Influence of Building Load on Braced Excavation of Dhaka Subway

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PROJECT REPORT APPROVAL

The thesis titled **Influence of Building Load on Braced Excavation of Dhaka Subway** submitted by Tamanna-E-Hafiz Maisha (160051003), Fahim Shahriar Hassan (160051081), Tahmid Shahriar Fahim (160051014) has been found as satisfactory and accepted as partial fulfilment of the requirement for the Degree Bachelor of Science in Civil Engineering.

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DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Professor Dr. Hossain Md. Shahin and this work has not been submitted elsewhere for any purpose.

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DEDICATION

Our combined thesis work is dedicated to our respective parents, family and friends. We also express our gratitude to our respected supervisor Professor Dr. Hossain Md. Shahin. It is a small token of appreciation towards all those who supported us throughout our endeavour and encouraged us to continue our work until the end.

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

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ABSTRACT

Keywords: *Braced Excavation, Soil Parameters, Finite Element Method, Plaxis-2D, Surface Settlement, Numerical Analysis, Hardening Soil Model, Building Foundation.*

The stability of a braced excavation and nearby ground surface depends primarily on the properties of struts (number of struts, stiffness of a strut and their vertical and horizontal spacings), strut prestressing, different combination of strut arrangement, properties of the retaining wall (depth of penetration below the final cut level and stiffness), foundation of nearby structures, excavation width and water table level. Hence it is required to consider the impact of the above factors on wall and ground movement of braced excavation to determine the optimum results in terms of force in the struts, moment developed in the wall, deflection of the wall and the displacement of the adjacent ground surface. A number of research work has been carried out in the past and are still ongoing to evaluate the effect of excavation component properties on braced excavation but none of these works emphasized the effect of nearby building foundation on Braced excavation. Hence in this thesis book, we will determine the influence of building foundation on Braced Excavation of Dhaka Subway considering groundwater drawdown and Slip elements along diaphragm wall.

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CHAPTER 1: INTRODUCTION

1.1. General

For the development and advancement of infrastructures such as underground transportation frameworks, storm cellars, water pipelines and other structures in a thickly populated and congested city like Dhaka, it is imperative to utilize the underground space effectively. It is believed that the demand for significant underground excavation will increase steadily with the increase of population. Hence, an appropriate plan strategy is in demand for deep, secure and temperate excavation.

There are two fundamental types of excavations: Open excavation and Braced excavation. In Open excavations stability is achieved by providing stable side slopes whereas in Braced excavation stability is obtained by laterally supporting the straight vertical faces by a sheeting and bracing system until the structure is built.

In recent times, braced excavation is predominantly utilized for construction of underground facilities in all types of soil since:

a. It is less costly and constructions are moderately simple
b. Minimizes excavation area
c. Ensures that the movements of soil will not cause any harm or damage to neighbouring structures

The design of braced excavation in soft soil is based on two distinct, yet interrelated requirements:

(1) Adequate support system required for achieving excavation stability,
(2) Control of ground movements without adversely affecting the adjoining structures

Deep excavations with vertical sides require lateral supports to prevent cave-in of the soil and to secure the adjacent zones against ground subsidence and lateral movement of the subsoil. When excavations are shallow and sufficient space is accessible, the sides of the excavation can be slanted at a secure angle to ensure stability. But in case of built-up regions, there may not be satisfactory space for providing safe slopes. Moreover, it becomes uneconomical to provide safe slope because of huge amounts of soil involved.

There are different sorts of earth retaining structures utilized for braced excavation project. Selection of earth-retaining structures incorporate type and size of the wall which depends upon many factors such as soil conditions, ground water table, depth and size of excavation project, site condition etc. Cost & safety of the construction are directly influenced by the selection of the type and size of earth retaining structures.

1.2. Background

Dhaka, the capital of Bangladesh is one of the largest growing megacities in the world. Continuous population increase is inflicting serious problems like stagnant traffic conditions throughout the city. Outdated traffic manoeuvring methods, lack of law-abiding tendencies, narrow road spaces are the main causes of elongated traffic jam situations. Economic losses that are sustained from these congestions are beyond negligence. It is also resulting in serious air pollution and noise pollution and thus worsens the overall environmental condition.

Bangladesh Government is planning to construct subway to improve the traffic condition of Dhaka city.

The underground depth of these subways will be from 20 to 40 meters. Sophisticated Tunnel Boring Machine (TBM) will be used to construct these subways so that during the implementation of the project, people will not suffer due to soil digging.

1.3. Study Area

The study area of this research is demonstrated in Fig. 1.1 which is located
Mirpur 14. The Coordinate (UTM) of the location is N: 2,634,311, E: 233,796 , Z: 6.350

Figure 1.1: Study area (Mirpur 14) from google map marked by a red circle

1.4. Objectives:

The aim of this study is:

a. To evaluate the effect of nearby building load on excavation
b. To evaluate the effect of deep foundations of nearby building on excavation
c. To evaluate the wall displacement induced by the existing structure and braced excavation

CHAPTER 2: LITERATURE REVIEW

2.1 Past Research Works:

There are many studies related to excavation project:

a. Murphy, et al. used an undrained, nonlinear pseudo-elastic model for curved clay response to braced excavation at the Bowline Point site. In their model Sheet-pile installation was not explicitly modelled; rather the wall was placed in the mesh with no effects on adjacent soil.

b. Richard J. Finno, Indra S. Harahap and Paul J. Sabatini in 1991 conducted analysis of braced excavations with coupled finite element formulations. The purpose of their study is to evaluate the relative effects of commonly-made assumptions on computed deformation behaviour of braced excavations.

c. Dao Thi Van Tram, Le Trang Nghia and Nguyen Cong Oanh in 2014 conducted a study of Braced Excavation Using Steel Sheet Pile Wall in Thi Vai Soft Clay in Vietnam. Their study is focused on stress-strain displacement behaviour with field monitoring of lateral displacement of the wall and settlement of the surrounding area.

d. Changjie Xu et al. in 2013 did research about Characteristics of Braced Excavation under Asymmetrical Loads.

e. Yuan Hai Li, Ping Liu, Ji Qiang Liu, Xue Feng Han conducted a study in 2011 of Stability and Safety Analysis of Braced Excavation for Subway Station during Construction under the Condition of Side Slope.

f. Bose and Som in 1998 used finite element method for parametric study of a braced cut in clayey soil where it was found that the performance of a braced cut is affected by the width of the excavation, strut prestressing force and the wall length.

g. Lim et al. in 2010 evaluated the performance of the most commonly used constitutive models modified Cam clay model, hardening soil model, hardening soil small strain model, fi = 0 Mohr–Coulomb model and the undrained soft clay model) of clay for the analysis of a deep excavation under undrained condition. It was found that for / = 0, Mohr–Coulomb model with Eu/su = 500 (Eu and su are the undrained elastic modulus and shear strength of the clay, respectively), can result in good prediction for the wall deflection at the final stage of an excavation, but none of the other models can predict the ground settlement profiles properly.

h. Based on a numerical study, Chowdhury et al. in 2013 proposed the range of design parameters for a braced excavation in cohesionless soils. the optimum values of the design parameters (position of struts, embedment depth of the wall, thickness of the wall and the strut stiffness) for braced excavation in clayey soil have been determined by using the numerical tool, FLAC. The results of the present numerical model are compared with the observed values obtained from a case study on braced excavation in a clayey soil. The water table is considered at the ground level and soil is modelled considering Mohr- Coulomb model. A close agreement between the result as obtained from the present numerical study and that measured in the field has been observed. On the basis of the parametric studies done on two different clayey soil profiles, it is found that the most effective design of excavation in a clayey soil can be done when the embedment depth of the wall, the thickness of the wall and the strut stiffness are kept within the range of (80–100)% of the depth of excavation (6–7)% of the depth of excavation and (5–25) 9 105 kN/m/m, respectively. The top strut can be kept at a height of (2–3) m below the ground level without endangering the safety of the system

i. Wang et al. in 2010 collected and analyzed 300 case histories of wall displacements and ground settlements due to deep excavations in Shanghai soft soil and found that the ratio of the maximum ground surface settlement and the maximum lateral displacement of a wall lie in between 0.4 and 2.0. Also, it was found that wall displacement decreases with increasing system stiffness.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Soil displacement prediction adjacent to braced excavations is critically vital, especially in urban areas, to prevent any potential damage of adjacent buildings, service lines, and other infrastructure facilities. As excavation progresses, movements of encompassing ground and wall displacements take place. Thus, prediction of soil and wall deformations is necessary to anticipate potential damage in surrounding buildings and other underground facilities. Recently, emphasis has been placed on the study of deformation behaviour of soil and wall during braced excavation.

Two common techniques to investigate deformation behaviour of braced excavation are:

a. Numerical analysis using FEM
b. Empirical or semi empirical methods using field measurements or a published database.

In this thesis, Finite Element method will be used to predict and determine settlement prediction through braced excavation. To realistically predict the deformation of soil as well as the factor of safety of excavation finite element method is a powerful tool for the analysis of excavation problems.

3.2 Finite Element Model

With different analytical method, it cannot be solved irregular structures accurately. But using the Finite Element Method (FEM), one can solve irregular structures accurately and easily. The *finite element method* (FEM), or *finite element analysis* (FEA), is based on the idea of building a complicated object with simple blocks, or, dividing a complicated object into small and manageable pieces.

It is a computational technique used to find approximate solutions of boundary value problems in engineering. These boundary value problems most often represent a physical structure. The analysis shows whether a product will break, wear out or work the way it was designed.

According to O. O. Ochoa and J. N. Reddy, Finite Element Analysis of Composite Laminates, 2nd ed. (1992) FEM has two features that no other method shares-

a. The domain of the problem is represented by a collection of simple sub-domains, called finite elements. The subdivision of a domain into elements is termed finite element discretization. The collection of finite elements is called finite element mesh.
b. Over each finite element, the solution of the governing equations is approximated by a linear combination of undetermined parameters and preselected approximation functions, almost always polynomials. Since the solutions is represented by polynomial on each element, a continuous approximation of the solution of the whole can be obtained only by imposing the continuity of the element solution and possibly its derivatives, at element interfaces. The procedure of putting the elements together is called the assembly of elements.

The algebraic equations relating physical quantities at selective points, called nodes. (J. N. Reddy, An Introduction to the Finite Element Method, 3rd ed.(2005))., The relationship between nodal forces and nodal displacements from equilibrium conditions at nodes in element analysis is expressed in terms of a stiffness matrix for the element. A system of equilibrium equations come from assembling all individual elements to form the complete structure from the stiffness matrices.

FEM is widely used in case of geotechnical purposes because of the following reason-

a. **Modeling:** FEM allows for easier modeling of complex geometrical and irregular shapes. Because the designer is able to model both the interior and exterior, he or she can determine how critical factors might affect the entire structure and why failures might occur.

b. **Adaptability:** FEM can be adapted to meet certain specifications for accuracy in order to decrease the need for physical prototypes in the design process. Creating multiple iterations of initial prototypes is usually a costly and timely process. Instead of spending weeks on hard prototyping, the designer can model different designs and materials in hours via software.

c. **Accuracy:** While modelling a complex physical deformity by hand can be impractical, a computer using FEM can solve the problem with a high degree of accuracy.

d. **Boundaries:** With FEM, designers can use boundary conditions to define to which conditions the model needs to respond. Boundary conditions can include point forces, distributed forces, thermal effects (such as temperature changes or applied heat energy), and positional constraints.

e. **Visualization**: Engineers can easily spot any vulnerability in design with the detailed visualizations FEM produces, then use the new data to make a new design.

3.2.1. Functional Steps of FEM:

a. Establishment of stiffness relations for each element. Material properties and equilibrium conditions for each element are used in this establishment.
b. Enforcement of compatibility, i.e., the elements are connected.
c. Enforcement of equilibrium conditions for the whole structure, in the present case for the nodal points.
d. By means of 2. And 3. the system of equations is constructed for the whole structure. This step is called assembling.
e. In order to solve the system of equations for the whole structure, the boundary conditions are enforced.
f. Solution of the system of equations.

There are several FEM software packages like-
a. *ANSYS* (General purpose, PC and workstations)
b. *SDRC/I-DEAS* (Complete CAD/CAM/CAE package)
c. *NASTRAN* (General purpose FEA on mainframes)
d. *ABAQUS* (Nonlinear and dynamic analyses)
e. *COSMOS* (General purpose FEA)
f. *ALGOR* (PC and workstations)
g. *PLAXIS (*Soil Model Simulation)
h. *PATRAN* (Pre/Post Processor)
i. *HyperMesh* (Pre/Post Processor)
j. *Dyna-3D* (Crash/impact analysis)

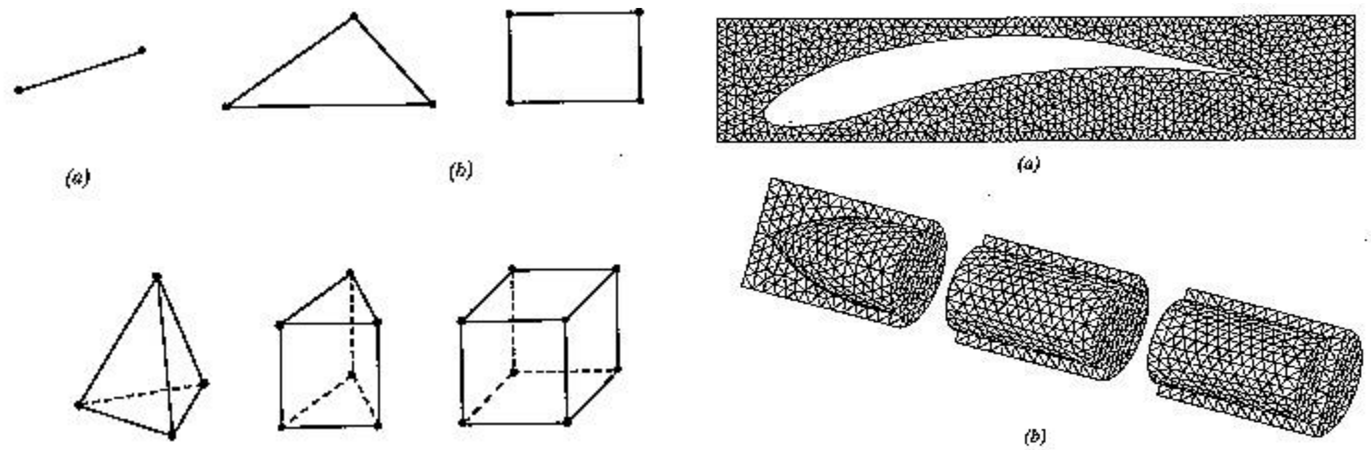


Fig 3.2.1. 1 Basic Finite Element

For this thesis, PLAXIS software is used to carry out 2-Dimensional Soil Model simulation.

3.3 Plaxis Software:

In this research, PLAXIS 2D (software version 2019) has been used to carry out two-dimensional finite element analysis by simulating & analysing soil model. Plaxis (Plane strain and axial symmetry, indicating the geometric types handled in the original code) is a computer programme that performs finite element analyses (FEA) within the realm of geotechnical engineering, including deformation, stability and water flow. Plaxis is capable of handling a wide range of geotechnical problems such as deep excavations, tunnels, and earth structures such as retaining walls and slopes. There are some specific reasons for selecting this software:

a. Fast and efficient model creation.
b. Realistic assessment of stress and displacements
c. Versatile post processing.
d. Ease to learn and use even for complicated models
e. Specialized in geotechnical modelling, hence, it has built in elements for soil modelling

3.3.1 Functions of Plaxis Software:

Mainly the software allows the automatic generation of six or fifteen node triangle plane-strain elements for the soil, and three or five node beam elements for the footing.

a. Initial step for analysing the model is to create the geometry of the model.
b. Put the geometry characteristics such as width and height of the excavation as well as the soil parameter.
c. Then design & simulate the model with mesh generation

3.4. Soil Model:

Soil ground is divided into a certain number of elements with 15 nodes. Since the excavation is not circular/cylindrical hence plane strain condition has been considered in lieu of Axisymmetric.

3.4.1. Soil Constitutive Model:

There exist a wide range of models which have been recommended in recent years to represent the stress-strain and failure behaviour of soils. Such as:

a. Mohr-Coulomb
b. (Modified) Cam-Clay
c. Hyperbolic Model
d. Plaxis Hardening Soil Model
e. Hyperelastic Model
f. Hypoelastic Model
g. Viscoplasticity Theory for 2D Ground Model

For this thesis, we will use Hardening Soil model, Soft Soil Model and Cement model.

3.4.1.1 HS Small Model:

Experimental evidence indicates that the plastic deformation in soils starts from the early stages of loading. To capture such a behavior in a constitutive model the typical elasto-perfect plastic models are not adequate. To simulate such behavior constitutive models that utilize a hardening law after initial yielding are required. The main feature of the Hardening Soil model (Schanz and Vermeer 1999) is its ability to simulate hardening behavior. The hardening in this model is divided to deviatoric and volumetric hardenings by utilizing a shear and a cap yield surface. The model also uses nonlinear elastic behavior that relates the elastic modulus to the stress level.
The model utilizes three yield surfaces that includes deviatoric (shear), volumetric (cap) and tension cut off. The hardening in this mechanism is attributed to plastic distortion by direct appearance of the plastic deviatoric strain in the definition of yield function.

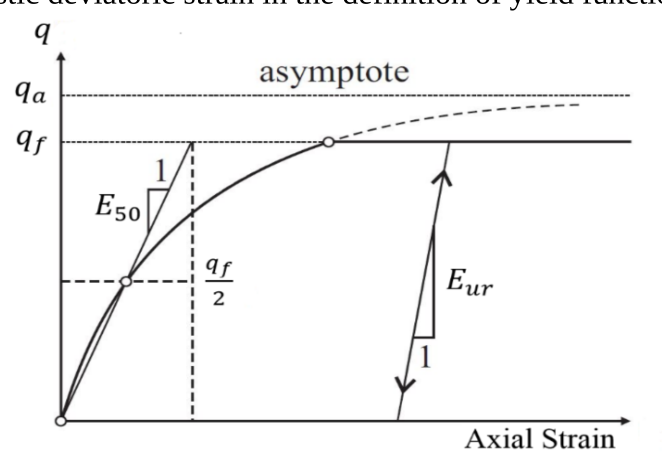


Fig 3.4.1. 1 Hyperbolic stress-strain curve in a drained compression triaxial test

3.4.1.2. Soft Soil Model

The Soft Soil model is a Cam-Clay type model especially meant for primary compression of near normally consolidated clay-type soils.

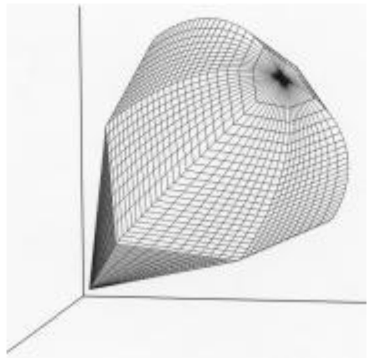


Fig 3.4.1. 2 Soft Soil Model

Some features of Soft Soil Model:

a. Stress dependent stiffness
b. Distinction between primary loading, unloading-reloading
c. Memory for pre-consolidation stress
d. Failure behaviour according to Mohr-Coulomb criterion

3.5. Soil Plug:

The behaviour of preventing or partially restricting the entering of additional soil and water inside excavation zone is referred to as “plugging” and soil plug is used for this purpose below excavation zone. The length of soil plug is less than the pile penetration depth. Here 2m soil plug is used by applying Mohr-Coulomb material model.

3.6. Geotechnical Parameters

Before a geotechnical analysis can be performed, the parameters values that is needed in the analysis must be determined for perfection.

3.6.1 Unit Weight (γ)

Unit weight of a soil mass can be defined as the ratio of the total weight of the soil to the total volume of the soil. Unit weight, γ, is usually determined in the laboratory by measuring the weight and volume of a relatively undisturbed soil sample obtained from the field. By measuring unit weight of soil directly in the field might be done through sand cone test, rubber balloon or nuclear densitometer.

3.6.2 Cohesion (c)

Cohesion, c, is usually determined in the laboratory by Direct Shear Test. Unconfined Compressive Strength S_{uc} can be determined in the laboratory 8 using the Tri axial Test or the Unconfined Compressive Strength Test.

3.6.3 Friction Angle (Ø)

The angle of internal friction, φ, can be determined in the laboratory by the Direct Shear Test or by Tri axial test.

3.6.4 Poisons Ratio (υ)

Poisson's ratio is a measure of the Poisson effect, the phenomenon in which a material tends to expand in directions perpendicular to the direction of compression. Conversely, if the material is stretched rather than compressed, it usually tends to contract in the directions transverse to the direction of stretching.

3.6.5 Angle of Dilatancy (ψ)

Clays (regardless of over consolidated layers) are characterized by a very low amount of dilation ($\psi \approx 0$). As for sands, the angle of dilation depends on the angle of internal friction. For non-cohesive soils (sand, gravel) with the angle of internal friction $\varphi > 30°$ the value of dilation angle can be estimated as $\psi = \varphi - 30°$. A negative value of dilation angle is acceptable only for rather loose sands. In most cases, however, the assumption of $\psi = 0$ can be adopted.

3.6.6 Modulus of Elasticity (E)

Elastic modulus (also known as modulus of elasticity) is a quantity that measures an object or substance's resistance to being deformed elastically (i.e., non-permanently) when a stress is applied to it. The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region.

3.7. Components of Braced Excavation

General components are-

a. Retaining wall
b. Anchor
c. Foundation

3.7.1 Retaining wall:

Retaining walls are moderately rigid walls and utilized for supporting soil laterally so that it can be retained at distinctive levels on two sides. It is outlined to limit soil to a slope that it would not naturally keep to (typically a steep, near-vertical or vertical slope). It may be of different types like: Gravity wall, Cantilevered wall, Sheet piling, Diaphragm walls, Bored pile etc. For the thesis we used Diaphragm wall. With the progress of excavation, the wall deflects laterally and the vertical movement of the adjacent ground surface occurs.

3.7.1.1. Diaphragm wall:

Diaphragm wall is a continuous wall constructed in ground to facilitate certain construction activities. Excavation works in soft ground inevitably induces the ground movements which in turn may damage the adjoining existing structures. But diaphragm wall minimizes the ground movement particularly in places where the work is to be carried out in close proximity to the existing sensitive buildings.

3.7.2 Anchors:

Ground anchors are utilized to hold, restrain and support building, civil engineering and other structures, either permanently or temporarily.

3.7.2.1. Strut:

A strut is a structural component designed to resist longitudinal compression. and provide external-facing support in its lengthwise direction, which can be used to keep components separate. It functions by transferring the earth pressure coming from the surrounding soil on the diaphragm walls.

3.7.2.2 Kingpost:

The vertical support which is provided when the distance between two retaining walls is so huge that the struts cannot resist such load is called kingpost.

3.7.3. Foundation:

The substructure which is placed below the ground surface to transmit the load from the superstructure to the underlying soil or rock is foundation. Generally, about 30 to 40% of the total construction cost is spent on the foundation. In this thesis, both Pile (Deep Foundation), Matt foundation (Shallow Foundation) will be used.

3.7.3.1. Matt Foundation:

A mat or raft foundation is a large slab supporting a number of columns and walls under the entire structure or a large part of the structure. A mat is required when the allowable soil pressure is low or where the columns and walls are so close that individual footings would overlap or nearly touch each other.

Mat foundations are useful in reducing the differential settlements on non-homogeneous soils or where there is a large variation in the loads on individual columns.

3.7.3.2. Pile Foundation:

When there is a layer of weak soil at the surface, this layer cannot support the weight of the building, so the loads of the building have to bypass this layer and be transferred to the layer of stronger soil or rock that is below the weak layer. Pile foundation transfers this load by means of end bearing and friction.

3.8 Numerical Modelling:

Numerical simulation is done for all the construction stages which are involved in the construction of a braced excavation The initial stage is the installation of a diaphragm wall in the ground and static equilibrium is achieved under K_0 condition i.e. at rest condition of stress. The construction sequence involves lowering of ground water table within excavation zone by considering 1 meter layer of soil plug below the excavation level and modelling of building foundation, diaphragm wall and king post up to the desired level. The subsequent stages involving removal of soil elements, installation of struts and excavation foundation are simulated in PLAXIS. Undrained and drained condition has been considered for cohesive and cohesion less soil layers respectively.

3.9 Assumptions:

a. The soil was assumed to remain under undrained conditions. Strains in soil were assumed to have occurred so fast so as not to permit any drainage of water out of the pore space.
b. Diaphragm wall construction before excavation was assumed to have no significant effect on the in situ stresses of soil.

CHAPTER 4: MODEL CONSIDERATIONS, SOIL PARAMETERS AND EXCAVATION GEOMETRY

4.1 Model Considerations:

a. 2-D ground model

b. Multi layered soil

c. Small deformation theory for deformation analysis

d. Plain strain condition

e. 15 node analysis

f. Water Table = 43 meter from top within excavation zone,

23.5 meter from top outside excavation zone

4.2 Soil Layer:

Layer no.	Layer name	Top (m)	Bottom (m)
1	Holocene soft (fine-grained, grey very soft to soft sediments, constituted by clayey silt with traces of fine sand and organic compound)	0	10
2	Dupi Tila, Coarse grained (brown to grey, very dense, fine to medium sand with quite a lot of silt.)	10	42
3	Dupi Tila, Fine grained (grey to brown, stiff to hard, silt with clay to clayey silt with some or traces of fine sand)	42	56
4	Dupi Tila, Coarse grained (brown to grey, very dense, fine to medium sand with quite a lot of silt)	56	70

Table 4.2. 1 Soil Layers and Depth

(Typsa Consulting Engineers and Architects, 2020)

4.3 Soil Parameters:

Parameters	Layer 1	Layer 2	Layer 3	Layer 4
Depth (m)	0-10	10-42	42-56	56-70
Unit weight γap (KN/m^3)	18.6	19	19	19
Unit weight γ_{sat} (KN/m^3)	18.7	20	19.2	20
Permeability Hydraulic Conductivity K (m/s)	5.0E-7	1.0E-6	5.0E-8	1.0E-6
Model	Soft soil Cc=0.26 Cs=0.03 OCR=1.1	HS small E50ref=26.4 Eurref=79.3 G0ref=158.7 m=0.25 Gamma0.7=1.0E-4	HS small E50ref=19.5 Eurref=58.4 G0ref=146.1 m=0.3 Gamma0.7=1.0E-4	HS small E50ref=26.4 Eurref=79.3 G0ref=158.7 m=0.25 Gamma0.7=1.0E-4
Modulus of Elasticity (E) (Kpa)	20.0	40 + 1.6·z	30 + 1.6·z	40 + 1.6·z
Cohesion (c) (Kpa)	20	5	20	5
Angle of Friction (Ø)	23	32	24	32
Angle of Dilatancy (ψ)	0	2	0	2
Poison's Ratio (Ʊ)	0.30	0.25	0.30	0.25
Void ratio	0.9	0.8	0.56	0.4
Unconfined Strength (KPa)	100		400	
Tensile strength	5		5	
Interfaces (Rinter)	0.65	0.75	0.7	0.75
OCR	1,1	1.5	1.5	1.5
Initial stress Ko	0.64	0.57	0.75	0.57

Table 4.2. 2 Soil Parameters

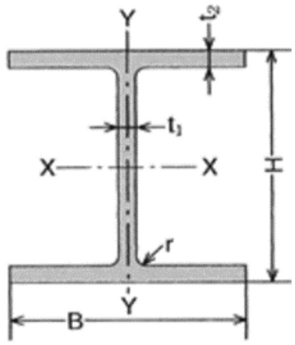
(Typsa Consulting Engineers and Architects, 2020)

4.4 Excavation Geometry

a. Excavation depth, De = 40 m
b. Excavation width, B = 15 m
c. Embedment depth of Diaphragm Wall = 65m

4.5 Technical consideration:

4.5.1. Technical consideration for I- strut:



Height, H = 400 mm
Breath, B = 400 mm
Thickness, t_1= 13 mm
t_2= 21 mm
Area, A = 0.02187 m^2
Modulus of Elasticity, E = 200 GPa
EA = 4.3740E+06 KPa

4.5.2 Technical consideration for Diaphragm Wall:

Unit weight of material, Wc = 25 KN/m^3
Strength of concrete, f'c = 45,000 KPa
Weight = 44.1 KN
Thickness, t = 1.8 m
Moment of Inertia, I = 0.486 m^4
Modulus of Elasticity, E = 1.20915E+07 KPa
EA = 2.17647E+07 KPa
EI = 5.87648E+06

4.5.3 Technical consideration for King Post:

Unit weight of material, Wc = 24.5 KN/m^3
Strength of concrete, f'c = 20,000 KPa
Weight = 35.62 KN
Thickness, t = 1.5 m
Modulus of Elasticity, E = 2.33931E+07 KPa
EA = 4.13390E+07 KPa

4.5.4 Technical consideration for Building Wall:
Unit weight of material, Wc = 25 KN/m^3
Strength of concrete, f'c = 45,000 KPa
Weight = 7.35 KN
Thickness, t = 0.3 m
Moment of Inertia, I = 0.00225 m^4
Modulus of Elasticity, E = 1.20915E+07 KPa
EA = 3.62746E+06 KPa
EI = 2.720590E+04

4.5.5 Technical consideration for Excavation Matt Foundation:
Unit weight of material, Wc = 25 KN/m^3
Strength of concrete, f'c = 45,000 KPa
Weight = 56.35 KN
Thickness, t = 2.3 m
Moment of Inertia, I = 1.014 m^4
Modulus of Elasticity, E = 1.20915E+07 KPa
EA = 2.78105E+07 KPa
EI = 1.22598E+07
Sleeve friction, fs = 50 KPa
Pile diameter, D = 0.75 m
Pile Length, L = 20 m

4.5.6 Technical consideration for Pile Cap design:
Unit Skin Friction = pi * D * fs
= 3.1416 * 0.75 * 50
= 117.8097 KPa
Ultimate Bearing Capacity, qu = Unit Skin Friction * L
= 117.8097 * 20
= 2356.194 KN/m2
Factor of Safety, F.S = 2.5
Allowable Bearing Capacity, qa = qu / F.S
= (2356.194/ 2.5)
= 942.4778 KN/m2 ≈ 900 KN/m2
Total Number of Piles = 4
Total Load = (900 * 4) = 3600 KN
Pile spacing = 2.25 m
Load in Pile Cap = (3600) / (4.5*4.5) = 177.7778 KN/m2

CHAPTER 5: PARAMETRIC STUDY

5.1 Construction simulation

The construction procedure essentially consisted of excavation and strut installation. Excavation was simulated numerically by placing diaphragm wall on both sides of excavation width and a kingpost through the middle of excavation width. Interface is simulated as slip/joint elements in order to prevent the entrance of water in excavation zone. Longitudinal struts were installed at a vertical spacing of 4m center to center. Simulation of strut installation was done exactly in the same way as followed in the field. For example, the first strut was installed after first stage of excavation. The diaphragm wall acts almost as an embedded cantilever till the installation of the first strut. Subsequent strut installations restrict the wall movement at those points and excavations, thereafter, made the wall deflect mostly below that strut level. Matt Foundation is simulated after the installment of last strut.

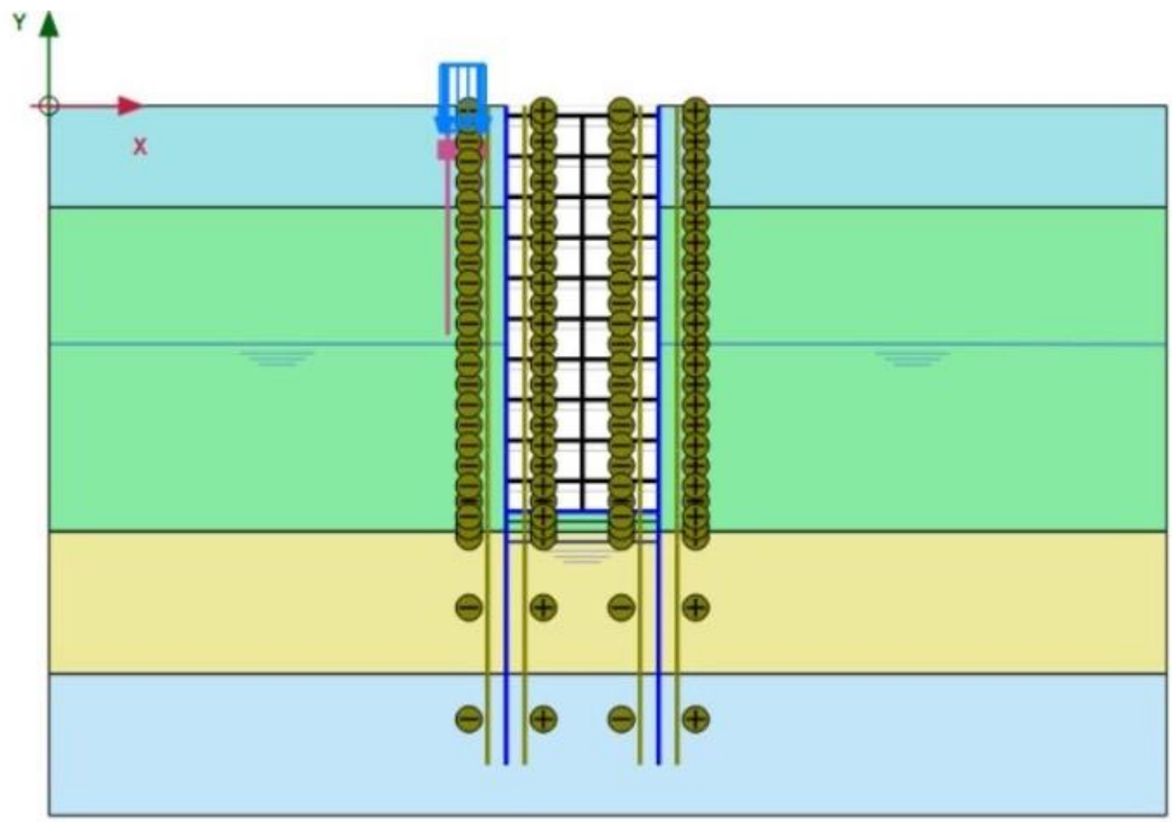


Fig 5.1 Arrangements of Components of Braced Excavation in Plaxis 2D

5.2 Displacement Boundary

The displacement boundary conditions are as follows:
At bottom: Both vertical and horizontal displacements are fixed.
At left edge: The horizontal displacement is fixed but vertical movement is allowed; i.e., vertical displacement is pinned.
At right edge: The horizontal displacement is fixed but vertical movement is allowed; i.e., vertical displacement is pinned.

5.3 Mesh Generation

There are different types of finite element meshes in PLAXIS 2D software for FEM analysis. For meshing, element distribution very fine has been considered.

5.4 Cases Considered

For this research work, the building foundation has been moved from the face of excavation by 2 meters repeatedly up to 18m thus producing 9 cases in total.

CHAPTER 6: RESULTS AND DISCUSSIONS

6.1 Ground Condition:

6.1.1. Lateral Wall Displacement:

Two figures of total displacements U_x and lateral wall displacement are given respectively.

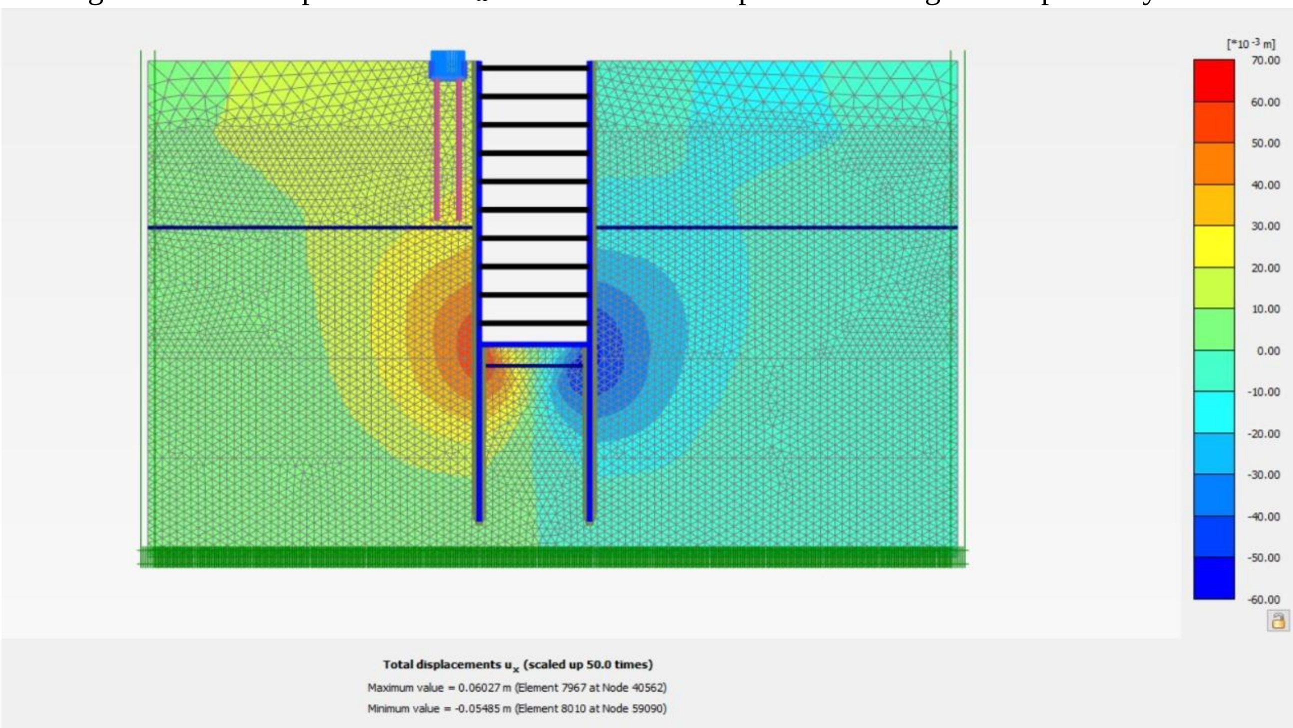


Fig 6.1.1.1 Total Displacement Ux in Plaxis 2D software

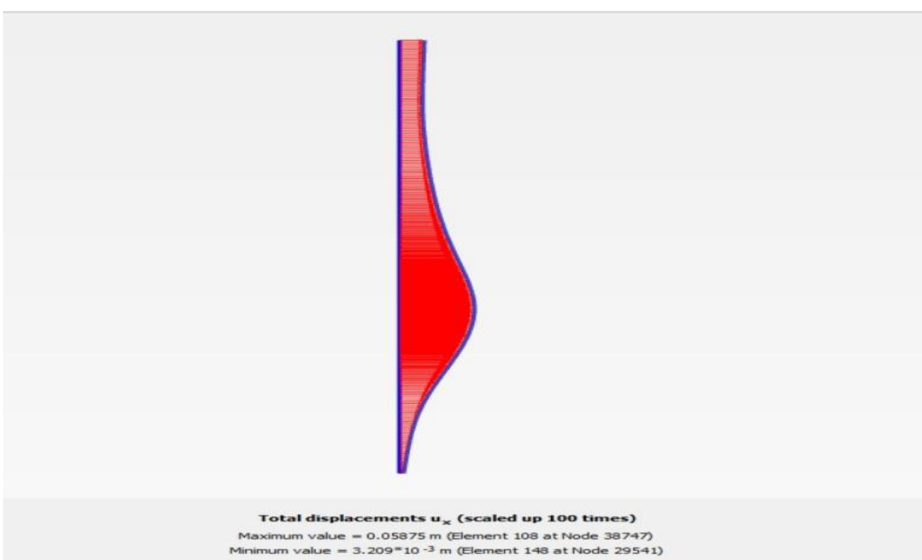


Fig 6.1.1.2 Lateral Wall Displacement in Plaxis 2D software

6.2. Results:

A table comparing the lateral wall displacement at varying distance of building load is showed below. The values are found from Plaxis 2D software.

Depth (m)	Lateral Wall Displacement (mm) when building load at 18 m	Lateral Wall Displacement (mm) when building load at 16 m	Lateral Wall Displacement (mm) when building load at 14 m	Lateral Wall Displacement (mm) when building load at 12 m	Lateral Wall Displacement (mm) when building load at 10 m	Lateral Wall Displacement (mm) when building load at 8 m	Lateral Wall Displacement (mm) when building load at 6 m	Lateral Wall Displacement (mm) when building load at 4 m	Lateral Wall Displacement (mm) when building load at 2 m
0.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-0.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-0.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-0.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-1.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-1.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-1.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-1.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-1.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-2.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-2.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-2.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
Depth (m)	**Lateral Wall Displacement (mm) when building load at 18 m**	**Lateral Wall Displacement (mm) when building load at 16 m**	**Lateral Wall Displacement (mm) when building load at 14 m**	**Lateral Wall Displacement (mm) when building load at 12 m**	**Lateral Wall Displacement (mm) when building load at 10 m**	**Lateral Wall Displacement (mm) when building load at 8 m**	**Lateral Wall Displacement (mm) when building load at 6 m**	**Lateral Wall Displacement (mm) when building load at 4 m**	**Lateral Wall Displacement (mm) when building load at 2 m**
-2.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-2.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-3.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-3.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-3.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-3.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-3.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-4.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

-4.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-4.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-4.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-4.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-5.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-5.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-5.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-5.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-5.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-6.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-6.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-6.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-6.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-6.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-7.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-7.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-7.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-7.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-7.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-8.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-8.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-8.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-8.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-8.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-9.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-9.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
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-9.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-10.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-10.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-10.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-10.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-10.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-11.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

-11.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-11.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-11.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-11.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-12.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-12.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-12.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-12.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-12.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-13.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-13.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-13.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-13.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
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-14.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-14.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-14.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-15.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-15.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-15.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-15.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-15.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-16.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-16.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-16.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
Depth (m)	**Lateral Wall Displacement (mm) when building load at 18 m**	**Lateral Wall Displacement (mm) when building load at 16 m**	**Lateral Wall Displacement (mm) when building load at 14 m**	**Lateral Wall Displacement (mm) when building load at 12 m**	**Lateral Wall Displacement (mm) when building load at 10 m**	**Lateral Wall Displacement (mm) when building load at 8 m**	**Lateral Wall Displacement (mm) when building load at 6 m**	**Lateral Wall Displacement (mm) when building load at 4 m**	**Lateral Wall Displacement (mm) when building load at 2 m**
-16.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-16.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-17.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-17.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-17.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-17.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-17.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-18.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

-18.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-18.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-18.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-18.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-19.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-19.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-19.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-19.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-19.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-20.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-20.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-20.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-20.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-20.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-21.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-21.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-21.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-21.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-21.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-22.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-22.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-22.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-22.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-22.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-23.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-23.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
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-23.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-23.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-24.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-24.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-24.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-24.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-24.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-25.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

-25.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-25.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-25.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-25.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-26.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-26.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-26.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-26.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-26.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-27.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-27.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-27.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-27.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-27.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-28.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-28.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-28.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-28.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-28.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-29.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-29.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-29.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-29.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-29.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-30.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-30.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-30.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
Depth (m)	**Lateral Wall Displace ment (mm) when building load at 18 m**	**Lateral Wall Displace ment (mm) when building load at 16 m**	**Lateral Wall Displace ment (mm) when building load at 14 m**	**Lateral Wall Displace ment (mm) when building load at 12 m**	**Lateral Wall Displace ment (mm) when building load at 10 m**	**Lateral Wall Displace ment (mm) when building load at 8 m**	**Lateral Wall Displace ment (mm) when building load at 6 m**	**Lateral Wall Displace ment (mm) when building load at 4 m**	**Lateral Wall Displace ment (mm) when building load at 2 m**
-30.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-30.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-31.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-31.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-31.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-31.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-31.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-32.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

-32.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-32.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-32.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-32.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-33.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-33.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-33.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-33.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-33.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-34.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-34.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-34.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-34.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-34.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-35.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-35.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-35.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-35.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-35.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-36.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-36.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-36.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-36.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-36.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-37.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-37.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-37.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

Depth (m)	Lateral Wall Displacement (mm) when building load at 18 m	Lateral Wall Displacement (mm) when building load at 16 m	Lateral Wall Displacement (mm) when building load at 14 m	Lateral Wall Displacement (mm) when building load at 12 m	Lateral Wall Displacement (mm) when building load at 10 m	Lateral Wall Displacement (mm) when building load at 8 m	Lateral Wall Displacement (mm) when building load at 6 m	Lateral Wall Displacement (mm) when building load at 4 m	Lateral Wall Displacement (mm) when building load at 2 m
-37.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-37.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-38.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-38.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-38.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-38.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-38.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-39.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

-39.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-39.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-39.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-39.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-40.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-40.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-40.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-40.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-40.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-41.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-41.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-41.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-41.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-41.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-42.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-42.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-42.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-42.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-42.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-43.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-43.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-43.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-43.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-43.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-44.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-44.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-44.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
Depth (m)	**Lateral Wall Displacement (mm) when building load at 18 m**	**Lateral Wall Displacement (mm) when building load at 16 m**	**Lateral Wall Displacement (mm) when building load at 14 m**	**Lateral Wall Displacement (mm) when building load at 12 m**	**Lateral Wall Displacement (mm) when building load at 10 m**	**Lateral Wall Displacement (mm) when building load at 8 m**	**Lateral Wall Displacement (mm) when building load at 6 m**	**Lateral Wall Displacement (mm) when building load at 4 m**	**Lateral Wall Displacement (mm) when building load at 2 m**
-44.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-44.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-45.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-45.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-45.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-45.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-45.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-46.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

-46.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-46.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-46.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-46.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-47.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-47.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-47.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-47.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-47.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-48.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-48.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-48.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-48.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-48.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-49.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-49.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-49.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-49.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-49.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-50.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-50.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-50.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-50.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-50.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-51.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-51.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-51.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
Depth (m)	**Lateral Wall Displacement (mm) when building load at 18 m**	**Lateral Wall Displacement (mm) when building load at 16 m**	**Lateral Wall Displacement (mm) when building load at 14 m**	**Lateral Wall Displacement (mm) when building load at 12 m**	**Lateral Wall Displacement (mm) when building load at 10 m**	**Lateral Wall Displacement (mm) when building load at 8 m**	**Lateral Wall Displacement (mm) when building load at 6 m**	**Lateral Wall Displacement (mm) when building load at 4 m**	**Lateral Wall Displacement (mm) when building load at 2 m**
-51.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-51.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-52.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-52.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-52.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-52.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-52.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-53.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

-53.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-53.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-53.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-53.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-54.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-54.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-54.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-54.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-54.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-55.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-55.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-55.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-55.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-55.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-56.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-56.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-56.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-56.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-56.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-57.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-57.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-57.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-57.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-57.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-58.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-58.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-58.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
Depth (m)	**Lateral Wall Displacement (mm) when building load at 18 m**	**Lateral Wall Displacement (mm) when building load at 16 m**	**Lateral Wall Displacement (mm) when building load at 14 m**	**Lateral Wall Displacement (mm) when building load at 12 m**	**Lateral Wall Displacement (mm) when building load at 10 m**	**Lateral Wall Displacement (mm) when building load at 8 m**	**Lateral Wall Displacement (mm) when building load at 6 m**	**Lateral Wall Displacement (mm) when building load at 4 m**	**Lateral Wall Displacement (mm) when building load at 2 m**
-58.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-58.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-59.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-59.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-59.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-59.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-59.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-60.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

-60.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-60.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-60.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-60.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-61.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-61.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-61.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-61.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-61.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-62.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-62.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-62.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-62.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-62.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-63.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-63.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-63.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-63.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-63.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-64.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-64.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-64.25	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-64.50	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-64.75	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333
-65.00	12.4306	13.1112	12.7687	12.7046	14.3388	14.9930	16.3595	17.6350	19.4333

Table 6.2. 1 Lateral Displacement of Diaphragm wall due to different position of building

From Figure 6.2.2 it is seen that the average value of maximum wall displacement is 64.94 mm.

Building foundation distance from excavation (m)	Maximum Diaphragm wall displacement (mm)
2.0	58.75
4.0	62.71
6.0	64.22
8.0	65.76
10.0	64.57
12.0	67.16
14.0	67.34
16.0	66.3
18.0	67.65

Table 6.2.2 Maximum wall displacement at different distance from building

A graph is drawn depicting the behaviour of diaphragm wall movement at varied distances between the excavation and building foundation. It is seen from the graph that after reaching a certain distance i.e., 40m the wall movement starts to decrease with increase in depth. This happens due to surface settlement.

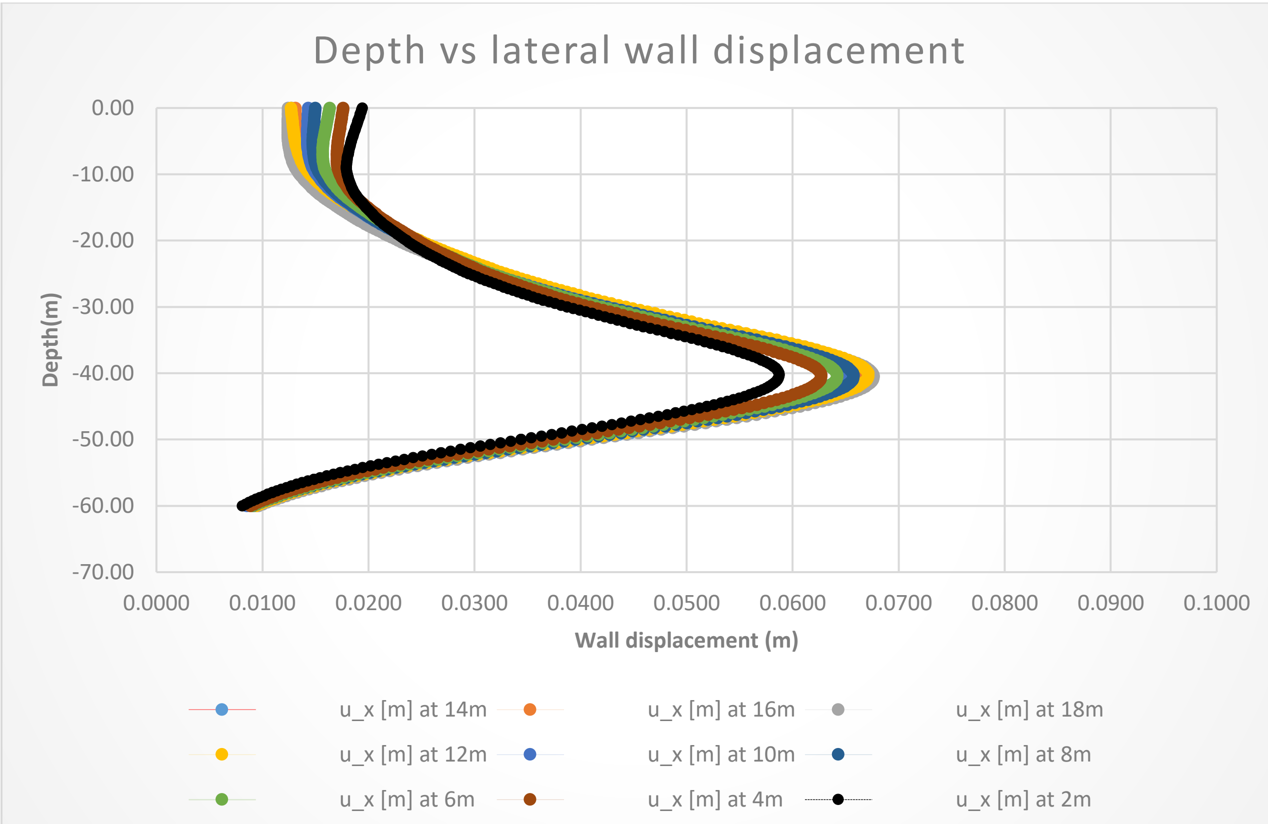

Figure 6.2.1 Depth vs Lateral Wall Displacement Graph

Chapter 7: CONCLUSION, FUTURE STUDY AND RECOMMENDATION

7.1. Conclusion:

The research works can be concluded as follows:

1. Diaphragm wall movement increases initially with increase of depth
2. After reaching a certain peak point wall movement decreases with increase in depth
3. Maximum value of wall displacement increases with increase of distance between building foundation and excavation zone

7.2. Future study and Recommendation:

Further study can be conducted in future considering the effect of following factors on braced excavation:

a. number of struts and their vertical and horizontal spacings
b. Varying stiffness of strut
c. Different combination of strut arrangement
d. Varying Diaphragm wall depth
e. Varying Wall thickness
f. Varying width of the excavation
g. Strut preloading force

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