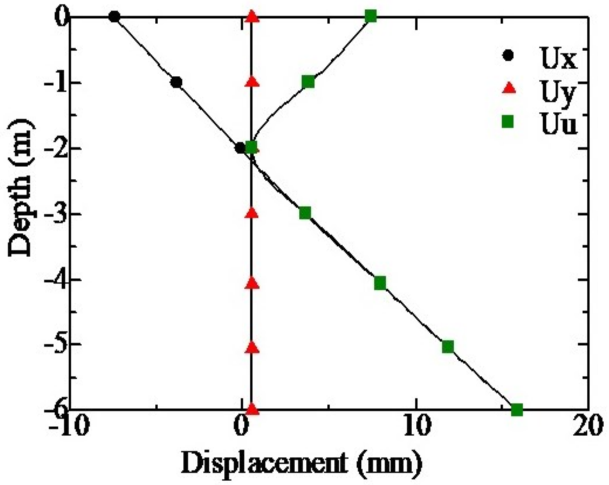


Figure 5.1.7: Single Basement MC model right wall (thickness 1.265m)

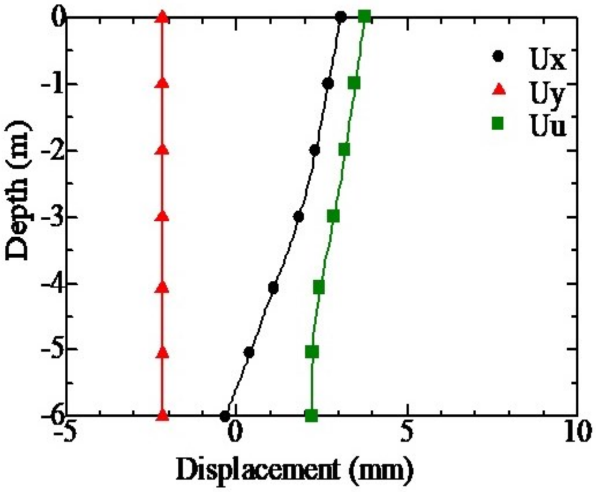


Figure 5.1.8: Single Basement MC model left wall (thickness 1m)

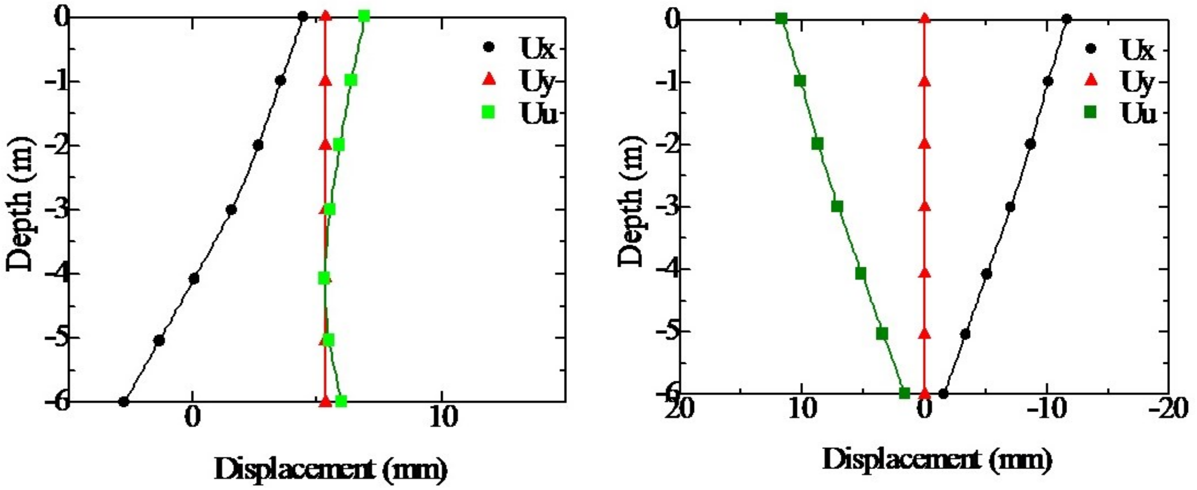


Figure 5.1.9: Single Basement MC Model with adjacent load Left and Right wall

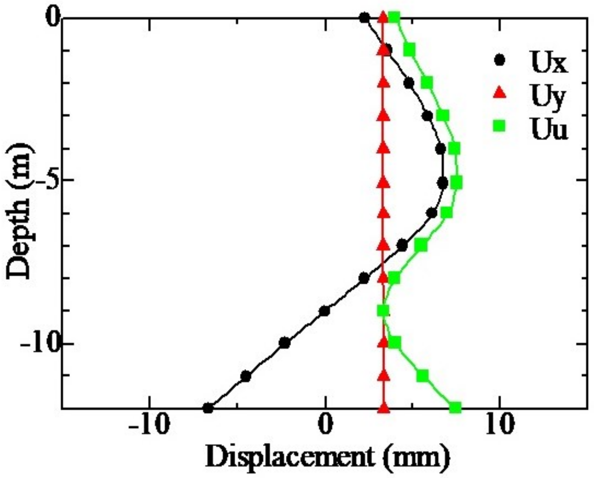


Figure 5.1.10: Double Basement MC Model Left wall

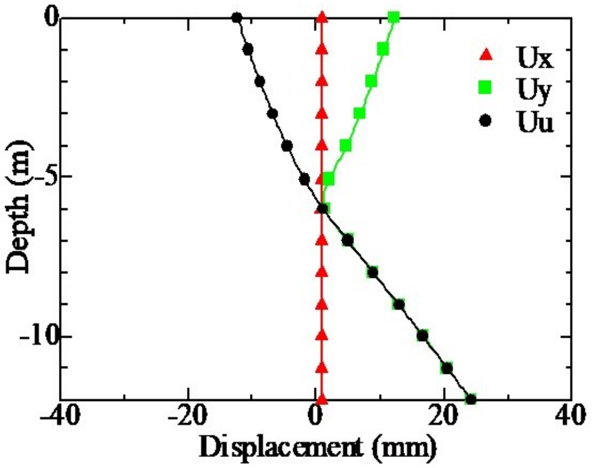


Figure 5.1.11: Double Basement MC Model right wall

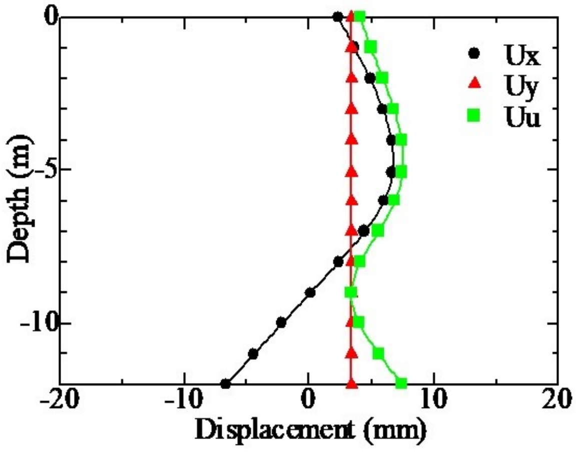


Figure 5.1.12: Double Basement MC Model 0.5 m Left wall

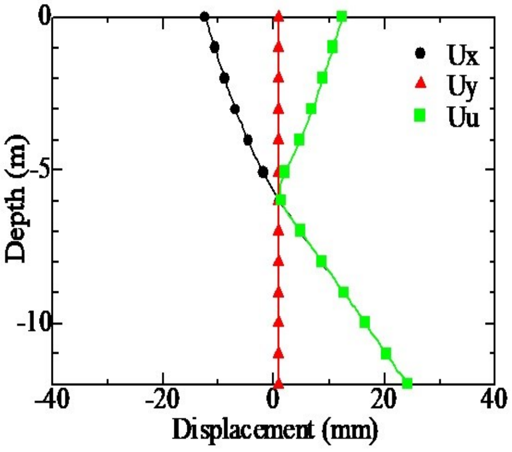


Figure 5.1.13: Double Basement MC Model 0.5 m Right wall

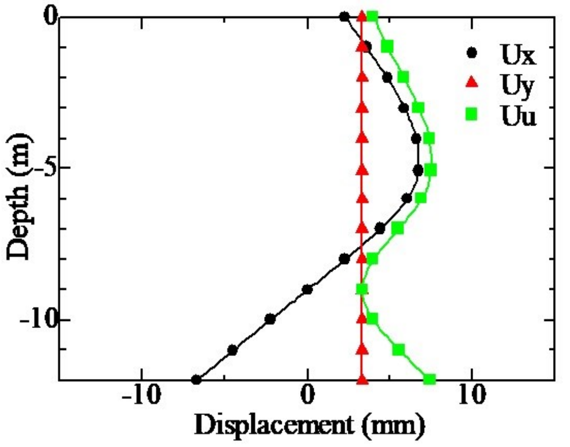


Figure 5.1.14: Double Basement MC Model 1m Left wall

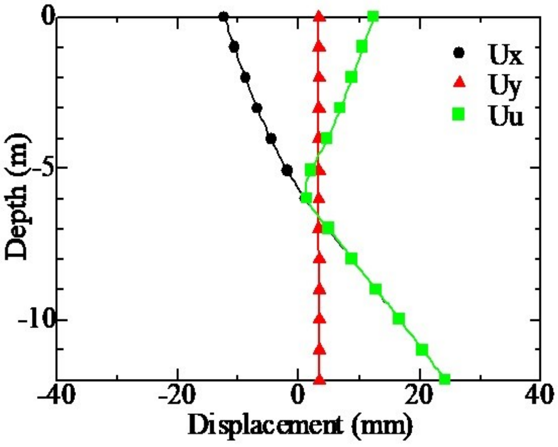


Figure 5.1.15: Double Basement MC Model 1 m Right wall

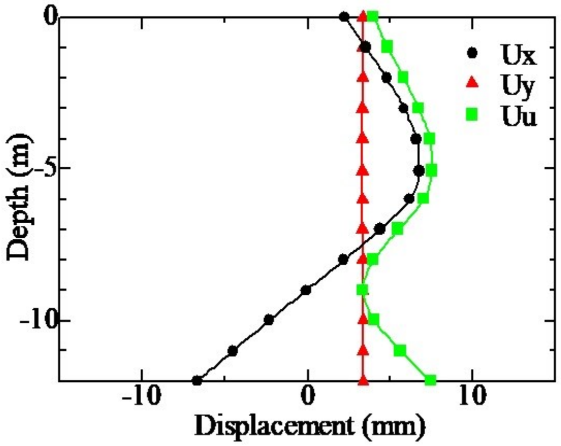


Figure 5.1.16: Double Basement MC model 1.5 m Left wall

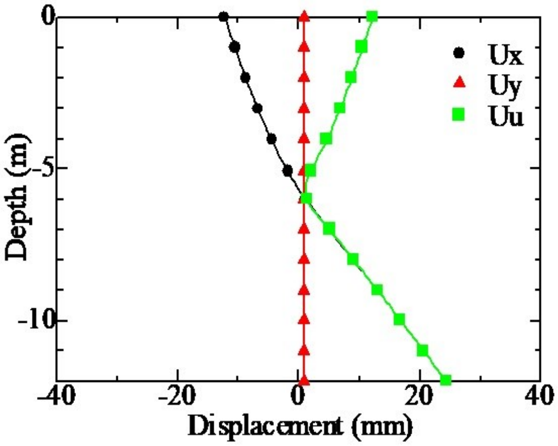


Figure 5.1.17: Double Basement MC model 1.5 m Right wall

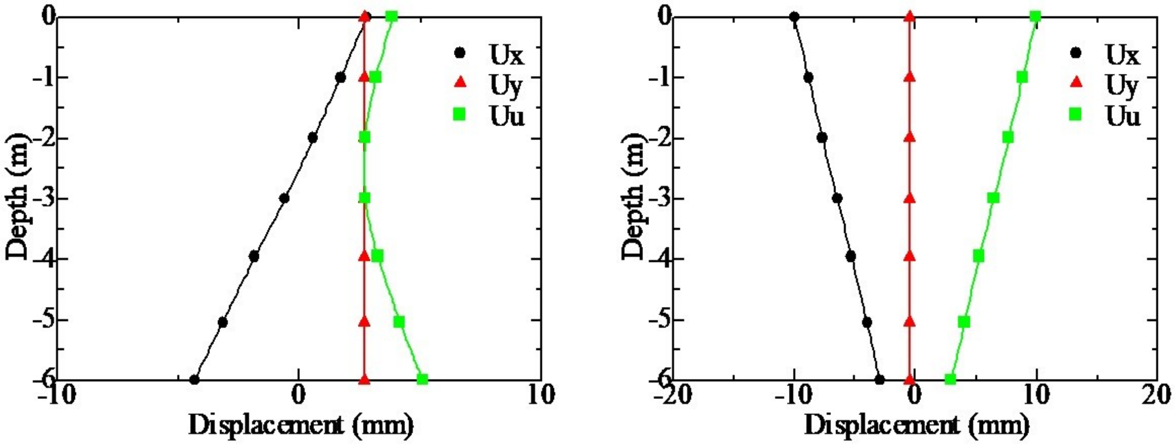


Figure 5.1.18: Single Basement HS Model with Adjacent Load Left & Right Wall

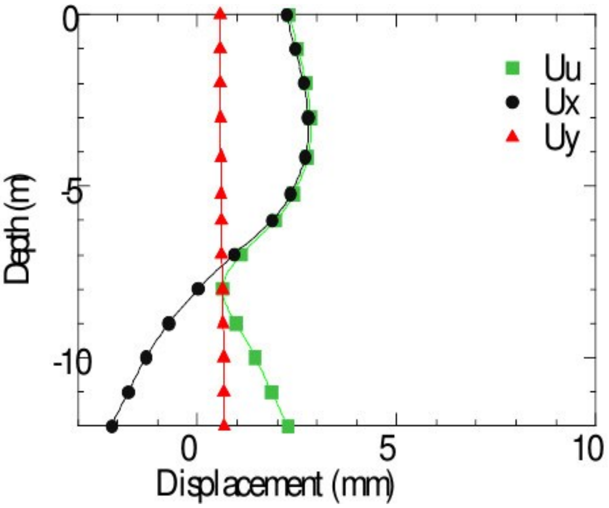


Figure 5.1.19: Single Basement HS 1.5 m Left Wall

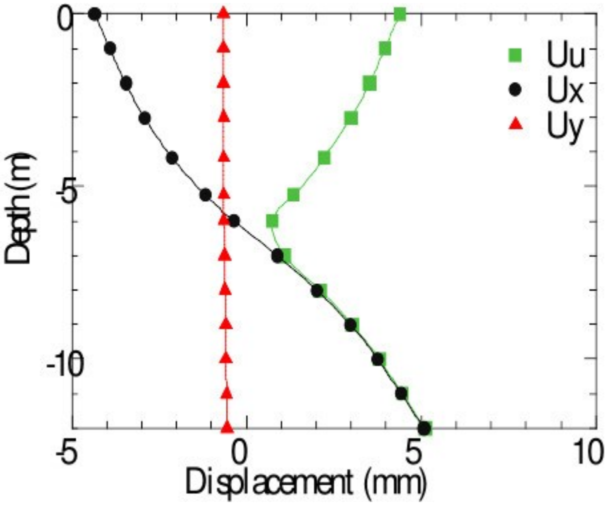


Figure 5.1.20: Single Basement HS 1.5 m Right Wall

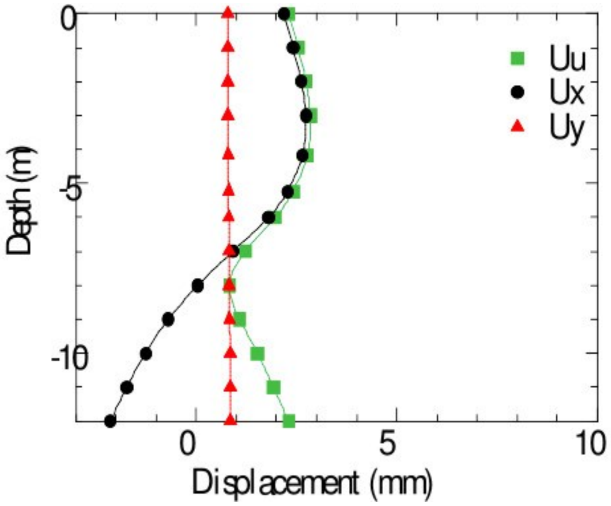


Figure 5.1.21: Single Basement HS 1 m Left Wall

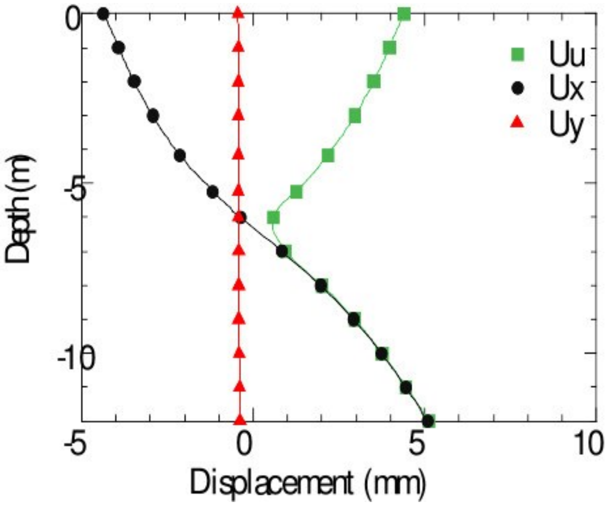


Figure 5.1.22: Single Basement HS 1 m Right Wall

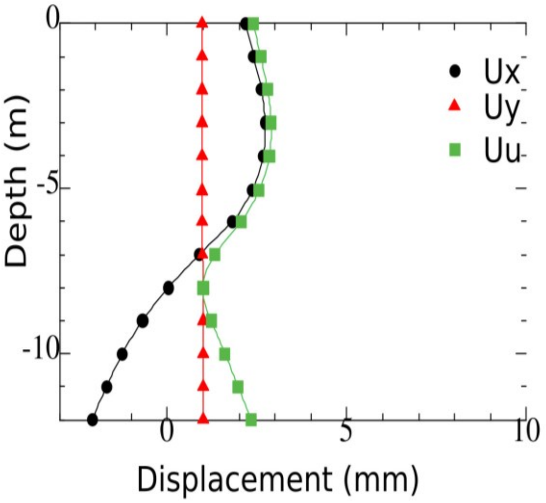


Figure 5.1.23: Single Basement HS Model Left Wall

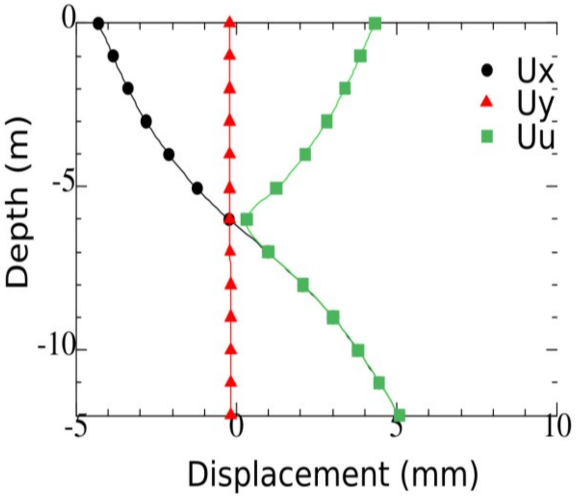


Figure 5.1.24: Single Basement HS Model Right Wall

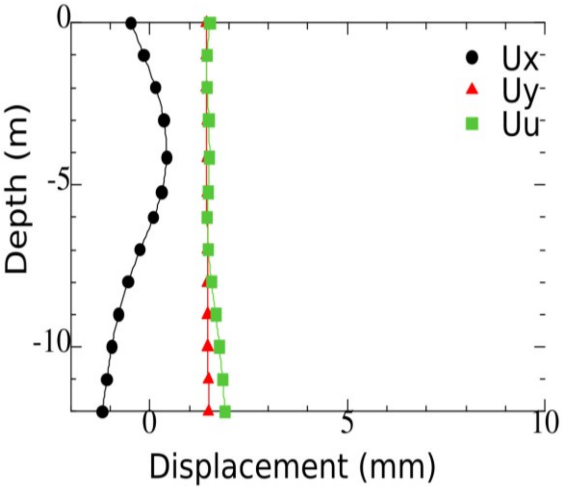


Figure 5.1.25: Single Basement HS with Adjacent Load Left Wall

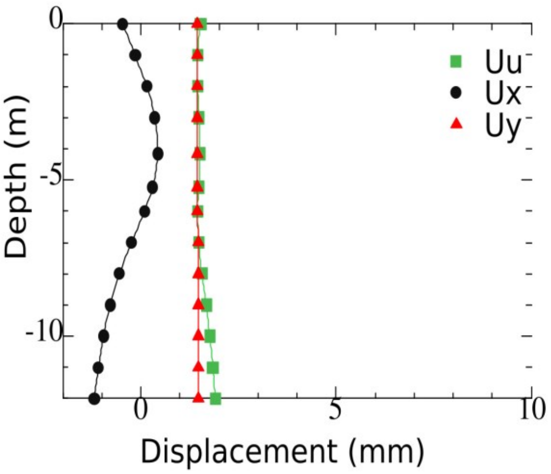


Figure 5.1.26: Single Basement HS with Adjacent Load Right Wall

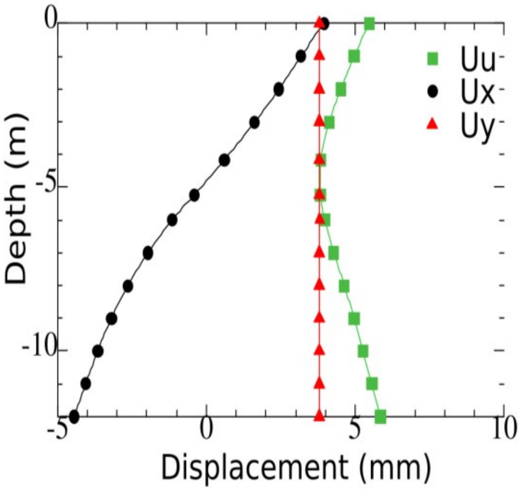


Figure 5.1.27: Single Basement MC Model with Adjacent Load Left wall

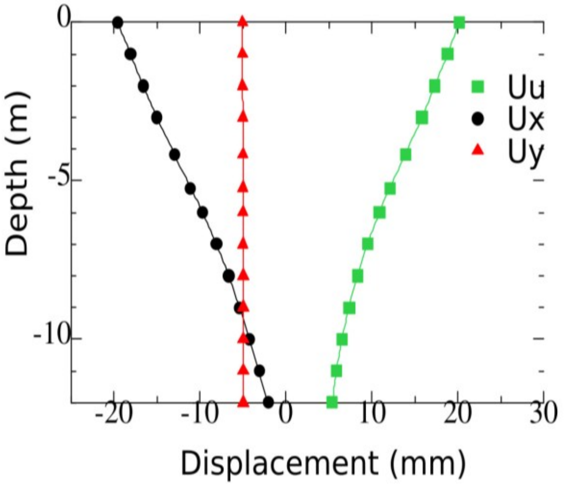
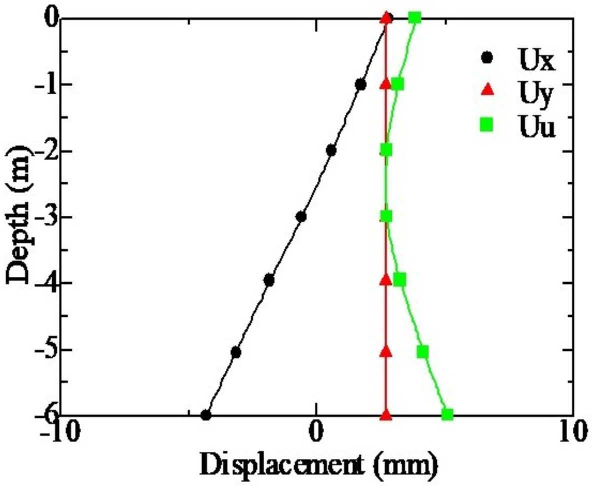
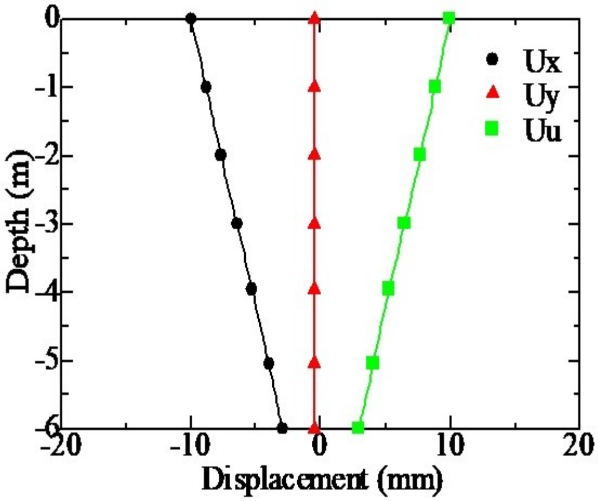


Figure 5.1.28: Single Basement MC Model with Adjacent Load Right wall





5.2 Soil Displacement graph

In this chapter the settlement of soil against distance from the wall graphs are shown. And in the end a summary table of wall deformations are shown.

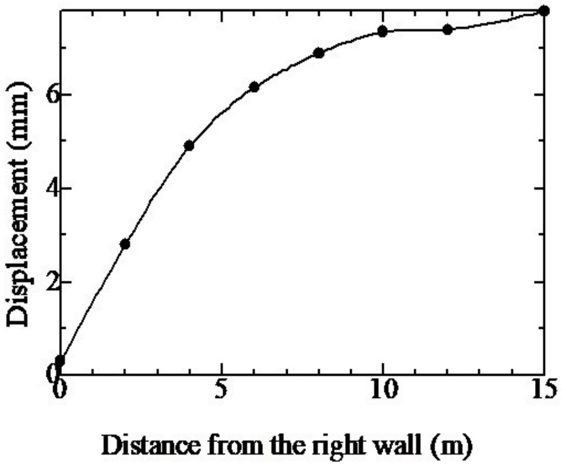


Figure 5.2.1: HS model for single basement from right wall (thickness 1m)

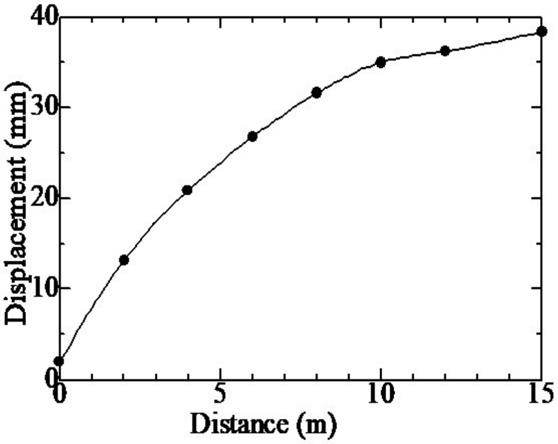


Figure 5.2.2: MC model for single basement (wall thickness 0.5m)

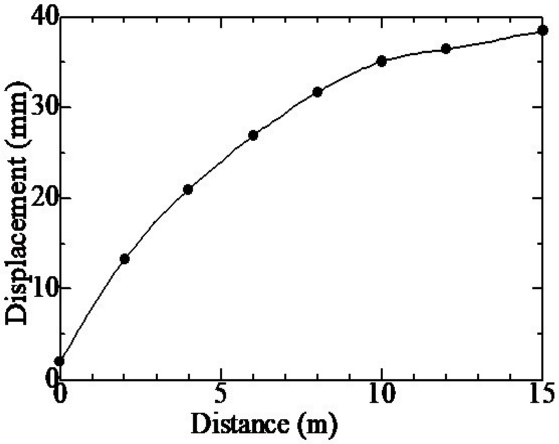


Figure 5.2.3: MC model for single basement (wall thickness 1.5m)

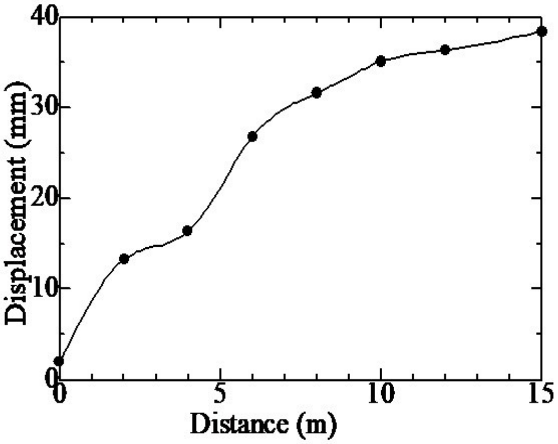


Figure 5.2.4: MC model for single basement (wall thickness 1m)

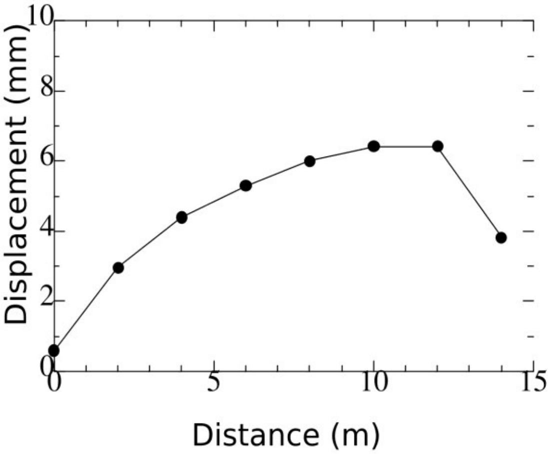


Figure 5.2.5: HS model for double basement (wall thickness 1m)

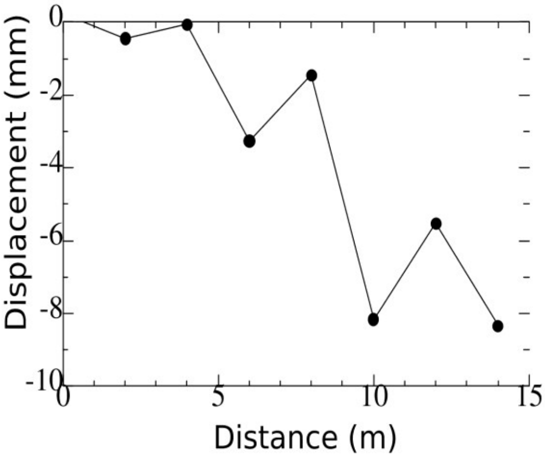


Figure 5.2.6: HS model for double basement with adjacent load (wall thickness 1m)

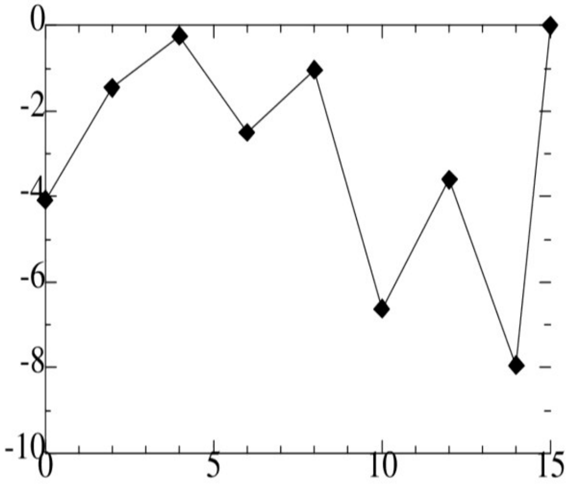


Figure 5.2.7: MC model for double basement with adjacent load (wall thickness 1m)

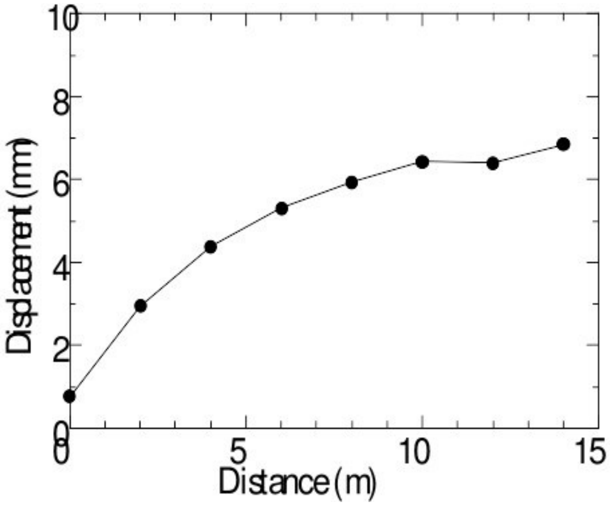


Figure 5.2.8: HS model for double basement right wall (thickness 1m)

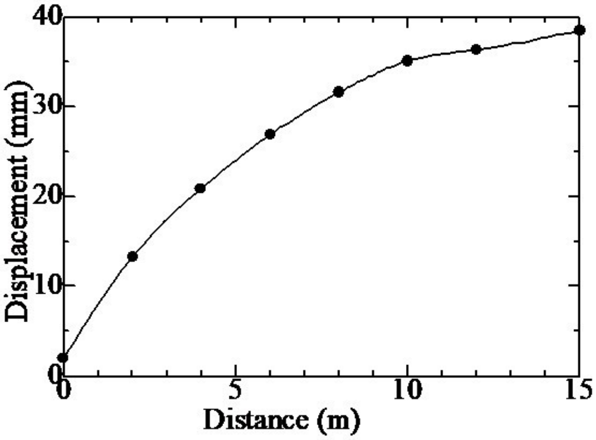


Figure 5.2.9: MC model for single basement (wall thickness 1m)

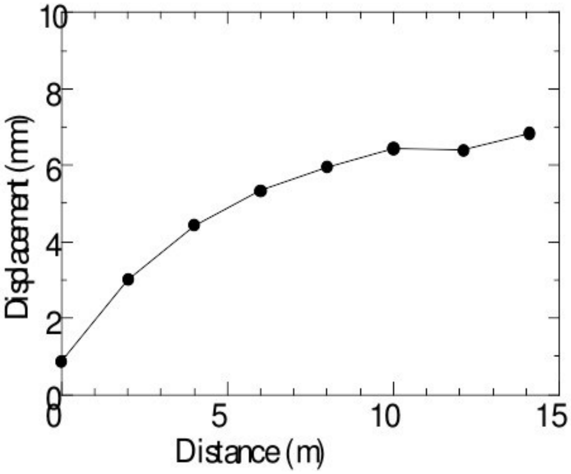


Figure 5.2.10: HS model for single basement (wall thickness 1m)

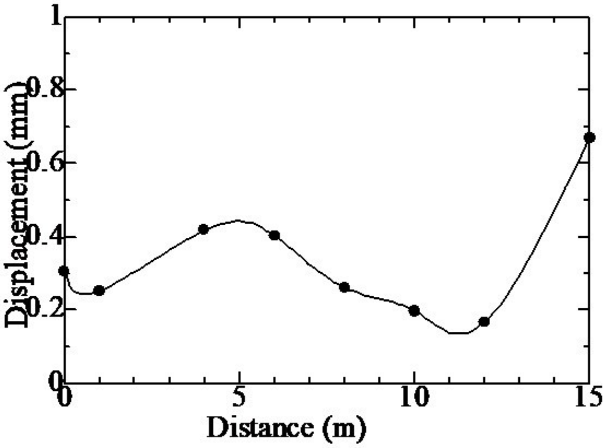


Figure 5.2.11: HS model for single basement (wall thickness 0.5m)

Summary of the MC Models Wall deformation

In the following table 5.2.1, the deformation of the MC Models have been summarized.

Table 5.2.1: Summary of the MC Models

Building Load(KN/m/m)	Adjacent Load(KN/m/m)	No. of Basement	Diaphragm wall thickness(m)	Deformation max (mm)
-288	0	2	1.265	6.79
-288	0	2	1	6.78
-288	0	2	0.5	6.76
-288	0	2	1.5	6.81
-288	0	1	1.265	7.48
-288	0	2	1.265	3.05
-288	-86	2	1.265	3.94
-288	-86	1	1.265	4.45

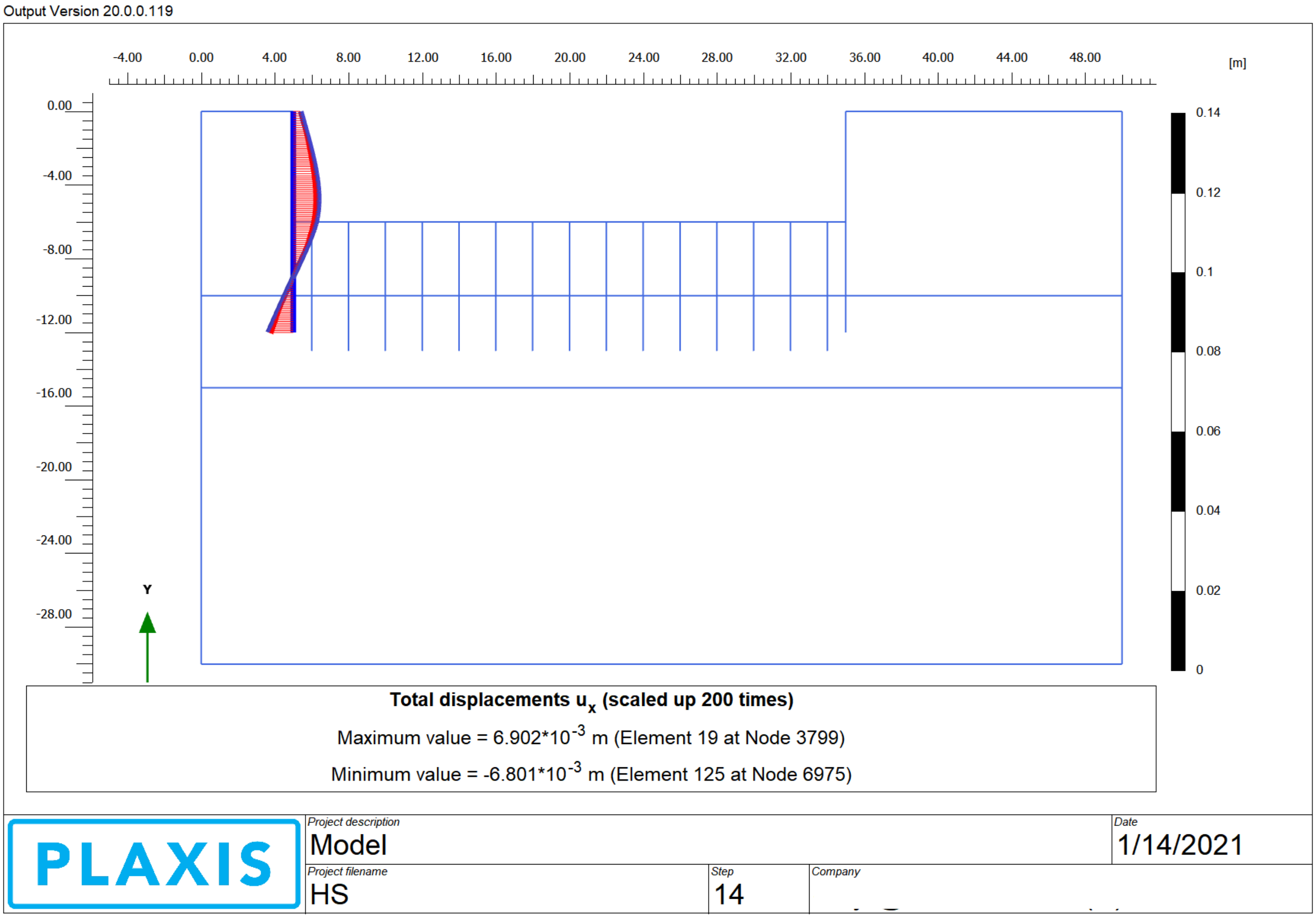
Summary of the HS Models Wall deformation

In the following table 5.2.2, the deformation of the HS Models have been summarized.

Table 5.2.2: Summary of the HS model wall deformation

Building Load(KN/m/m)	Adjacent Load(KN/m/m)	No. of Basement	Diaphragm wall thickness(m)	Deformation max (mm)
-288	0	1	1.265	4.061
-288	0	2	0.5	2.766
-288	0	2	1.5	2.79
-288	0	2	1	2.73
-288	-86	2	1.265	4.3
-288	0	2	1.265	2.73
-288	-86	1	1.265	2.77

5.3 Maximum Displacement in Graphs



Output Version 20.0.0.119

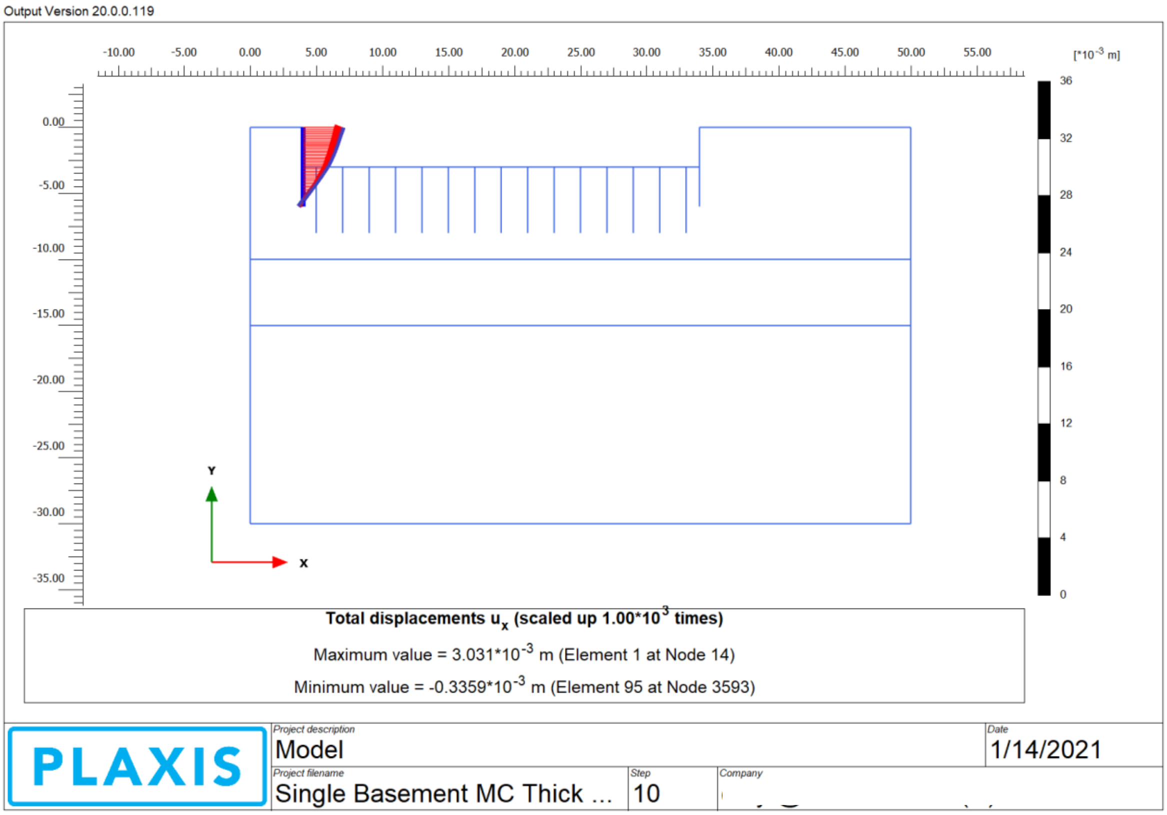
Total displacements u_x (scaled up 200 times)

Maximum value = $6.902*10^{-3}$ m (Element 19 at Node 3799)

Minimum value = $-6.801*10^{-3}$ m (Element 125 at Node 6975)

Project description Model			*Date* 1/14/2021
Project filename HS	*Step* 14	*Company*	

Figure 5.3.1: Maximum Displacement of Diaphragm wall in HS model (wall thickness 1m)



Total displacements u_x (scaled up 1.00×10^3 times)

Maximum value = 3.031×10^{-3} m (Element 1 at Node 14)

Minimum value = -0.3359×10^{-3} m (Element 95 at Node 3593)

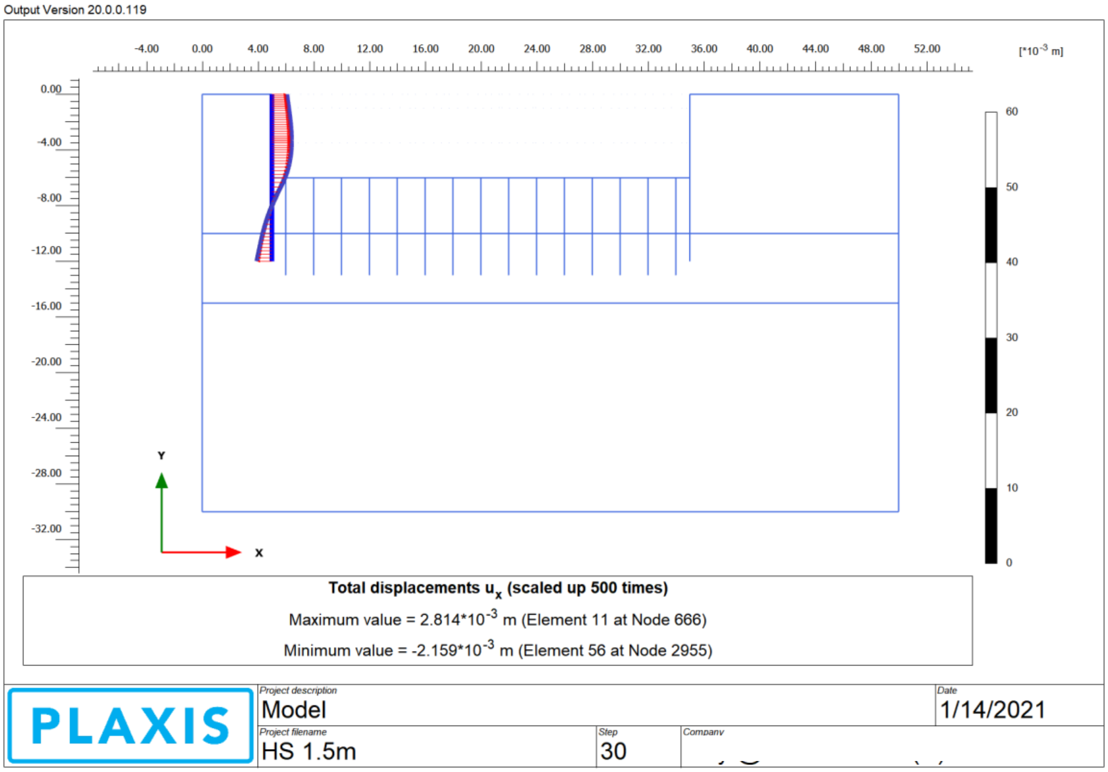
Project description: Model

Date: 1/14/2021

Project filename: Single Basement MC Thick ...

Step: 10

Figure 5.3.2: Maximum Wall displacement for MC Model (wall thickness 1.265m)



Total displacements u_x (scaled up 500 times)

Maximum value = 2.814×10^{-3} m (Element 11 at Node 666)

Minimum value = -2.159×10^{-3} m (Element 56 at Node 2955)

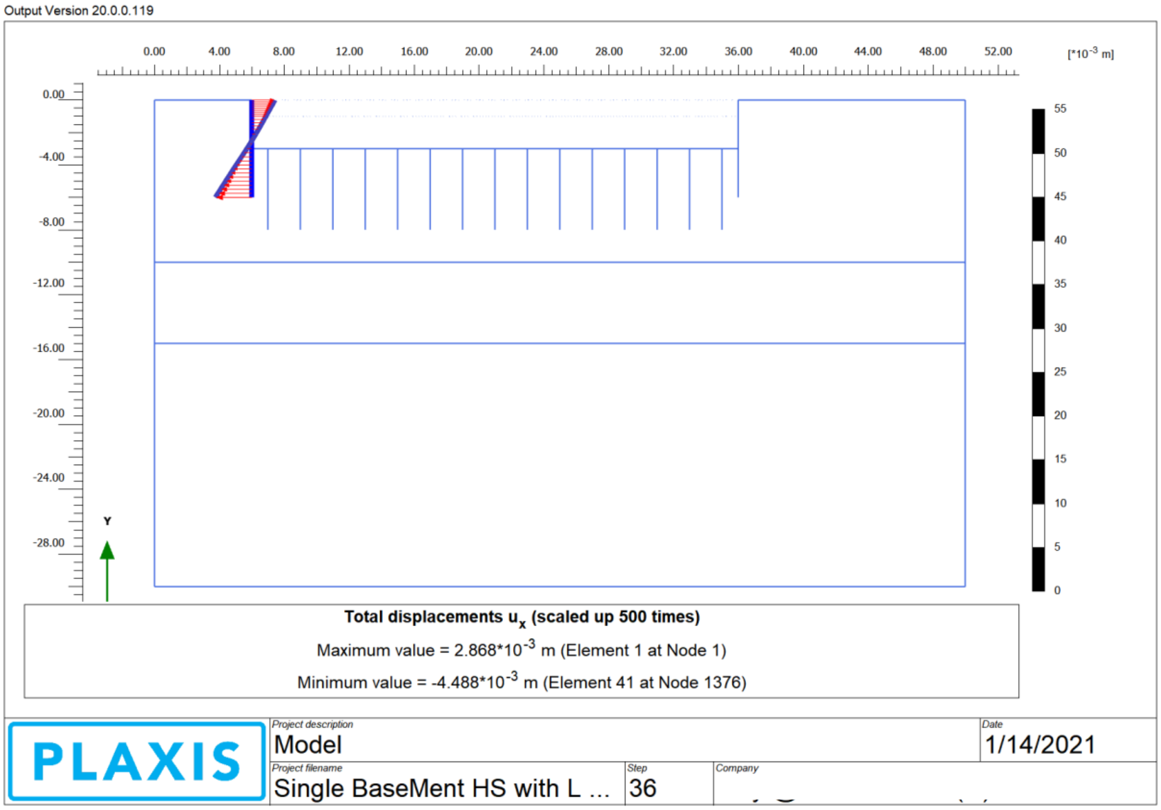
Project description: Model

Date: 1/14/2021

Project filename: HS 1.5m

Step: 30

Figure 5.3.3: Maximum Wall displacement for HS Model (wall thickness 1.5m)



Total displacements u_x (scaled up 500 times)

Maximum value = $2.868*10^{-3}$ m (Element 1 at Node 1)

Minimum value = $-4.488*10^{-3}$ m (Element 41 at Node 1376)

Project description: Model

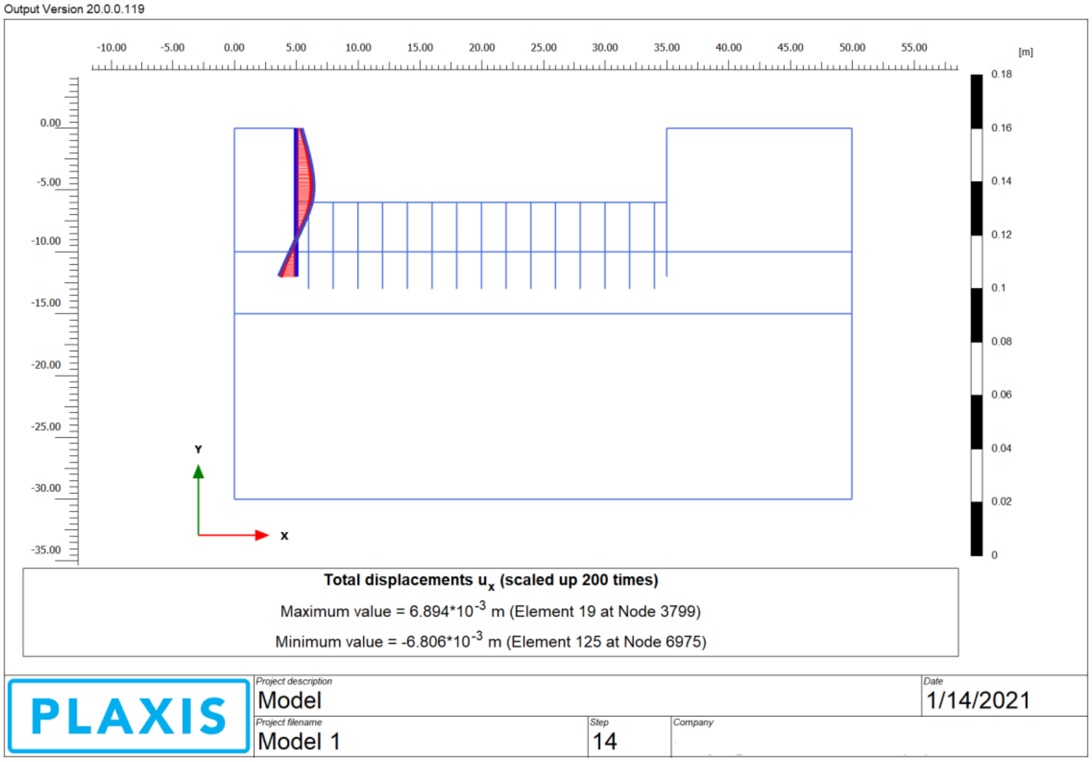
Date: 1/14/2021

Project filename: Single BaseMent HS with L ...

Step: 36

Company:

Figure 5.3.4: Maximum Wall displacement for HS Model with adjacent load (wall thickness 0.5m)



Total displacements u_x (scaled up 200 times)

Maximum value = $6.894*10^{-3}$ m (Element 19 at Node 3799)

Minimum value = $-6.806*10^{-3}$ m (Element 125 at Node 6975)

Project description: Model

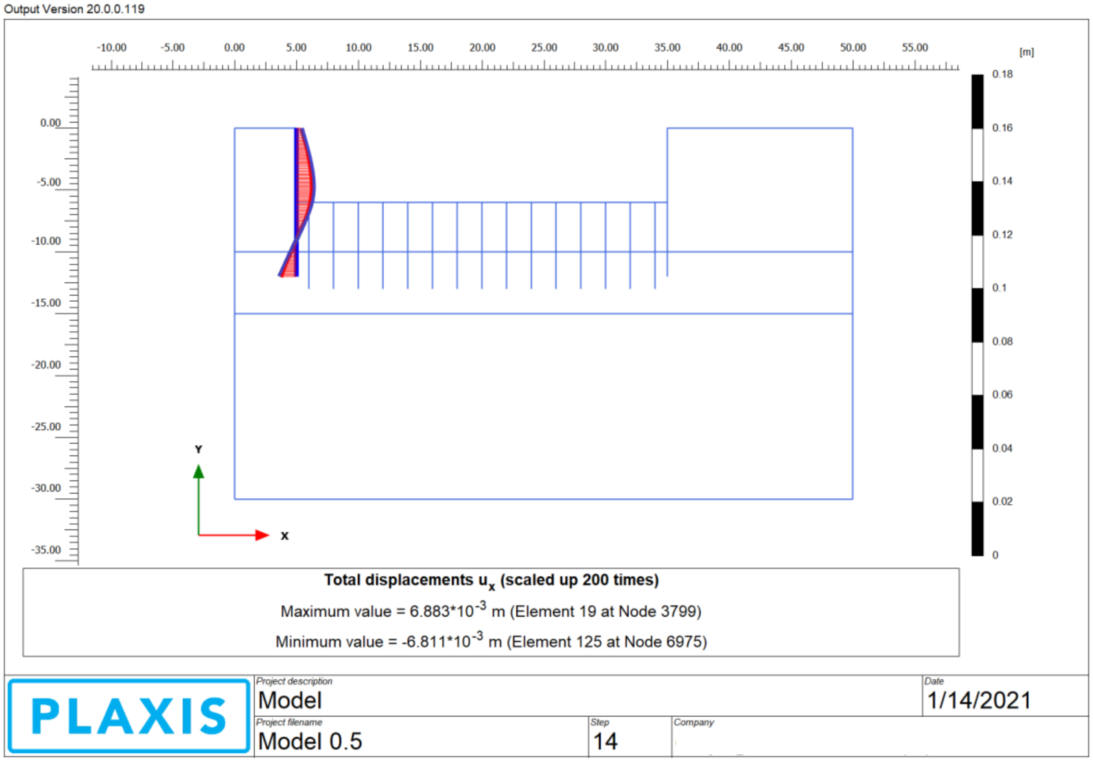
Date: 1/14/2021

Project filename: Model 1

Step: 14

Company:

Figure 5.3.5: Maximum Wall displacement for MC Model (wall thickness 1m)



Output Version 20.0.0.119

Total displacements u_x (scaled up 200 times)

Maximum value = $6.883 * 10^{-3}$ m (Element 19 at Node 3799)

Minimum value = $-6.811 * 10^{-3}$ m (Element 125 at Node 6975)

Project description: Model

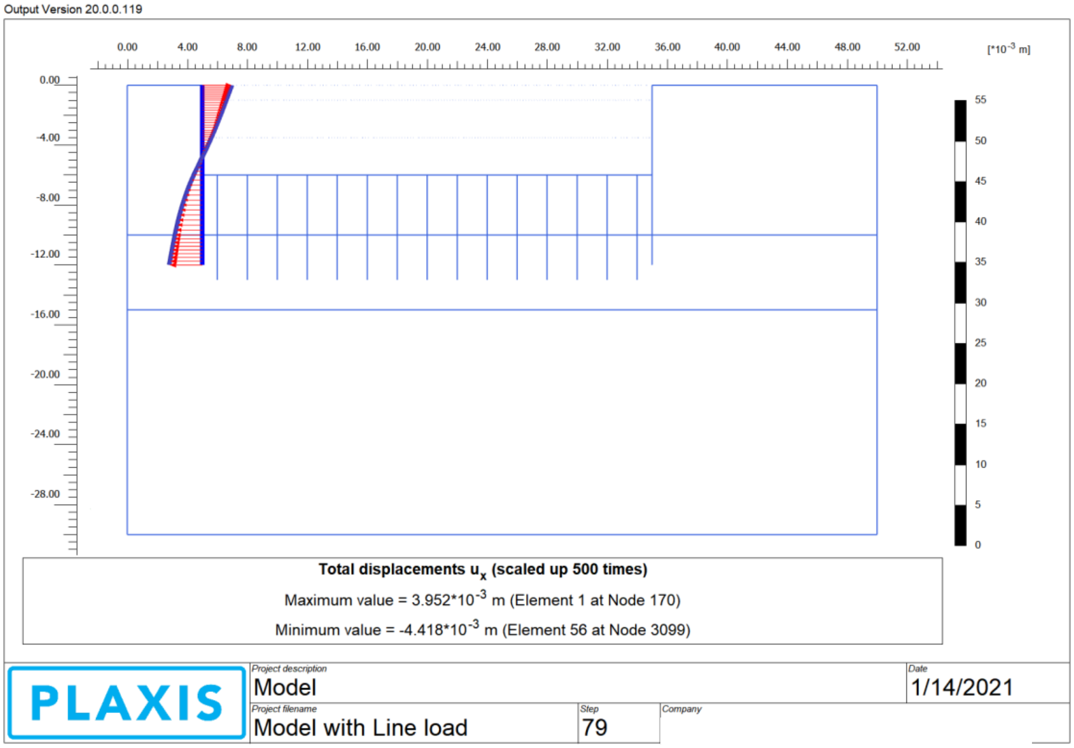
Date: 1/14/2021

Project filename: Model 0.5

Step: 14

Company:

Figure 5.3.6.: Maximum Wall displacement for MC Model (Wall thickness 0.5m)



Output Version 20.0.0.119

Total displacements u_x (scaled up 500 times)

Maximum value = $3.952 * 10^{-3}$ m (Element 1 at Node 170)

Minimum value = $-4.418 * 10^{-3}$ m (Element 56 at Node 3099)

Project description: Model

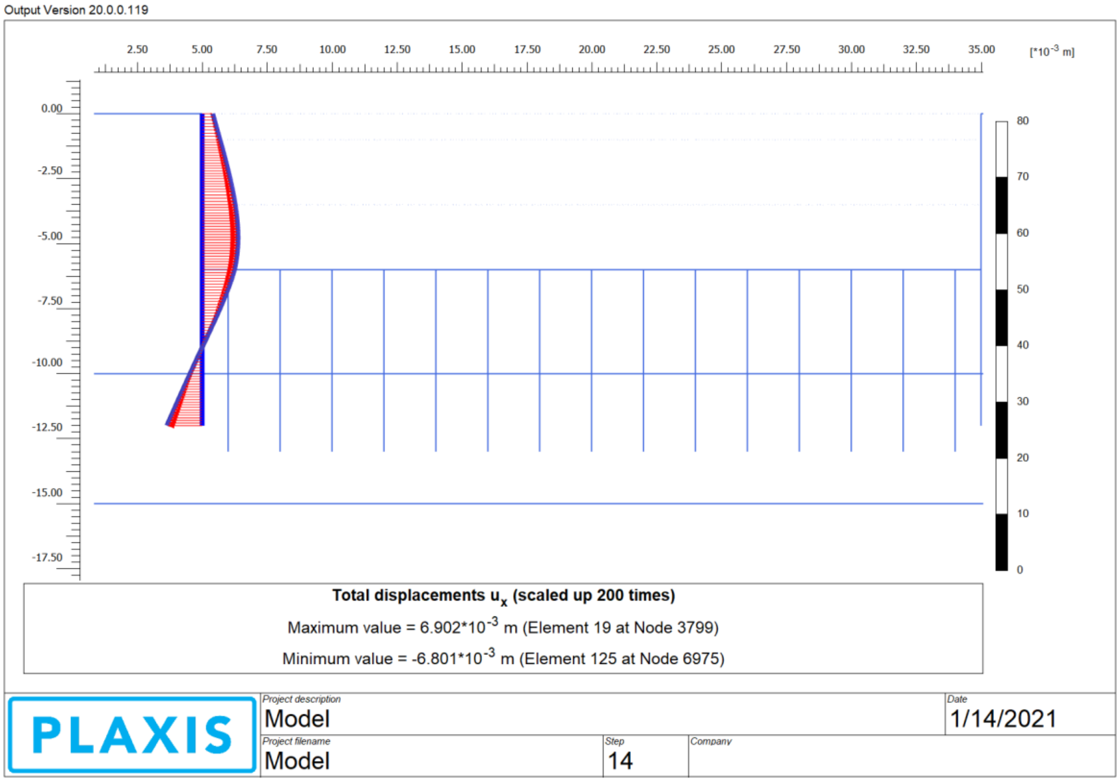
Date: 1/14/2021

Project filename: Model with Line load

Step: 79

Company:

Figure 5.3.7: Maximum Wall displacement for MC Model with adjacent load (wall thickness 1.265m)



Total displacements u_x (scaled up 200 times)

Maximum value = $6.902*10^{-3}$ m (Element 19 at Node 3799)

Minimum value = $-6.801*10^{-3}$ m (Element 125 at Node 6975)

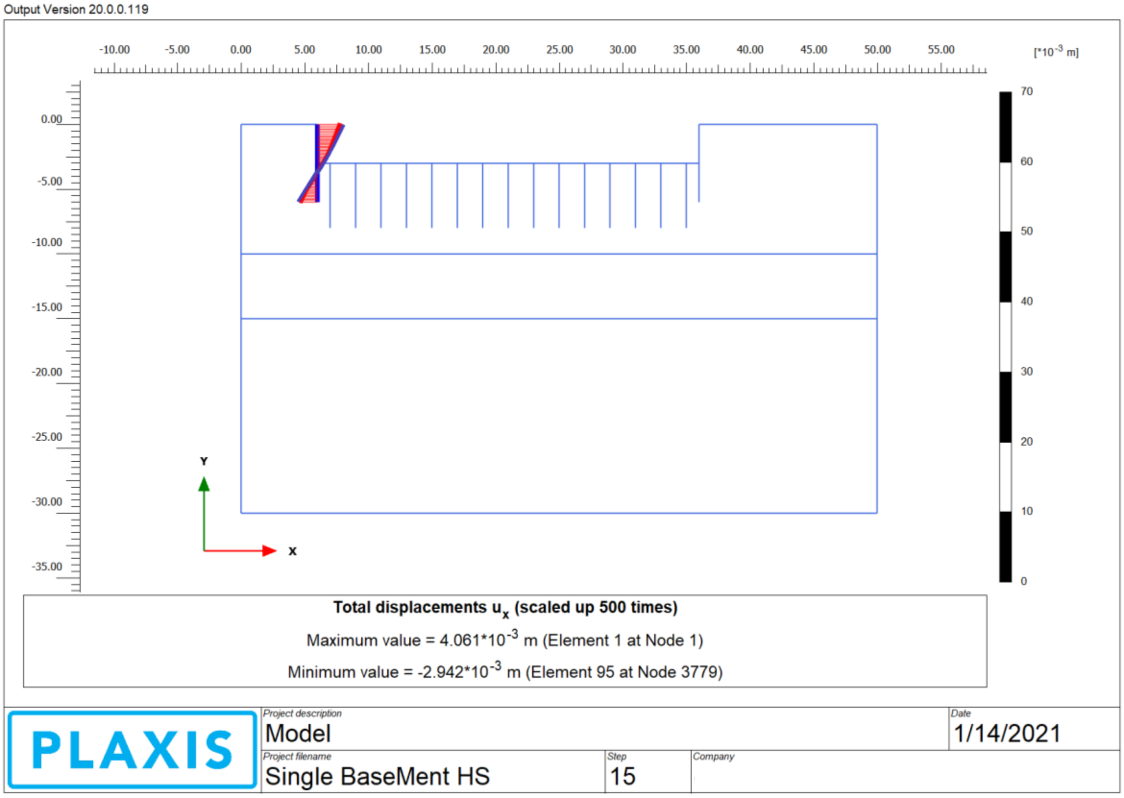
Project description: Model

Project filename: Model

Step: 14

Date: 1/14/2021

Figure 5.3.8: Maximum Wall displacement for MC Model (single basement)



Total displacements u_x (scaled up 500 times)

Maximum value = $4.061*10^{-3}$ m (Element 1 at Node 1)

Minimum value = $-2.942*10^{-3}$ m (Element 95 at Node 3779)

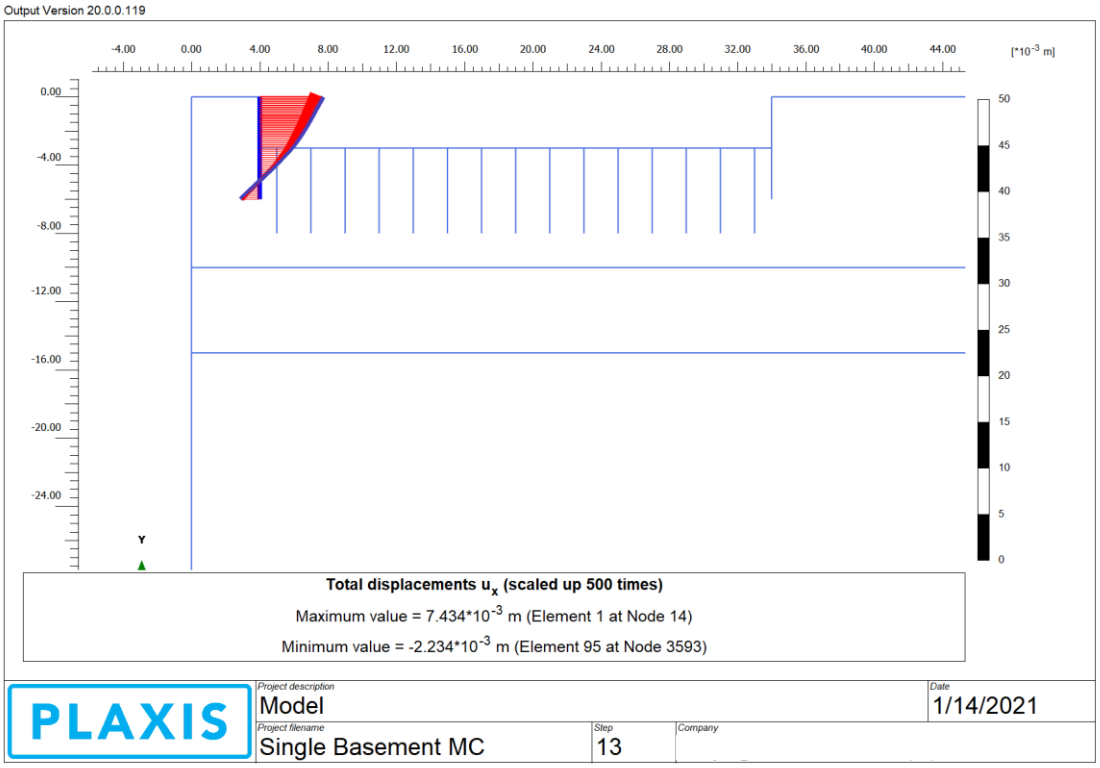
Project description: Model

Project filename: Single BaseMent HS

Step: 15

Date: 1/14/2021

Figure 5.3.9: Maximum Wall Displacement for HS model (single basement)


Output Version 20.0.0.119

Total displacements u_x (scaled up 500 times)

Maximum value = $7.434*10^{-3}$ m (Element 1 at Node 14)

Minimum value = $-2.234*10^{-3}$ m (Element 95 at Node 3593)

Project description: Model

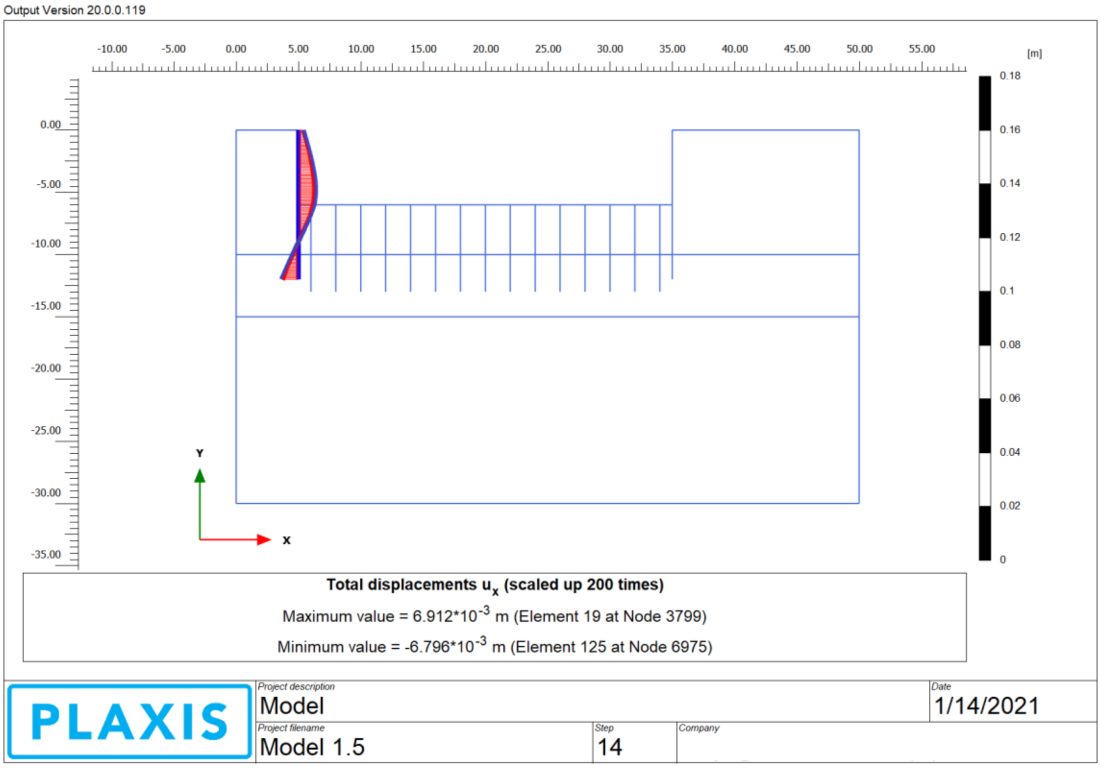
Date: 1/14/2021

Project filename: Single Basement MC

Step: 13

Company:

Figure 5.3.10: Maximum Wall displacement for MC Model (wall thickness 1m)


Output Version 20.0.0.119

Total displacements u_x (scaled up 200 times)

Maximum value = $6.912*10^{-3}$ m (Element 19 at Node 3799)

Minimum value = $-6.796*10^{-3}$ m (Element 125 at Node 6975)

Project description: Model

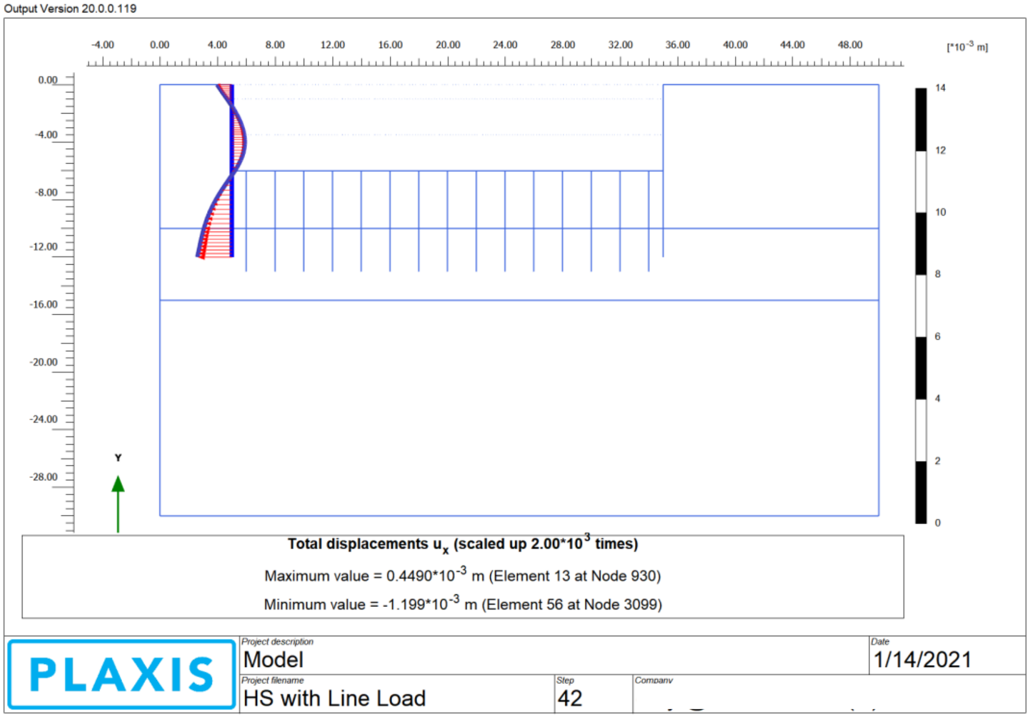
Date: 1/14/2021

Project filename: Model 1.5

Step: 14

Company:

Figure 5.3.11: Maximum Wall displacement for MC Model (wall thickness 1.5m)



Output Version 20.0.0.119

Total displacements u_x (scaled up $2.00*10^3$ times)

Maximum value = $0.4490*10^{-3}$ m (Element 13 at Node 930)

Minimum value = $-1.199*10^{-3}$ m (Element 56 at Node 3099)

Project description: Model

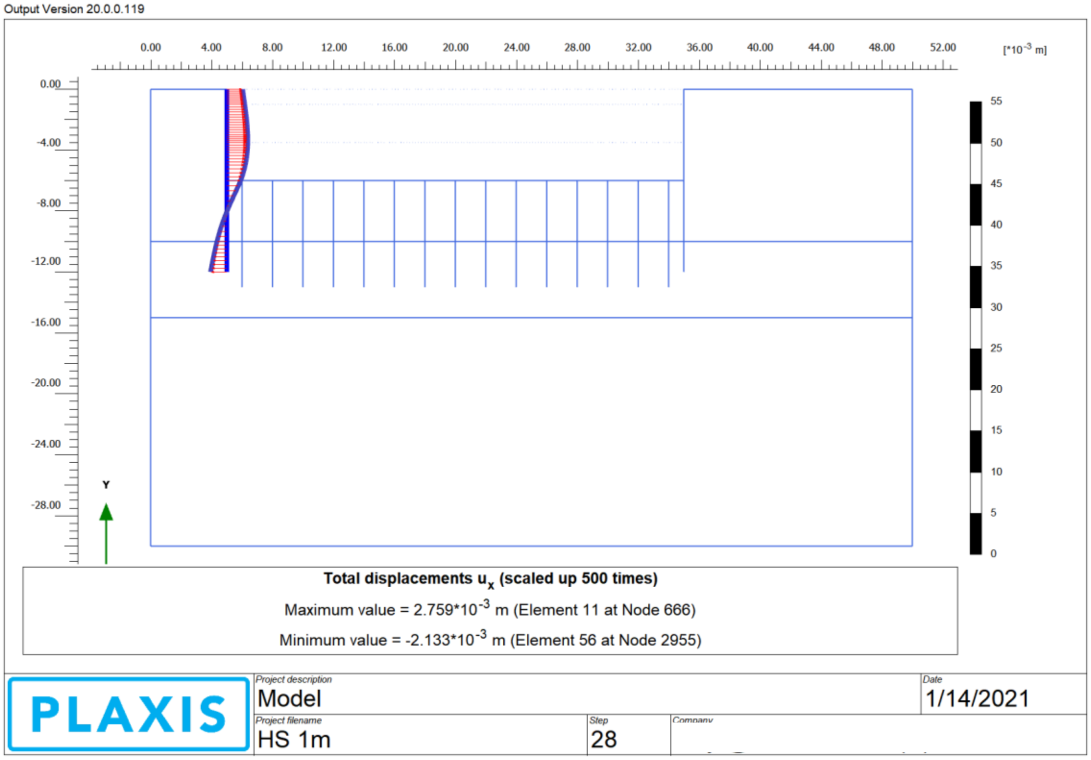
Date: 1/14/2021

Project filename: HS with Line Load

Step: 42

Company

Figure 5.3.12: Maximum wall displacement for HS Model with adjacent load (wall thickness 1m)



Output Version 20.0.0.119

Total displacements u_x (scaled up 500 times)

Maximum value = $2.759*10^{-3}$ m (Element 11 at Node 666)

Minimum value = $-2.133*10^{-3}$ m (Element 56 at Node 2955)

Project description: Model

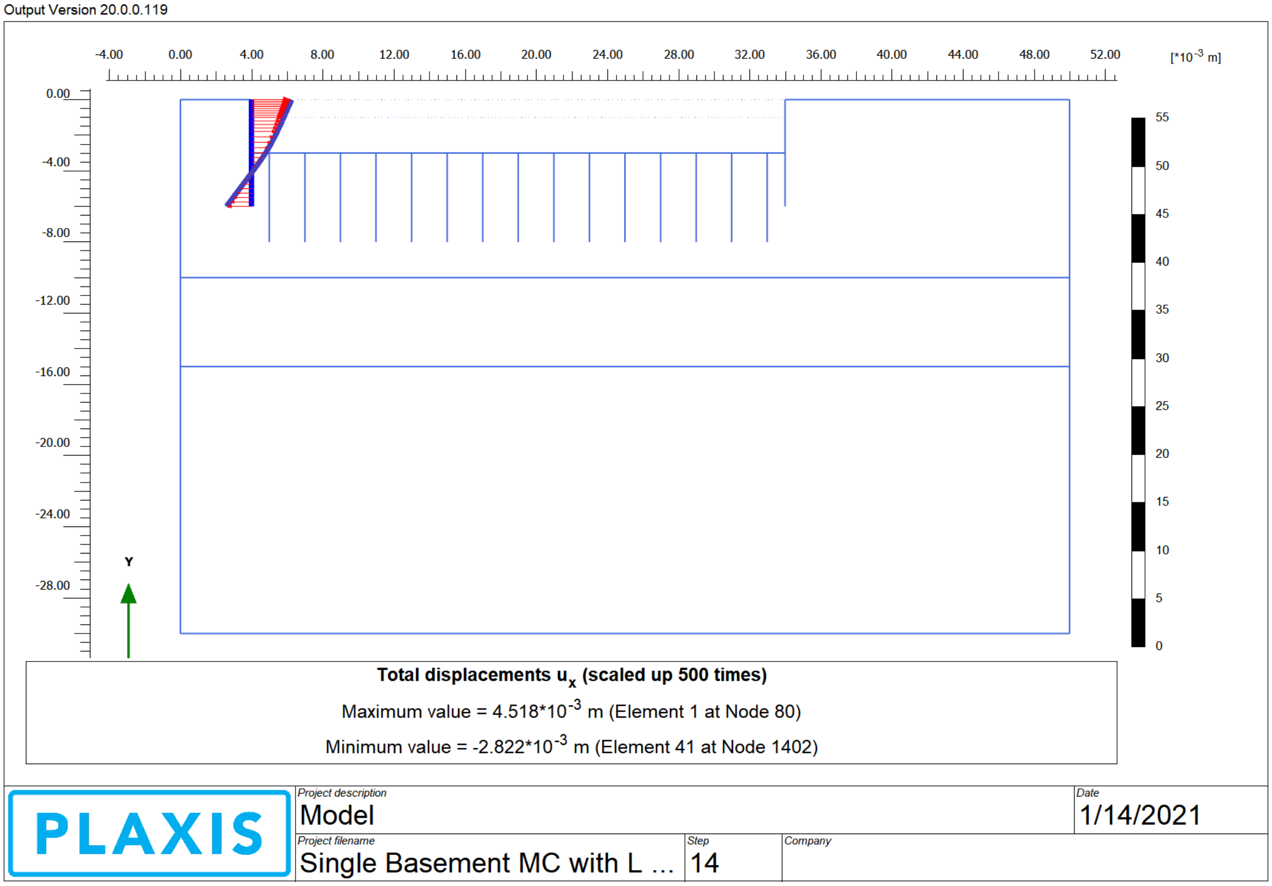
Date: 1/14/2021

Project filename: HS 1m

Step: 28

Company

Figure 5.3.13: Maximum wall displacement for HS Model with adjacent load (double basement)



Total displacements u_x (scaled up 500 times)

Maximum value = 4.518*10^{-3} m (Element 1 at Node 80)

Minimum value = -2.822*10^{-3} m (Element 41 at Node 1402)

Project description: Model

Date: 1/14/2021

Project filename: Single Basement MC with L ...

Step: 14

Company:

Figure 5.3.14: Maximum Wall displacement for MC model with adjacent load (Single basement)

5.4 Comparison

Here, the depth and displacement comparisons between HS model and MC model are given.

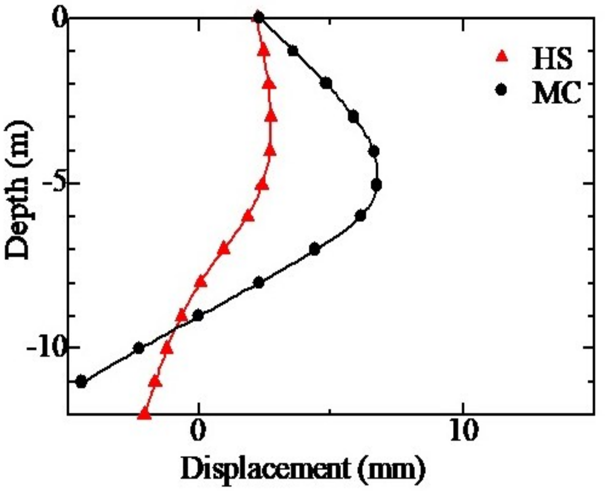


Figure 5.4.1: Depth vs displacement graph comparison between MC and HS model for double basement

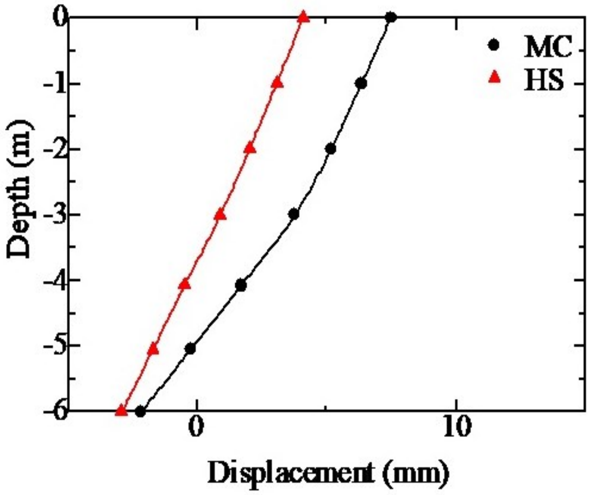


Figure 5.4.2: Depth vs displacement graph comparison between MC and HS model for single basement.

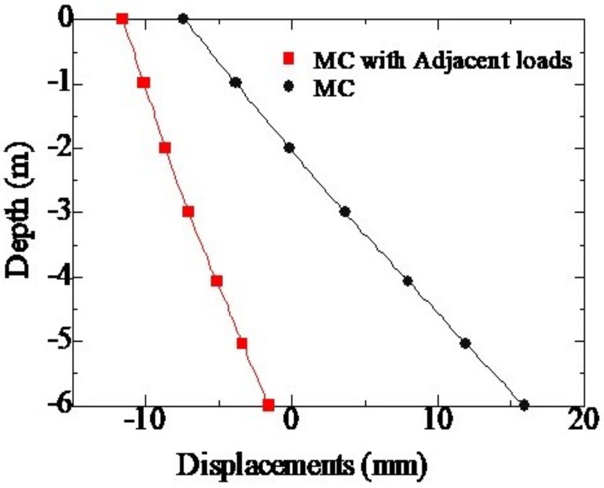


Figure 5.4.3: Depth vs displacement graph comparison between MC and HS model for single basement with adjacent load.

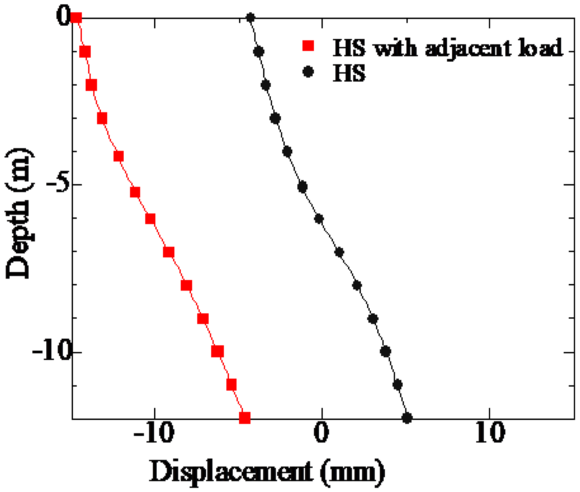


Figure 5.4.4: Depth vs displacement graph comparison between MC and HS model for double basement with adjacent load

5.4.1 Comparison with Available Literature

The data we have obtained from our model tests will be compared with the findings from available literature. In table 5.3.1-2 the maximum wall displacement has been shown for both MC and HS models. In table 5.3.3-4, we have compared our results with available literature for both MC and HS model and found them to be within acceptable margins.

In tables 5.3.5-6, the Maximum ground settlements have been summarized for both MC and HS model. These results have been compared with available literatures in tables 5.3.7-8 and have been found to be within acceptable margins.

Maximum wall Displacement for MC Model

Table 5.4.1: Maximum wall Displacement for MC Model

Building Load(KN/m/m)	Adjacent Load(KN/m/m)	No. of Basement	Diaphragm wall thickness(m)	Deformation max (mm)	Excavation Depth, He (m)	Maximum Lateral Wall deformation(%)
-288	0	2	1.265	6.79	6	0.1131
-288	0	2	1	6.78	6	0.1130
-288	0	2	0.5	6.76	6	0.1126
-288	0	2	1.5	6.81	6	0.1135
-288	0	1	1.265	7.48	3	0.2493
-288	0	1	1.265	3.05	3	0.1016
-288	-86	2	1.265	3.94	6	0.0656
-288	-86	1	1.265	4.45	3	0.1483

Maximum Wall Displacement for HS Model

Table 5.4.2: Maximum Wall Displacement for HS Model

Building Load(KN/m/m)	Adjacent Load(KN/m/m)	No. of Basement	Diaphragm wall thickness(m)	Deformation max (mm)	Excavation Depth, He (m)	Maximum Lateral Wall deformation(%)
-288	0	1	1.265	4.061	3	0.1354
-288	0	2	0.5	2.766	6	0.0461
-288	0	2	1.5	2.79	6	0.0465
-288	0	2	1	2.73	6	0.0455
-288	-86	2	1.265	4.3	6	0.0716
-288	0	2	1.265	2.73	6	0.0455
-288	-86	1	1.265	2.77	3	0.0923

Relative comparison with other studies for MC Models

Table 5.4.3: Relative comparison with other studies for MC models

Researcher Group	Basis of Comparison	Result from the literature	Result from the model	Comments
Clough and O'ourke (1990)	Lateral Displacement for Single Basement	6mm	5.7mm	Acceptable
Kung (2009)	Lateral Displacement Single Basement	6mm	5.7mm	Acceptable
Bentler(1998)	Lateral Displacement	5.7mm	5.7mm	Acceptable
Konstantakos (2008)	Lateral Displacement	6mm	5.7mm	Acceptable
Moorman (2004)	Lateral Displacement	26.1mm	5.7mm	Acceptable

Relative Comparison with other studies for HS Models

Table 5.4.4: Relative Comparison with other studies for HS models

Researcher Group	Basis of Comparison	Result from the literature	Result from the model	comments
Clough and O'ourke	Lateral Displacement for Single Basement	6mm	3.12mm	Acceptable
Kung	Lateral Displacement Single Basement	6mm	3.12mm	Acceptable
Bentler	Lateral Displacement	5.7mm	3.12mm	Acceptable
Konstantakos	Lateral Displacement	6mm	3.12mm	Acceptable
Moorman	Lateral Displacement	26.1mm	3.12mm	Acceptable

Maximum Ground Settlement for MC model

Table 5.4.5: Maximum Ground settlement for MC model

Building Load(KN/m/m)	**Adjacent Load(KN/m/m)**	**No. of Basement**	**Diaphragm wall thickness(m)**	**Maximum Ground settlement (mm)**	**Excavation Depth, He (m)**	**Maximum Ground Deformation (%)**
-288	0	2	1.265	38.5	6	.6416
-288	0	2	1	38.4	6	.6400
-288	0	2	0.5	38.4	6	0.6400
-288	0	2	1.5	38.5	6	0.6416
-288	0	1	1.265	13.2	3	.44
-288	0	1	1.265	13	3	.4333
-288	-86	2	1.265	14.3	6	.2383
-288	-86	1	1.265	13.1	3	.4366

Maximum Ground Settlement for HS model

Table 5.4.6: Maximum Ground Settlement for HS model

Building Load(KN/m/m)	**Adjacent Load(KN/m/m)**	**No. of Basement**	**Diaphragm wall thickness(m)**	**Maximum Ground settlement (mm)**	**Excavation Depth, He (m)**	**Maximum Ground Settlement(%)**
-288	0	1	1.265	7.79	3	.2596
-288	0	2	0.5	6.88	6	.1146
-288	0	2	1.5	6.86	6	.1143
-288	0	2	1	6.86	6	.1143
-288	-86	2	1.265	16.5	6	.275
-288	0	2	1.265	6.87	6	.1145
-288	-86	1	1.265	9.4	3	.3133

Relative Comparison with other studies for MC model

Table 5.4.7: Relative Comparison with other studies for MC model

Researcher Group	**Basis of Comparison**	**Result from the literature**	**Result from the model**	**comments**
Clough and O'ourke (1990)	Maximum Ground Settlement	9mm	25.92mm	Not acceptable
Kung (2009)	Maximum Ground Settlement	6mm	25.92mm	Not acceptable
Bentler (1998)	Maximum Ground Settlement	16.5mm	25.92mm	Not Acceptable
Konstantakos (2008)	Maximum Ground Settlement	12mm	25.92mm	Not Acceptable
Moorman (2004)	Maximum Ground Settlement	33mm	25.92mm	Acceptable

Relative Comparison with other studies for HS model

Table 5.4.8: Relative Comparison with other studies for HS model

Researcher Group	**Basis of Comparison**	**Result from the literature**	**Result from the model**	**comments**
Clough and O'ourke (1990)	Maximum Ground Settlement	18mm	8.73mm	Acceptable
Kung (2009)	Maximum Ground Settlement	12mm	8.73mm	Acceptable
Bentler (1998)	Maximum Ground Settlement	33mm	8.73mm	Acceptable
Konstantakos (2008)	Maximum Ground Settlement	24mm	8.73mm	Acceptable
Moorman (2004)	Maximum Ground Settlement	66mm	8.73mm	Acceptable

6 CONCLUSION & SUMMARY

Finally, in the last chapter we conclude with the result and discussion from what we have learned from this thesis project. We have graphically represented the maximum displacement observed by the retaining wall in PLAXIS for both MC and HS model with varying basement levels, wall thicknesses and adjacent loads.

6.1 Conclusion

This research compares the effect of diaphragm wall for deep foundations in the context of Bangladesh using numerical analysis. Moreover, this research has investigated the ground response as well as diaphragm wall horizontal deflections for deep excavations. Initially, MC model has been used in the finite element code PLAXIS 3D. Later, an attempt has been made to see if it is possible to obtain better predictions using a more advanced HS model based.
A parametric study on a simplified excavation and detailed analyses of two additional case histories investigated the performance of deep excavations and the influence of several critical aspects.The studies shed light on acomplex soil structure interaction problem, and can be used to design and analyze deep excavationsmore effectively. There is an in-depth discussion and conclusion for each chapter.Throughout this chapter, we summarize these conclusions for a more complete understanding.

In this study, the results are compared with the available literatures and based on the comparison, different color codes are used to show the harmony of the results with the available literatures. In spite of the fact that the advancements available through cheap computer hardware and the improvement of modeling techniques have made numerically modeling a necessity for routine design. The advanced models such as the HS model remain unpopular due to lack of necessary advanced tests (at least the drained tri axial test), especially in the commercial environment where these tests are considered not only time-consuming but expensive. Besides, because of the lack of field calibration to obtain confidence in the method and especially the input soil stiffness, it is understandable that the simple MC model remains a popular choice.

6.2 Summary

- Diaphragm wall have shown fewer bulging effects.
- In general, HS model shows less displacement and ground settlement compared to MC model.
- Ground settlement and wall displacements show harmony with the available literature.
- Enough variations of Diaphragm wall models of single and double basement with and without adjacent loads by using PLAXIS 2D with different parameters of soil.
- The maximum lateral deflection of Diaphragm wall towards the excavation measured is generally within 0.2% of excavation depth. And ground settlement should be 0.3% of excavation depth.
- No sign of structural damage at the joint between the Diaphragm wall and the basement slab.
- An approximate cost estimation for the various models. The cost was efficient for constructing such as structures
- Diaphragm wall with thickness 0.5m of single basement is most cost efficient and satisfactory.
- Diaphragm wall is recommended as the retaining structure in Bangladesh for future projects.

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