NUMERICAL PREDICTION OF DIAPHRAGM WALL MOVEMENT OF MRT LINE 1

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ABSTRACT

The presented subterranean excavation for the building of Mass Rapid Transit Line 1 in Dhaka has sparked significant interest from engineers and specialists. This is not only in response to the construction limitations provided by the densely-built metropolis, but also because of the potential ground movement that may be caused by the excavation. This study investigates the movement of the ground surface caused by the advancement of excavation through the use of numerical analysis. Two finite element (FE) models have been developed using PLAXIS 2D, in which Mohr–Coulomb (MC) and hardening soil (HS) have been considered. The field data from the Bangkok blue line expansion was compared to validate the effectiveness of PLAXIS 2D in excavation modelling. Finally, the HS soil model showed maximum d-wall displacement 36mm while MC model depicted 22mm.

Keywords: *Deep excavation; Mass rapid transit, Dhaka metro, Finite element method, diaphragm wall.*

1. INTRODUCTION

Since time immemorial, humans have migrated to cities in search of a better life. Those cities have become the engines of growth. Today we are witnessing urbanization at an unprecedented rate. Every stone we lay should be on top of a stronger one. These great monuments of modernity which we build must be on strong foundations. For building such mega projects, the role of foundation structures cannot be overstated. Every innovation we do here, will help the world make infrastructure safer, reliable, durable and affordable. It will make lives better for many for sure. The remarkable progress of humanity, from horse-drawn carts to high-speed bullet trains and the newest advancements in subsurface space technology, has been facilitated by individuals who have translated breakthroughs from research and academia into practical applications in engineering and industry.

Various cities globally, such as Dhaka, are making significant investments in urban transport infrastructure, including underground systems, through expanding their current networks or establishing new lines. Consequently, extensive excavations would be conducted in these highly compacted regions. These works offer the chance to evaluate the actual behavior of the support system through comprehensive monitoring. Nevertheless, the resulting records often only provide displacement measures in specific excavation areas. Using only one measurement type in numerical modeling can yield accurate and consistent outcomes. However, it can also pay attention to certain aspects of behavior that the model might not accurately represent.

Hsiung et al., 2018 employed PLAXIS 3D for deep excavation supporting D-wall at Jakarta, Indonesia for metro underground station. The length and width are 430m and 22-30m respectively. Total 10Nos boreholes were drilled upto 45m bGL to assess the subsoil parameters. The CPTs, SPTs, PMTs and DS Log as well as the permeability through deep well system were employed. The test results revealed that the subsurface contained mostly clay, silts and clayey silts. The maximum excavation depth is about 19m which have been performed in total five phases. The D-wall thickness is 1m and 24m length to support the excavation works. The inclinometers were used to measure the d-wall displacement due to each excavation stage. The maximum displacement was recorded about 13mm. In PLAXIS 2D-3D, hardening soil model has been used to model this displacement and showed good agreement with field. Likitlersuang et al., 2013 conducted study on the ground movement of Bangkok metropolitan area due to the construction of MRT Blue Line Extension project. In this project, the alignment is 22KM in length and total 18 underground station would be constructed by cut-cover method. These stations are 230m long and 25m wide with 16-32m depth below the ground level (bGL). In cut-cover method, the top-down construction techniques have been used. In this study, Sokhumvit station is considered for the analysis (Figure 2). The subsoil of the station area was very soft to medium stiff clay and d-wall was needed to retained this subsoil. The d-wall thickness was 1-1.2m and length was 20-46m. Four stages of excavations were required in Sokhumvit station. To monitor the ground movement as well as the d-wall displacement, inclinometers, extensometers and surface settlement markers were installed. Due to the excavation, about 32mm d-wall displacement were observed at 20m depth. The surface settlement was 27mm behind the d-wall. To model this ground movement behavior, author used MC, SS, HS and HSsmall models. Among the four constitutive models, HSsmall has been shown better agreement with field measurement.

Nejjar et al., 2022 performed modeling of 32m deep excavation in France. That is the metro station of the Grand Paris Express project, Fort d' Issy-Vanves-Clamart (FIVE). The station is 110m long and 22m wide and rectangular boxed shape. 1.2m thick and 40m deep d-wall has been constructed to support the excavation system as well as the soft eye of the tbm entrance and exit. Four stages of excavation works have conducted to avoid any instability. To monitor the ground movement as the deflection of d-wall, inclinometers, fiber optical strain gauges, piezometers has been installed. PLAXIS 2D and 3D have been employed conjunction with HS Small constitutive model. The maximum wall deflection has been observed 20m depth and below 15mm.

In this study, Bangkok blue line extension project's deep excavation modelling has been used to Class-A prediction by using the subsoil parameters of the MRT Line-1. The d-wall displacement due to stagewise excavation and shear force and bending moments have been predicted. To make this prediction simple, only MC and HS models have been used.

1.1 Project Description

The total length of MRT line 1 is scheduled to be 28.2 kilometres, consisting of 19 stops and one depot located in the Purbachal region (KS Consultants Ltd. & EQMS Consulting Limited, 2018). Out of the altogether length, 14.8 km will be allocated to an underground railway, connecting a total of 12 subterranean stops to the rear of the airport. The subterranean section of the track will be constructed via a Tunnel Boring Machine (TBM), while the stations will be constructed employing the Cut and Cover technique. The proposed subterranean station would have a length of 250 metres and an outside circumference of 7 metres. The metro tunnels have been specifically engineered to be hung at a normal depth of 35 metres. Figure 1 depicts the alignment map of MRT Line 1, illustrating the underground portion, raised section, underground stations, and elevated stations with a green line, red line, green labels, and red labels. The subsoil investigation of a typical borehole has been given in Table 1.

Table 1: Subsoil properties of the MRT Line 1 (After Sakil Ahmed et al., 2023)

SL No.	Soil Layer	Description	Consistency	Depth	SPT-N
1	SF	Made ground		0-4.5	10-15
2	AC3	Lean Clay	Medium stiff	4.5-5	7
3	AC4	Fat Clay	Stiff	5-6	12
4	AC4	Lean Clay	Stiff	6-7.5	15
5	AS3	Sandy silt	Medium dense	7.5-9	11
6	AS3	Silt		9-12	16
7	AC5	Lean Clay	Very stiff	12-13.5	19-21
8	AS3	Silt		13.5-16.5	21-29
9	AS3	Sandy silt	Medium dense	16.5-18	31
10	AS4	Silty sand	Dense	18-21	37
11	AS4	Sandy silt	Dense	21-22.5	42-45
12	AS5	Silty sand	Very Dense	22.5-40	38-50

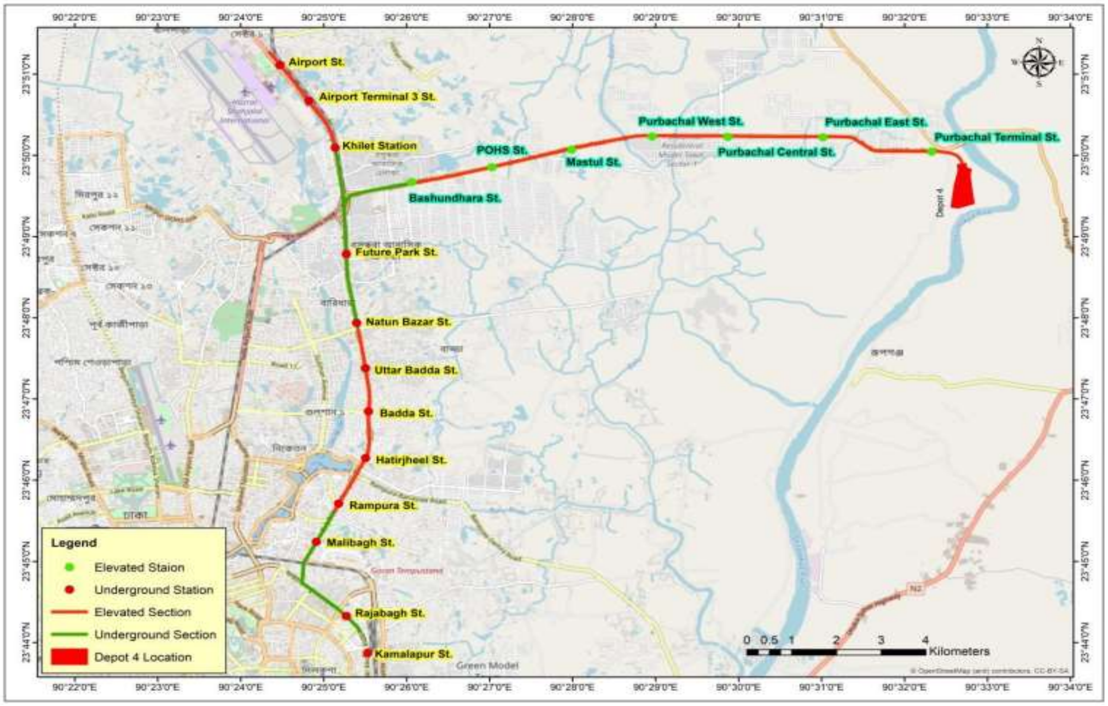

Figure 1: Alignment of MRT Line-1 project (Source:(KS Consultants Ltd. & EQMS Consulting Limited, 2018)

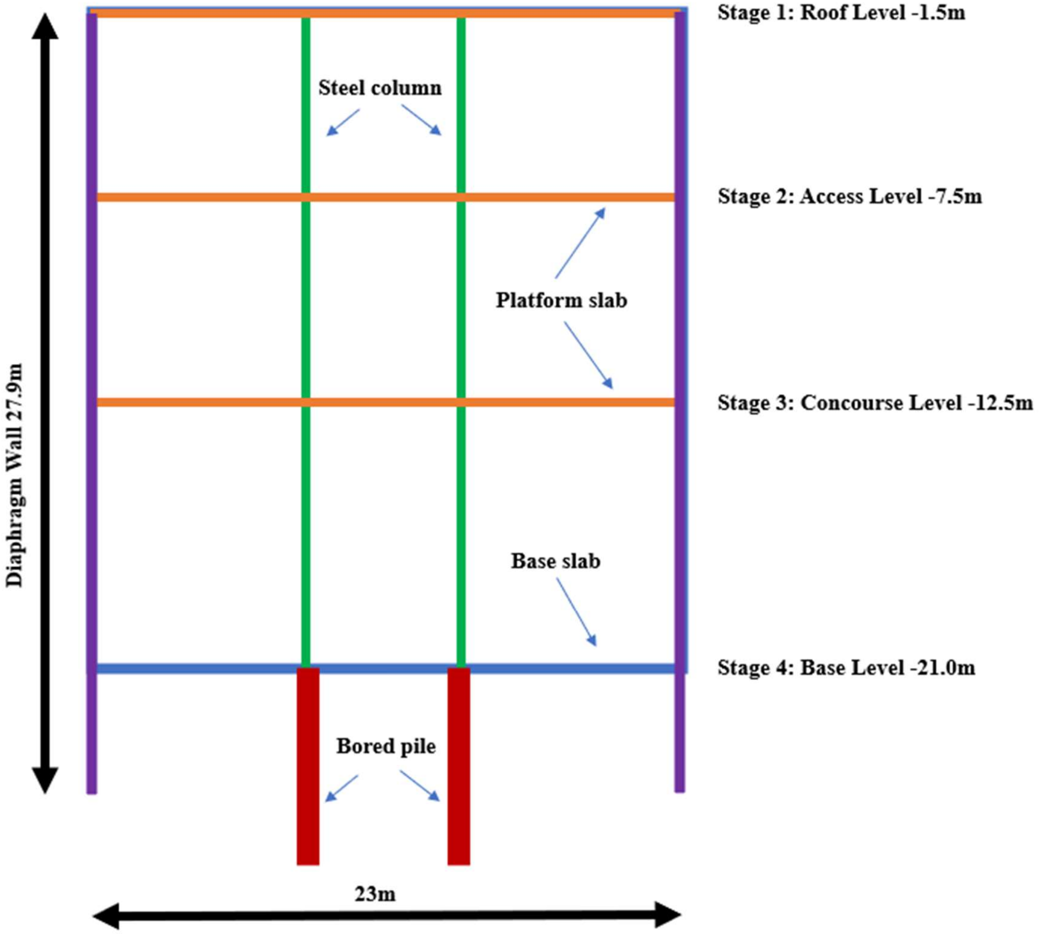

Figure 2: Layout of Sukhumvit Station of Bangkok Blue Line metro project

2. METHODOLOGY

Author first remodelled same type of problem from Bangkok blue line metro project (Likitlersuang et al., 2013) to understand venturing of numerical modelling in PLAXIS. The result of this remodelling has been depicted in the next section. After the ensuring of reasonable results, this problem has been ventured. The subsoil properties have been used from (Sakil Ahmed et al., 2023) which is based on the MRT Line 1 project for the ground movement due to tunnelling at various depth. To reduce time and computation costs, only HS and MC model parameters have been used. The length and wide of the underground station are 230m and 25m respectively. The structural arrangement of the deep excavation has been kept similar as the Bangkok blue line metro. The structural elements as pile, steel column, diaphragm wall, base slab, platform slab's properties have been depicted in Table 3. The interface element stiffness values are in the range of 0.7-0.9, depending on the soil profile, to simulate the ground disturbance.

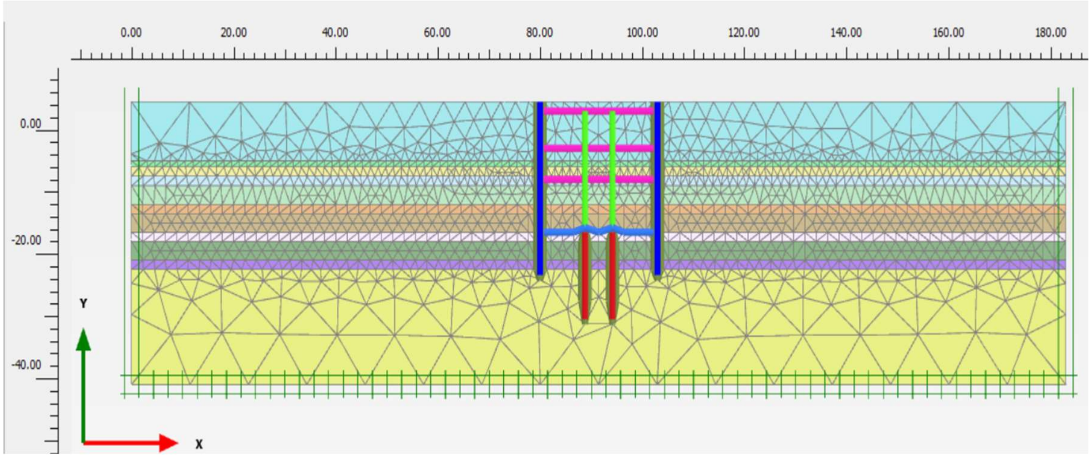

Figure 3: Meshed model of underground excavation of MRT Line 1

2D plane strain option has been selected due to the L/B ratio is high. The 3D effect of the long sides of the metro station would be small. Very fine mesh and standard fixities have been applied in the modeling (Figure 3). Though the system is symmetric, full section has been considered in the modeling stage. The water level at Dhaka city is about below the 40m bgl (Sakil Ahmed et al., 2023). However, to consider worst condition, the water table has been kept at 1.5m bgl. The Mohr-Coulomb model (MC) has been selected due to its simplycity, only few parameters are required. The HS model has been used, because it is widely used in previous researches (Surarak, 2011) . To perform green field analysis, no traffic load or the nearby buliding load is not considered (El Naggar et al., 2023; Hsiung et al., 2018b).

Table 2: Input of the material models (After Sakil Ahmed et al., 2023)

Layer	Depth (m)	Υ_d (kN/m^3)	Υ_{sat} (kN/m^3)	S_u (kPa)	e_0	E_u (kN/m^2)	v_u	E_{50} (kN/m^2)	E_{oed} (kN/m^2)	E_{ur} (kN/m^2)	v
Lean clay	4.5-5	17.5	21.01	48	0.6	2.82E+05	0.495	2.82E+05	2.72E+05	1.05E+06	0.2
Fat Clay	5-6m	17.1	20.72	48	0.57	2.82E+05	0.495	2.82E+05	2.22E+05	1.01E+06	0.2
Lean clay	6-7.5m	17.5	21.04	48	0.6	2.82E+05	0.495	2.82E+05	2.72E+05	1.05E+06	0.2
Sandy silt	7.5-9	18.7	21.71	30	0.44	2.82E+05	0.495	2.82E+05	2.29E+05	1.05E+06	0.2
Silt	9-12m	18.67	21.76	30	0.45	2.82E+05	0.495	2.82E+05	2.23E+05	1.05E+06	0.2
Lean clay	12-13.5m	17.5	21.04	48	0.6	2.82E+05	0.495	2.82E+05	2.72E+05	1.05E+06	0.2
Silt	13.5-16.5m	18.67	21.76	30	0.45	2.82E+05	0.495	2.82E+05	2.23E+05	1.05E+06	0.2
Sandy silt	16.5-18m	18.7	21.71	30	0.44	2.82E+05	0.495	2.82E+05	2.26E+05	1.05E+06	0.2
Silty sand	18-21m	17.85	20.22	30	0.32	2.82E+05	0.495	2.82E+05	2.25E+05	1.05E+06	0.2
Sandy silt	21-22.5m	18.7	21.71	30	0.44	2.82E+05	0.495	2.82E+05	2.26E+05	1.05E+06	0.2
Silty sand	22.5-41m	17.85	20.22	30	0.32	2.82E+05	0.495	2.82E+05	2.25E+05	1.05E+06	0.2

Table 3: Strucutral properties of members (After Likitlersuang et al., 2013)

Parameter	D-Wall	Platform Slab	Base Slab	Steel column	Pile
Dia. / thickness (m)	1	1	1.8	0.8	1.8
Axial Stiffness, EI (MN/m)	28000	28000	50400	1712	3852
Flexural Rigidity, EA (MN/m)	2333	2333	13608	91.3	1040
Weight, w (kN/m^2)	16.5	25	45	25	25
Poisson ratio, v	0.15	0.15	0.15	0.15	0.15

In PLAXIS, two functions were defined as undrained: Undrained (A) and Undrained (B). Undrained (A) necessitates the utilisation of effective stress parameters for both soil modulus and shear strength, while Undrained (B) employs the effective soil modulus and undrained soil shear strength. As previously mentioned, due to the low number of high-quality UU tests undertaken, a comprehensive profile of effective shear strength parameters could not be established. The subsoil parameters have been tabulated in

Table 2. Thus, the Undrained (B) function was chosen for investigation, utilising the effective soil modulus and undrained soil shear strength. All the steps of modeling have been shown in the Table 4.

Table 4: Modeling sequences of excavation (After Likitlersuang et al., 2013)

Sequences	Activities
1	Initial Phase K_0 procedure
2	Installation of D-Wall
3	Construction Pile
4	Construction of steel column from the top of the pile
5	Excavation upto -1.5m
6	Construction of Platform slab at -1.5m
7	Excavation upto -7.5m
8	Construction of Platform slab at -7.5m
9	Excavation upto -12.5m
10	Construction of Platform slab at -12.5m
11	Excavation upto -21m
12	Construction of Base slab at -21m

3. RESULTS AND DISCUSSION

This Figure 4 shows the output of the remodelling and prediction of MC model. The stagewise excavation curves of d-wall displacement depicts good agreement with the study of (Likitlersuang et al., 2013). This outcome confirms the efficiency of the remodelling. However, some discrepancies have been observed with field measurement and the previous study.

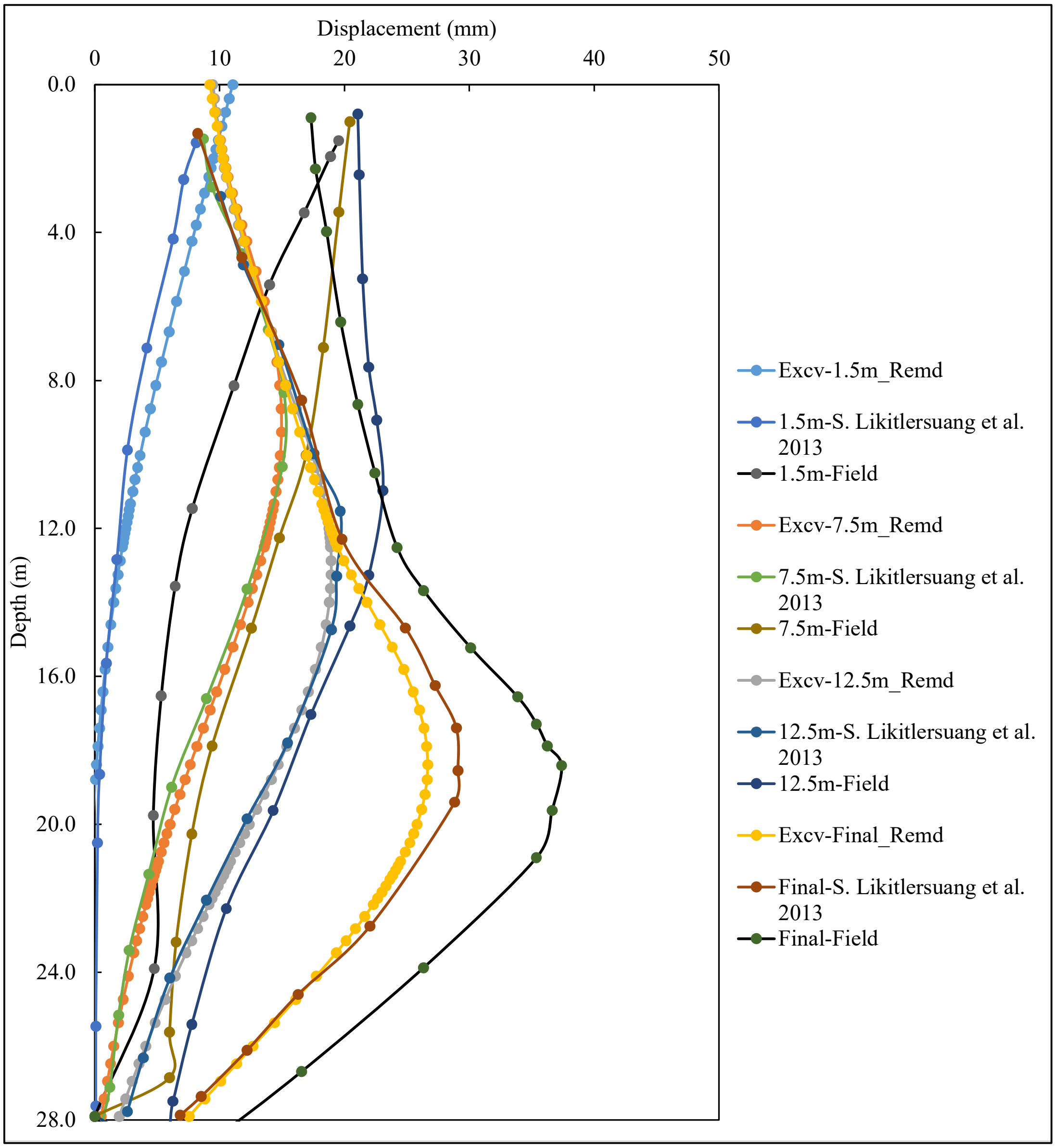

Figure 4: Remodelling of Diaphragm wall displacement due to the deep excavation in Sukhumvit Station

Figure 5 compares the Class-A prediction of the HS and MC model with the previous study, The maximum wall displacements are 36mm depicted by HS model while MC model showed 22mm. Similar findings were observed in study (Likitlersuang et al., 2013).

Despite the MC Model's widespread use in numerous geotechnical construction projects, the model still faces some issues stemming from its assumptions and limitations, particularly in the context of unloading problems. The MC Soil Model lacks the ability to differentiate between primary loading, unloading, and reloading difficulties. Indeed, the sole concerning stiffness modulus for every category of problems is E_{50}. When dealing with unloading issues, the soil's undrained behaviour may be impractical, leading to an inaccurate estimation of its shear strength.

Total strains in the HS model are determined using a stress-dependent stiffness that varies with loading and unloading/reloading. Depending on the plastic shear and volumetric strains, hardening is expected to be isotropic. In the HS Model, the stress-strain relationship owing to main loading is assumed to be a hyperbolic curve (Surarak, 2011). Thus, the HS model shows larger displacement than MC model.

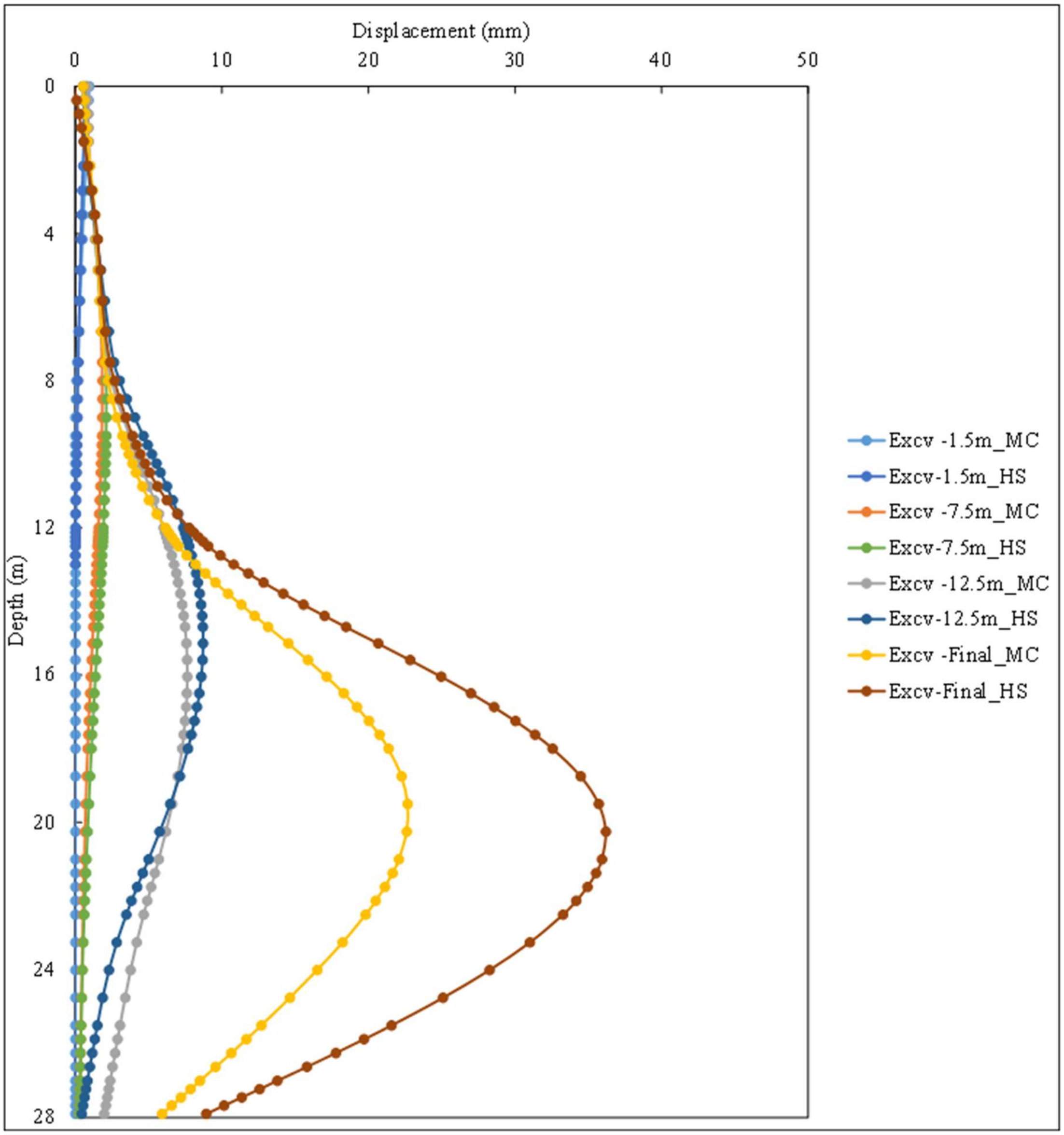

Figure 5: Class-A prediction of Diaphragm wall displacement due to the deep excavation in MRT Line-1 Dhaka

4. CONCLUSIONS

This study discusses the behaviour of D-wall movements through numerical calculations. The study's findings can be summarised as follows:

i. In the remodelling of Bangkok Blue line extension project, it was found that maximum D-wall displacement for PLAXIS 2D are very close to the real monitored data as well as the previous numerical modelling.
ii. The lateral wall movements were generally improved with increasing sophistication of the constitutive models, following the order of MC and HS.

iii. This study concludes that regardless of the analysis or numerical method used, accurate prediction of ground movement is not possible without selecting the appropriate parameters. For FEM, it is necessary to choose an appropriate simulation approach.

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