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Case Study of Double-Wall Retaining Wall System for Deep Excavation in Jakarta, Indonesia

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ABSTRACT This paper presents a case study of diaphragm wall behavior in a deep excavation project under double-wall condition. A double-wall condition occurs when two layers of diaphragm wall, either side by side or with gaps between them, are used as a retaining wall system. The project discussed in this paper is located in a soft clay area of Jakarta, Indonesia, with a main excavation depth of approximately 33 meter and a side excavation depth of 23 meter. The project utilizes the top-down construction method, where the retaining walls for both the main and side structures are initially built before the excavation begins, creating the double wall condition. However, due to site issues, main excavation activities commenced after the construction of the main structure wall but before the side structure wall was completed, changing the plan to a single-wall condition. The behavior of the main structure wall under both single-wall and double-wall condition is studied. The study simulated two separate FEM models to evaluate the sequence of construction up to the final excavation level of the main station. According to the analysis result, single wall condition has relatively larger deformation than double wall condition. However, the wall bending moment did not change much, meaning that double-wall did not contribute effectively towards providing higher stiffness. The results contradict the initial assumption that the double-wall condition would be more advantageous for the main structure wall design than single-wall condition. Several critical parameters were found to significantly influence the outcome. The findings of this case study can provide valuable insights for the preliminary design of future excavation projects.

KEYWORDS Deep excavation; double-wall system; case study; diaphragm wall; underground structure

1 INTRODUCTION

The construction of public transport such as Jakarta MRT (Mass Rapid Transit) is one of Indonesia National Strategic Project announced under current government. Indonesia and Japan government agreed to collaborate on Jakarta MRT construction project, which has been divided into several phases. Phase 1 spans from Lebak Bulus Station until Bundaran HI Station and has been operating since March 2019. Jakarta MRT Phase 1 requires deep excavation in highly developed areas, requiring careful design and construction sequence to minimize deformation. Jakarta MRT phase 2 also faces similar challenges.

The construction of phase 2, which is currently under construction, is divided into 3 contract packages for underground station and tunnel construction named CP201, CP202, and CP203. The construction of CP202 is executed by contractor Shimizu-Adhi Karya Joint Venture (SAJV). The project consists of 3 underground stations named Harmoni Station, Sawah Besar Station, and Mangga Besar Station, along with tunnel trackway for 1180 m length. The layout plan is shown in Figure 1. As shown in the figure, CP202 MRT project is located very close to a residential area with many old buildings. The entrances encroach on private land, causing several challenges during the design development stage that required changes to the construction sequence.

Figure 1. Jakarta MRT CP202 stations and tunnel layout plan

In previous literature regarding deep excavation, Hsiung et al. (2018) shared that a top-down construction for 18.9 m maximum excavation depth using 1.0 m thick and 24.1 m deep diaphragm wall (*D-wall* in short). To minimize the deformation, stiffness of the retaining wall system was increased by installing steel H-beams as kingposts in the middle of the excavation. Another literature by Bui et al. (2024) shared the diaphragm wall used in Ho Chi Minh City Metro. A top-down construction method is adopted for 33.2 m excavation depth with a 1.5 m thick and 44 m deep diaphragm wall. Similarly steel H-beam strut and kingpost are used to provide additional stiffness, minimizing lateral deformation. In Jakarta MRT Phase 2, other than H-beam as kingpost, double-wall retaining wall system was initially planned to reduce construction effects on adjacent existing buildings. However, the side structure D-wall cannot be constructed at the same stage as the main station D-wall; instead, it will be built after main station excavation has reached its final excavation level. This sequence change is expected to result in different D-wall behavior. Since the side structure wall will not be in place during the initial stages, greater wall movement is anticipated.

The station excavation was simulated using the two-dimensional Finite Element Method (FEM) with PLAXIS software. Simulations for all three stations were conducted based on the soil conditions, structural parameter inputs, and actual construction sequence. The Hardening Soil model in undrained B condition was applied to represent the soil behavior in the model.

A comparative analysis was performed to evaluate the effectiveness of single-wall and double-wall systems in providing time-efficient and cost-effective solutions. Several critical parameters were identified as having a significant influence on the results. The findings from this case study offer valuable insights for the preliminary design of future excavation projects.

1.1 Project Description

CP202 project is a deep excavation project located in the middle of a densely populated urban area. Moreover, there are several heritage buildings along the project area, which are built during the Dutch colonial era. The Indonesia National Standard (SNI) for geotechnics design requirement and the employer’s requirement design guideline strictly limit the criteria of building damage and settlement due to excavation activity. The diaphragm wall was selected as the Earth Retaining Stabilizing Structure (ERSS) for the station excavation and for the permanent structure of underground station. D-wall provides relatively more stiffness and water tightness rather than other possible options, such as soldier pile, secant pile, and sheet pile. With the higher stiffness and less water infiltration to excavation area, ground movement of the surrounding area was predicted to have less movement.

Figure 2 show the plan view of Harmoni station and the cross-section location for this study. Harmoni station is a parallel track type station with 16.6 m width and up to 20.0 m excavation depth. The main station consists of 2 basement levels, namely concourse level and platform level. Side structure is an adjacent structure with 6.75 m width and up to 12.0 m excavation depth, functioning as station entrance, ventilation tower, or cooling tower. This structure also acts as a connecting concourse level for passengers moving to the main station. The D-wall in main station side is 1.0 m thickness and 33.3 m length, while side structure D-wall is 0.8 m thickness and 26.3 m length.

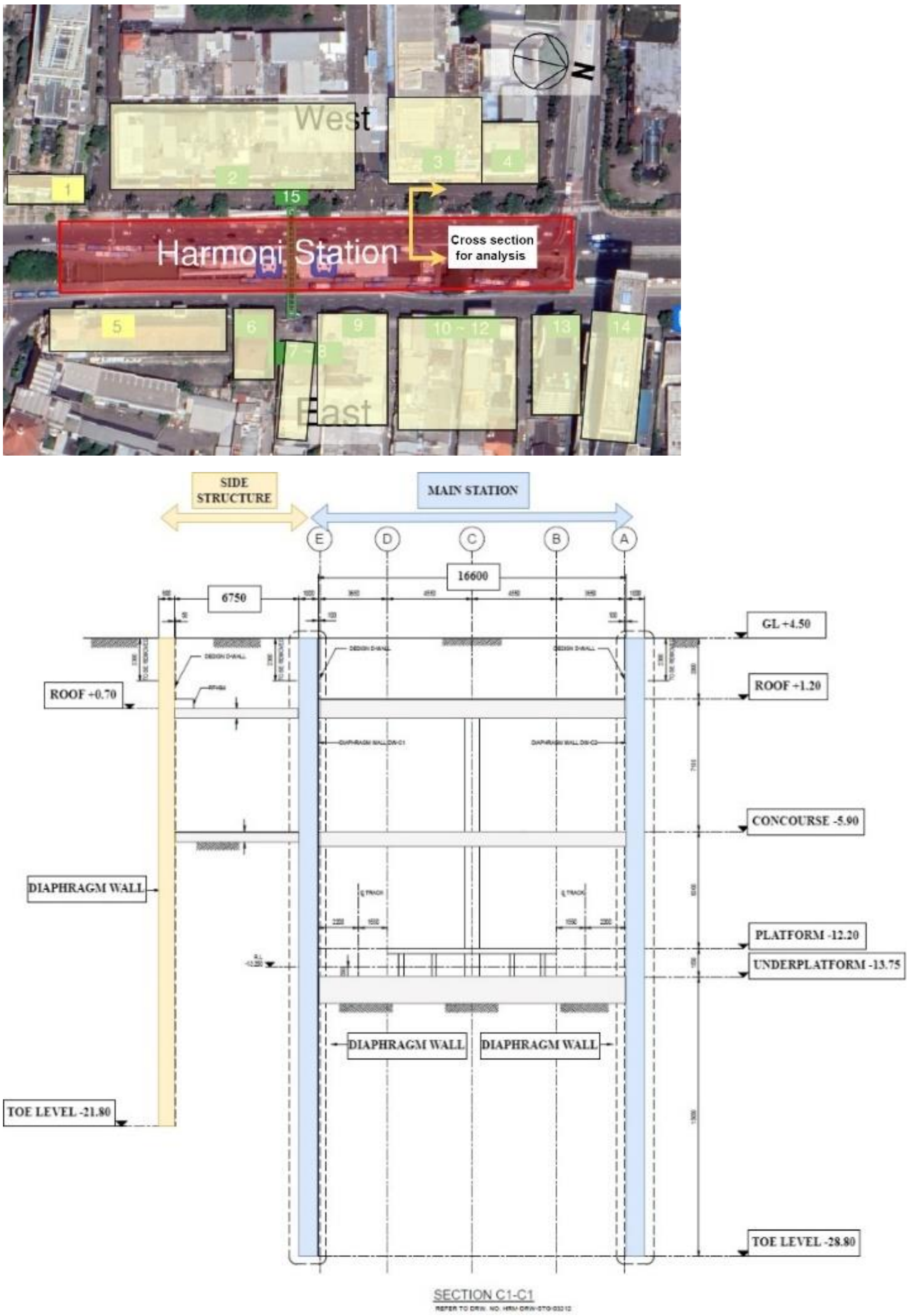


Figure 2. Plan view and cross-section of Harmoni Station permanent structures

Sawah Besar station (Figure 3) and Mangga Besar station (Figure 4) are stacked track type stations with 14.0 m width and up to 31.0 m excavation depth. The main station consists of 4 basement levels, namely concourse level, B2 platform level, mechanical level, and B4 platform level. Side structures dimensions vary with maximum width of 7.85 m and final excavation level can be as deep as 23.0 m depth depending on the functionality of the structure.

Since the excavation is deeper compared with Harmoni station, therefore thicker and deeper D-wall is used. Main station D-wall thickness in both stations is 1.2 m, however the length varies depending on which location the cross-section is taken. In this study, the cross-section in Sawah Besar station cooling tower and ventilation tower is taken. Main station D-wall maximum length is 48.0 m, while side structure D-wall is 1.0 m thickness and 48.0 m length. The cross-section in Mangga Besar station is taken in Entrance 2 area with main station D-wall 49.0 m in length, while side structure D-wall is 1.0 m thickness and 26.6 m length.

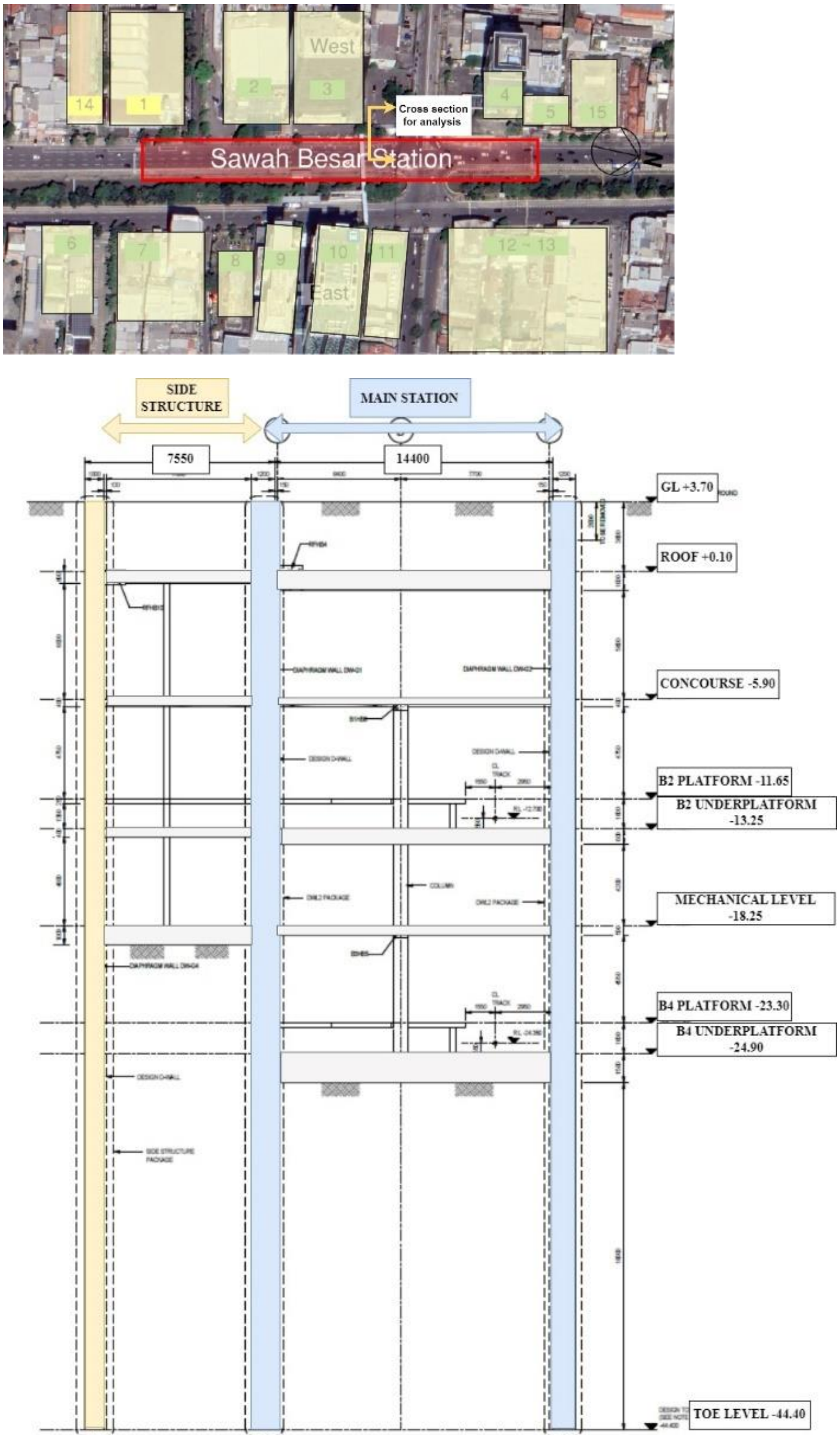


Figure 3. Plan view and cross section of Sawah Besar Station permanent structures

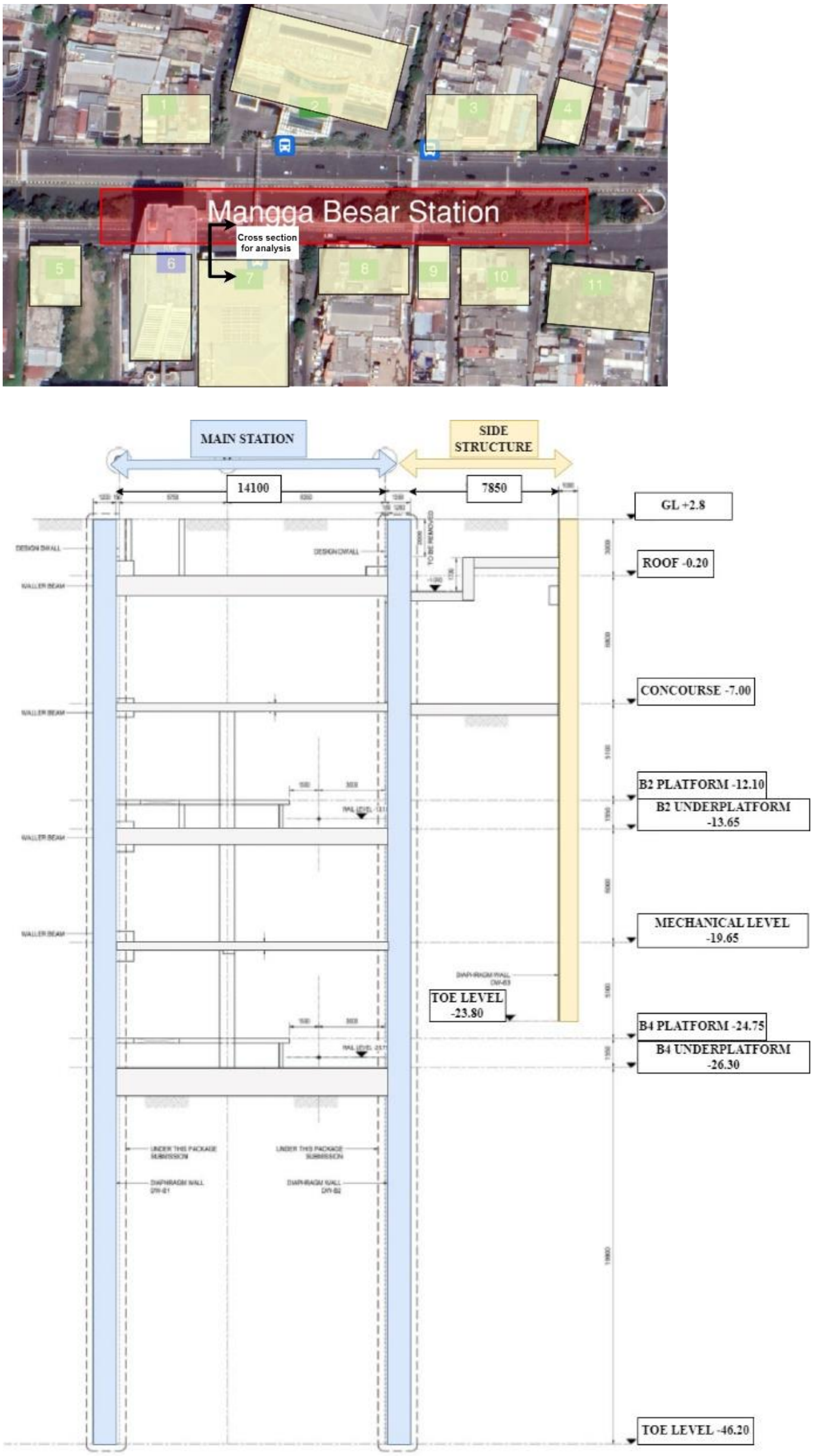


Figure 4. Plan view and cross section of Mangga Besar Station permanent structures

The slab thickness differs from each station. Table 1 shows the summary of slab thickness in every level and station. Slab thickness of side structure is not shown, since it is not simulated in this study.

Table 1. Summary of Station Slab Thickness

Station	Slab thickness (mm)				
	Roof	Concourse	B2 platform	Mechanical level	B4 platform
Harmoni	1000	800	1400	-	-
Sawah Besar	1000	400	800	500	1500
Mangga Besar	1000	400	800	400	1500

1.2 Double-Wall System

The main station D-wall and side structure D-wall were initially planned to be constructed at the same stage. The double row retaining wall has several advantages, such as a relatively low cost and very fast construction time needed. This system is usually called double-wall system as shown in Figure 5. During main station excavation (between east and west wall), entrance and west wall will act as double-wall system. Although double-wall system is an old method, it is relatively unpopular due to the mechanism how the system resists the lateral loading remain unclear. Major factors, such as soil-structure interaction, penetration depth, spacing between the front and rear walls, capping beam, strutting, and wall inclination determine the effectiveness of the system. Whether a project is suitable or not for adopting double-wall system should evaluate those factors.

Sim, et al. (2015) provided behavior and effectiveness of double-wall system (regarded as self-supported earth-retaining wall with stabilizing piles in the paper) in deep excavation located in South Korea. The ERSS system consists of two rows of soldier piles, timber lagging, wale, and H-beam as a tie beam between front and rear piles. Figure 6 shows the sketch of double-wall system components.

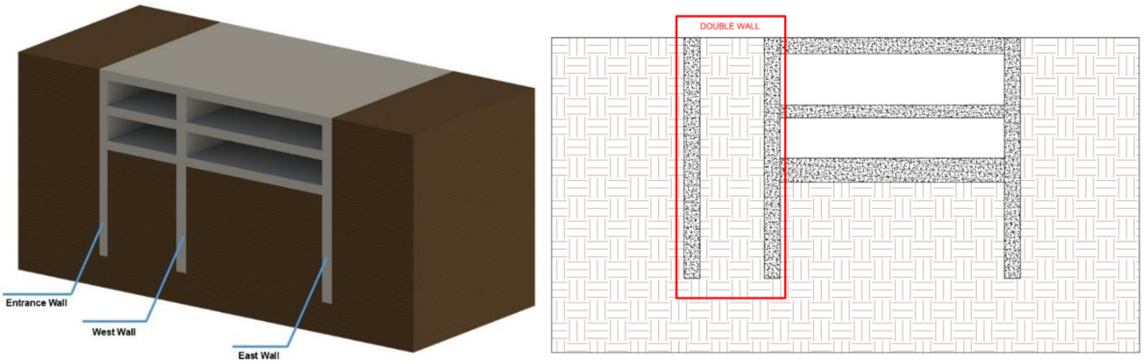


Figure 5. Components of Station Permanent Structures in CP202

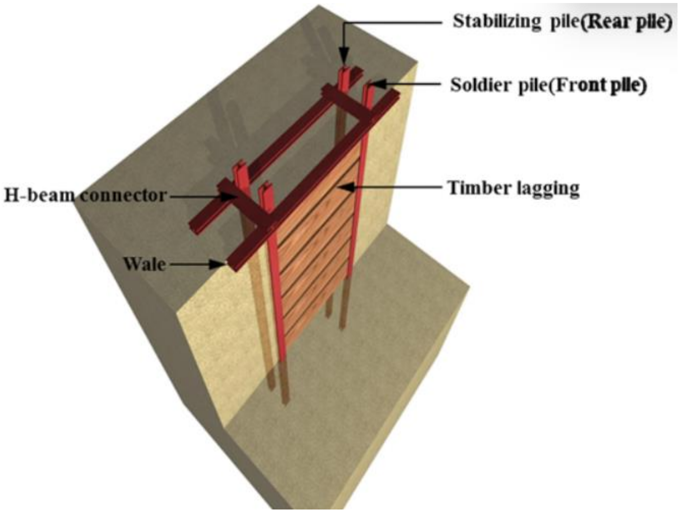


Figure 6. Components of a Self-Supported Earth-Retaining Wall with Stabilizing Piles (Sim et al., 2005)

Several past studies were done to determine the effectiveness and mechanism of double-wall system. Hsieh et al. (2003) recommended to use double-wall (using the rail steel beam as the pile) if the excavation has a very good sandy or rock conditions and excavation is less than 7.0 m. Utama (2021) conducted three-dimensional finite element analysis for two projects and showed maximum wall deflection can be reduced by 63% and 72% respectively for Taoyuan Guanyin and Taoyuan Yangmei cases. The research also highlighted the importance of capping beam to restrain the movement of front pile's head and keeping double-wall integrity.

The double-wall system in CP202 projects is without any tie beam connecting front row (main station D-wall) and rear row (side structure D-wall). The space between front and row piles is relatively wide. The South Korea project as presented by Sim, et al. (2015) used 2.5m spacing, while Taoyuan Guanyin and Taoyuan Yangmei project as presented by Utama (2021) used 1.0 m and 0.6 m spacing respectively. All three cases installed tie beam to connect front and rear row. This condition is different from CP202 project and will be highlighted later in the discussion chapter.

1.3 Soil Conditions of Jakarta MRT CP202 Project

Soil investigation was done to get the soil characteristic and parameters for design analysis purposes. In total, there are 48 boreholes and 23 Cone Penetration Tests (CPT) done across the project area. Based on the soil investigation, the general soil conditions in CP202 area are categorized as Alluvium Clay (AC), then Dilluvium Clay (DC) or Sand (DS). Clay and sand formed alternate layers found across the project area. In-situ tests and laboratory tests show the soil stratigraphy as:

a) The topmost soil is Alluvium Clay 1 (AC1) with varying thickness of 5 ~ 19 m.
b) followed by Upper Dilluvium Clay 1 (DC1) of approximately 1 ~ 12 m thickness.
c) The Lower Dilluvium Clay 1 (DC1) typically ranges from 4 ~ 14 m.
d) Dilluvium Sand 1 (DS1) separates the upper and lower DC1 layer, with varying thickness of 2 ~ 15 m.
e) Dilluvium Clay 2 (DC2) underlain AC1, upper and lower DC1, while Dilluvium Sand 2 (DS2) mostly appears as sand pockets inside DC2 layer.

Figure 7 shows the soil profile at the specific design section that will be analyzed in this research at each station.

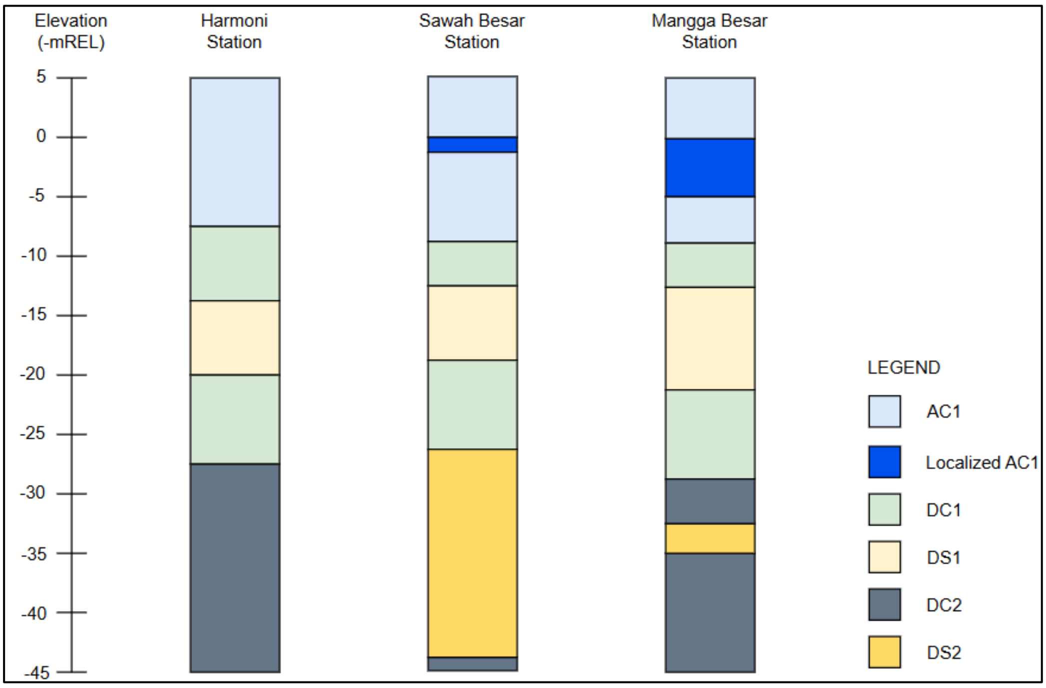


Figure 7. Soil Layer for Harmoni Station, Sawah Besar Station, and Mangga Besar Station

The groundwater level for each station taken from the average of observation wells, piezometer readings, and boreholes during standard penetration test (SPT) activity. Based on the available data, the groundwater level taken for analysis are:

Table 2. Groundwater level used in the analysis model

Station	GWL (m)
Harmoni	+3.20
Sawah Besar	+2.70
Mangga Besar	+2.10

1.4 Station excavation construction sequence

All three stations will be constructed using the top-down construction method with additional strut and waler system to further reinforce the ERSS system. Kingposts were constructed in the middle span of excavation to support the steel strut. Since there are 2 basements and 4 basements stations, the construction sequence is separated. Table 3 shows the construction sequence adopted in the Harmoni station analysis model, while Table 4 shows the construction sequence for Sawah Besar and Mangga Besar station analysis model.

Table 3. Construction sequence of Harmoni Station excavation

Sequence	Activity
1	Construct diaphragm wall, temporary bored piles, and kingpost (**side D-wall is activated in double-wall condition*)
2	Excavate to soffit of traffic deck and cast traffic deck
3	Excavate to soffit of roof slab and cast roof slab
4	Excavate to soffit of concourse slab and cast concourse slab
5	Excavate to -11.30 and install strut S1
6	Excavate to final excavation level

Table 4. Construction sequence of Sawah Besar and Mangga Besar station excavation

Sequence	Activity
1	Construct diaphragm wall, temporary bored piles, and kingpost (**side D-wall is activated in double-wall condition*)
2	Excavate to soffit of traffic deck and cast traffic deck
3	Excavate to soffit of roof slab and cast roof slab
4	Excavate to temporary prop and soffit of concourse slab. Cast concourse slab and install temporary prop.
5	Excavate to temporary prop and soffit of B2 underplatform slab. Cast B2 underplatform slab and install temporary prop.
6	Excavate to -22.60 and install strut S1
7	Excavate to -25.60 and install strut S2
8	Excavate to final excavation level

2 ANALYSIS METHOD

The Hardening Soil Model Undrained B was used because of the limitation on soil properties information and a more advanced constitutive model in PLAXIS analysis would take additional computational cost. Additionally based on Bui (2024), Hardening Soil model Undrained analysis can predict the retaining wall movement closely in MRT Ho Chi Minh Metro Line 1 Vietnam.

D-wall and concrete slab were simulated as plate elements. The steel struts were simulated as node-to-node anchors. The kingposts were simulated as fixed-end anchors (to capture more realistic condition by restraining vertical slab and strut movement). Temporary bored piles were simulated as embedded beam rows. The adjacent building nearby excavation area was simulated as a surcharge load (line load in PLAXIS).

Table 5. Soil parameter used in the FEM model

Soil Parameter	Units	Soil layer					
		AC1[**]	Upper DC1	Lower DC1	DC2	DS1	DS2
γ	kN/m^3	16	16.5	16.5	17.5	17.5	18
c_u	kPa	45~55[*]	85	100	150	-	-
ϕ	°	-	-	-	-	40	45
K_0	-	0.79	0.77	0.70	0.67	0.37	0.29
E_{50}	MPa	12	40	40	60	75	125
E_{oed}	MPa	9.6	32	32	48	75	125
E_{ur}	MPa	36	120	120	180	225	375
m	-	0.7	0.7	0.7	0.7	0.5	0.5
OCR	-	2	2	1.6	1.5	-	-

*For Harmoni and Mangga Besar station, cu = 45 kPa; Sawah Besar station, cu = 55 kPa

** For localised AC1 in Mangga Besar cu = 25 kPa and Sawah Besar cu = 20 kPa

The retaining wall deformation is dependent on the soil stiffness modulus. The Hardening-Soil (HS) stiffness E_{50} of the material can be estimated using the downhole seismic test as well as empirical correlations with SPT ‘N’.

For design $E_{50} = 0.2\, E_o$ and $E_{ur} = 0{,}6\, E_o$ based on Vardanega & Bolton (2011); Seed & Idriss (1970); S. Likitlersuang et. al. (2013).

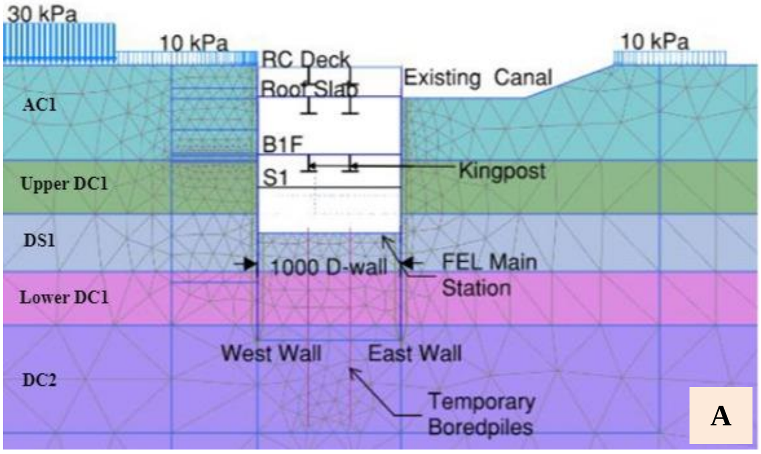
The shear modulus G_o obtained from the downhole seismic test is related to young modulus E_o based on the equation:

$$E_o = 2\,(1 + v)G_o$$

where G_o is the shear modulus and ν is the poisson ratio, assumed to be 0.3

E_{50} can also be correlated to SPT ‘N’ values. As proposed by Hsiung (2018) and Yong (2015), E_{50} is estimated to be 4‘N’ (MPa) for clay and 2‘N’ for sand. The Architectural Institute of Japan (2001) recommends a correlation of E_{50} = 2.8‘N’ for all types of soil.

The study simulated two separate models to evaluate the sequence of construction up to the final excavation level of the main station: one model with the side structure wall constructed and another without it. The results of these simulations were compared to assess the effectiveness of double-wall system in this project. Comparisons were made by analyzing D-wall deformation and bending moments.



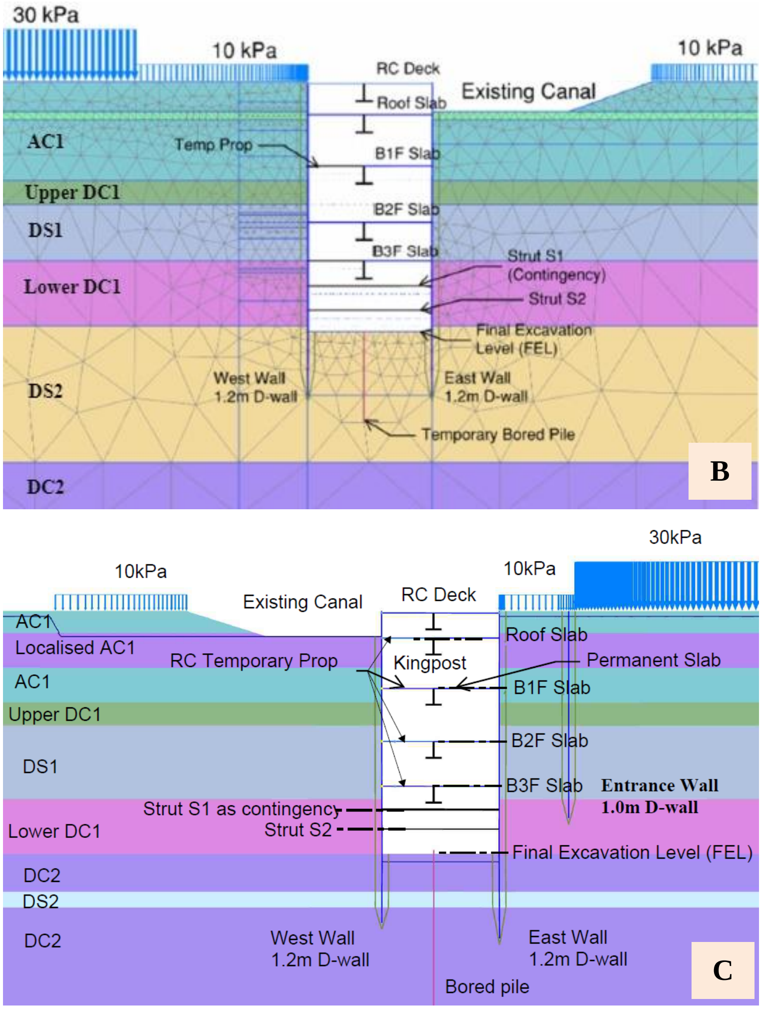


Figure 8. Station excavation PLAXIS Model for 3 stations: (a) Harmoni Station, (b) Sawah Besar Station, and (c) Mangga Besar Station

3 RESULTS

In this chapter, the results shown are taken from both PLAXIS models, which are taken at the stage “Excavation to the final excavation level” only. The “single wall” condition refers to the condition without side structure wall, while “double wall” condition refers to the condition where the side structure wall is constructed. The parameter input of both cases are identical, only D-wall structures activation differs.

According to the analysis result, single wall condition has relatively larger deformation than double wall condition. The result is following logical point of view that double wall condition provides more restraint to soil movement, hence a smaller deformation will occur. In Harmoni station, the deformation reduction shown is only maximum at 2 mm on the west wall. Moreover, the wall bending moment did not change much, meaning that double-wall did not contribute effectively towards providing higher stiffness. Please note the unbalanced condition, in this station the west wall is in the building area, while the east wall is located on the canal side. Bending moment is highly related to the D-wall rebar provision, therefore considering the time and cost needed to construct double-wall condition then it can be considered not beneficial. East wall is not directly influenced by the double-wall, the behavior change is due to the east-west walls are connected by struts and concrete slabs.

In Sawah Besar and Mangga Besar station, where D-wall length and excavation depth is deeper than Harmoni station, a similar wall behavior was observed. The side structure wall was not effectively contributing to reduce maximum wall deformation and bending moment, even at the deepest side structure wall, located in Sawah Besar station as shown in Figure 3. The West wall of Sawah Besar station is in a building area, while the East wall is near the canal. Meanwhile, in Mangga Besar station west wall is located near the canal, and east wall is in building area.

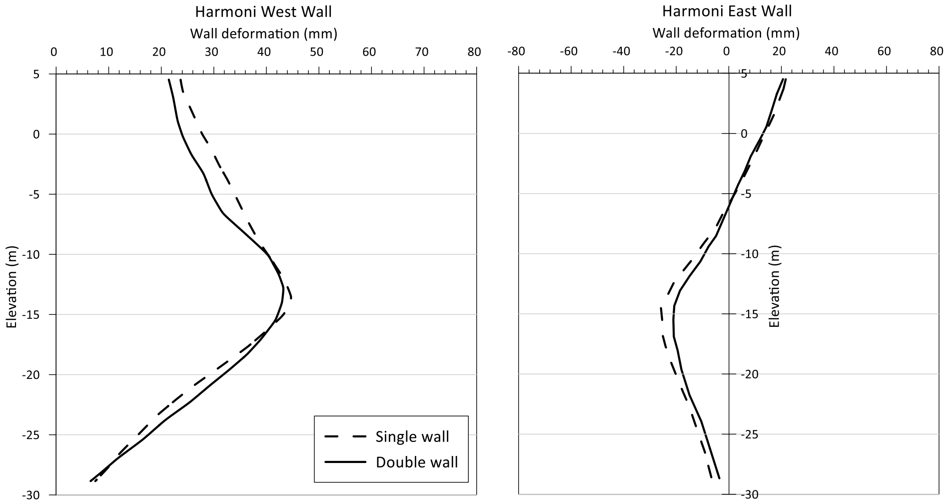


Figure 9. Wall deformation results for Harmoni Station in single and double wall condition

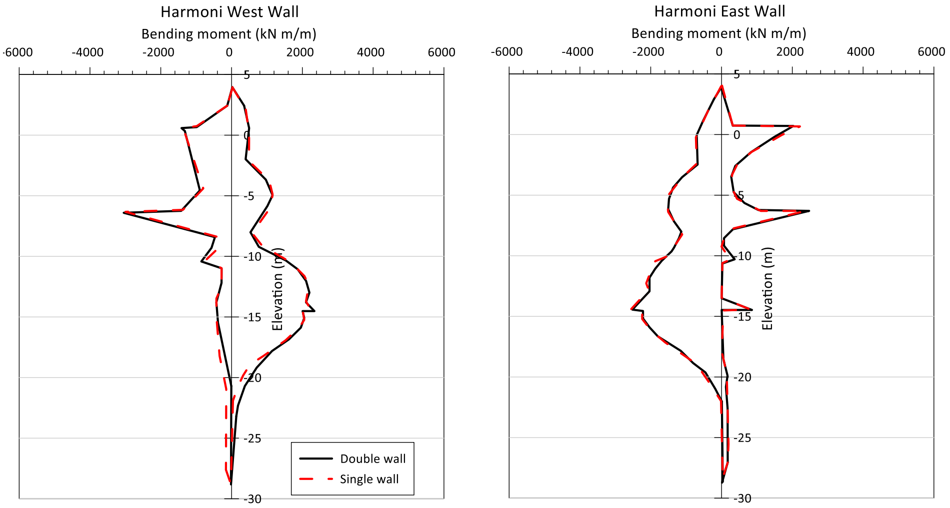


Figure 10. Diaphragm wall bending moment results for Harmoni Station in single and double wall condition

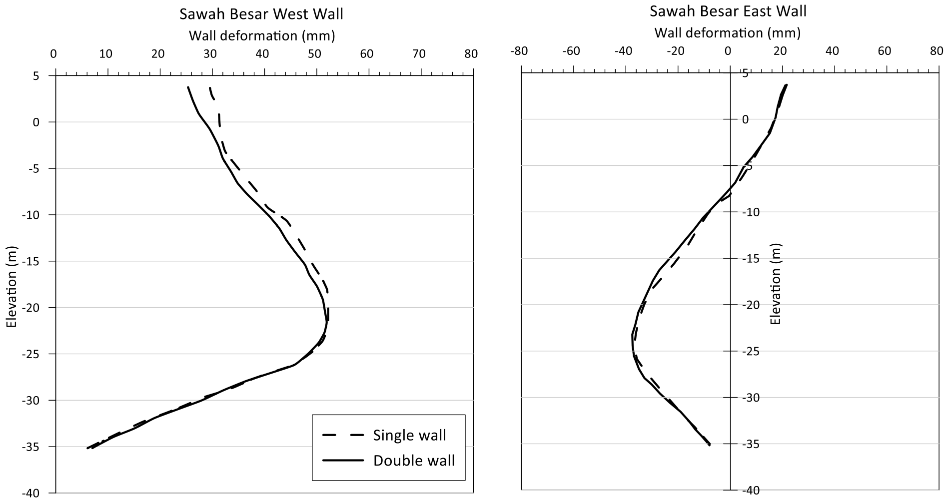


Figure 11. Wall deformation results for Sawah Besar Station in single and double wall condition

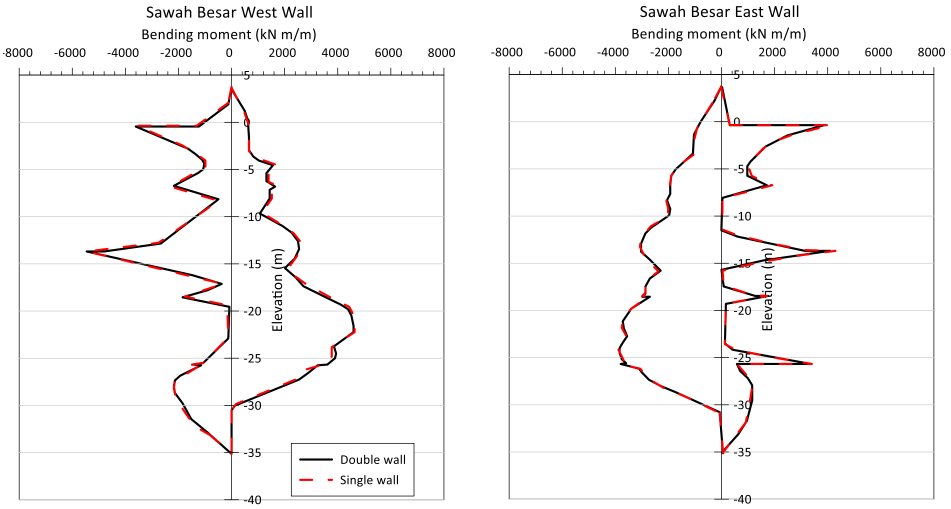


Figure 12. Diaphragm wall bending moment results for Sawah Besar Station in single and double wall condition

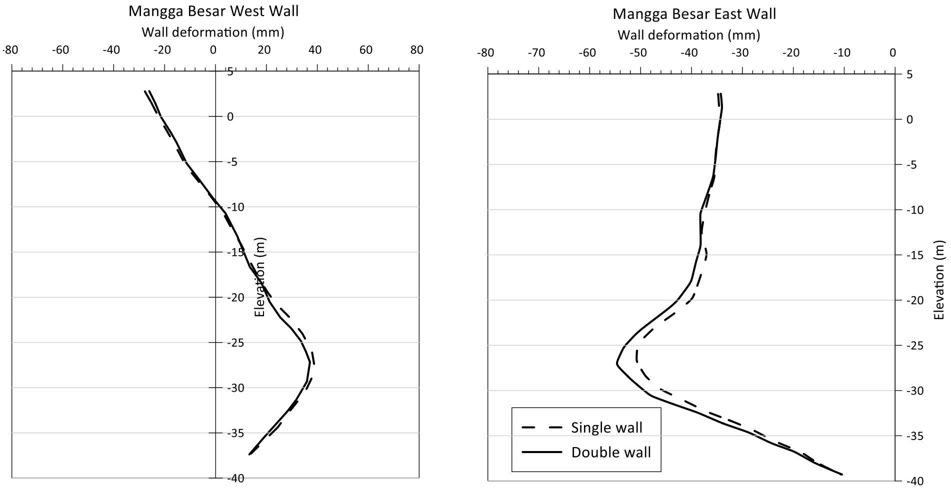


Figure 13. Wall deformation results for Mangga Besar station in single and double wall condition

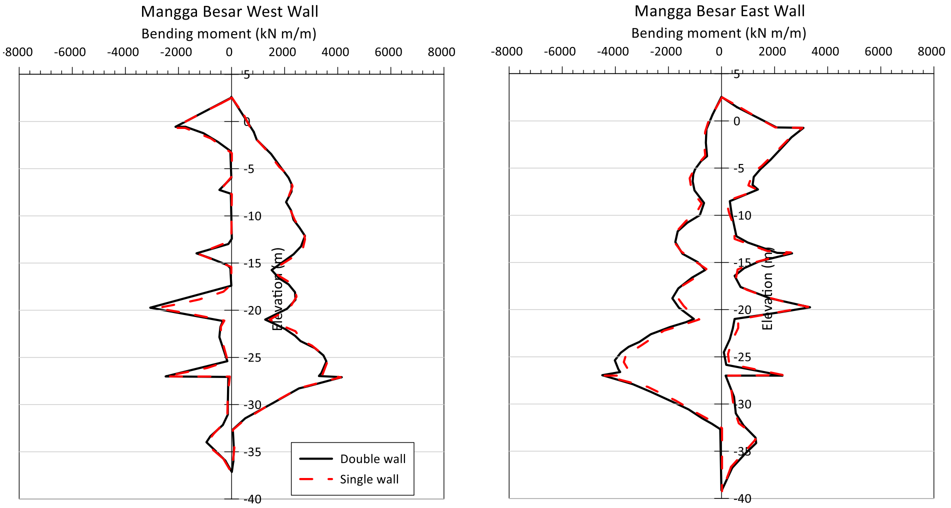


Figure 14. Diaphragm wall bending moment results for Mangga Besar Station in single and double wall condition

4 DISCUSSION

A notable contribution from the side structure wall can be seen in the upper elevation, from ground level up to around -20.0 m. The wall deformation in double-wall condition was smaller than single-wall condition. The side structure wall provides movement restriction for upper soil part to some extent. A notable wall behavior can be seen in Mangga Besar station result as shown in Figure 13, where the side structure wall depth is shorter than the main station wall. The wall deformation during double-wall condition is larger than the single-wall condition. The main station wall seems to be pushed by the self-weight of side structure wall, therefore increasing maximum deformation near the belly area. Figure 15 shows the sketch on different side wall conditions. Knowing this fact, lesser rebar ratio for D-wall reinforcement may be implemented due to less bending moment on the main station wall. It is beneficial from the contractor's point of view that rebar ratio can be reduced by comparing every possible construction sequence.

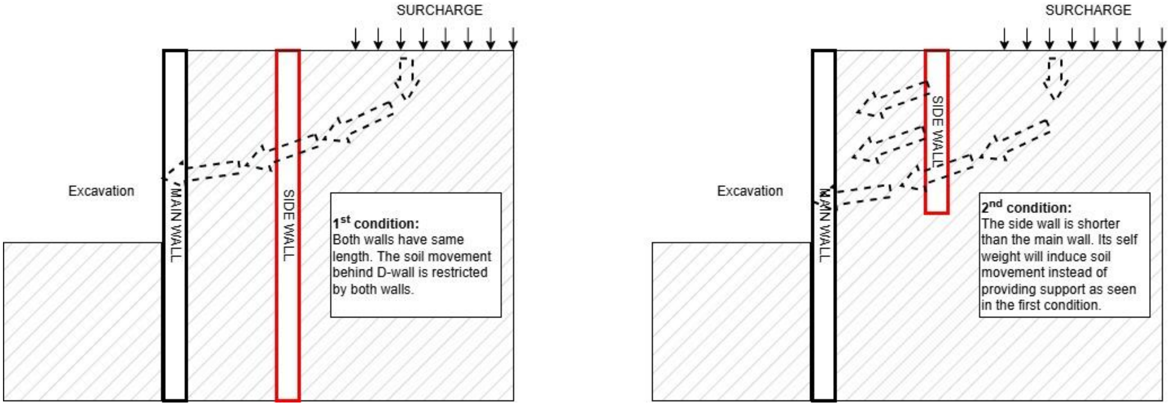


Figure 15. Different side wall conditions and its behavior

The double-wall system in CP202 project does not include capping beam between front row and rear row. The spacing between both walls was mostly governed by architectural plan layout and other contract conditions. This study does not exercise different conditions such as different caping beam conditions and different wall spacings.

Other case study by Utama (2021) compared Taipei Guanyin case under different excavation condition as shown in Figure 16. The soil layer for Taipei Guanyin case is clay in the top 3 meters, then underlain by a gravel layer. The red lines show excavation with capping beam installed can be compared with green lines for excavation without capping beam and strut installed. The front and rear piles with capping beam show maximum wall deflection of 1.75cm, on the other hand higher wall deflection until 2.6cm is observed for the condition without capping beam. The maximum wall deflection, which is located at the pile head, can be reduced up to 30% by installing capping beam. Therefore, capping beam installation is essential to make double-wall system works effectively and the maximum wall deflection moved to the middle of excavation.

The important role of capping beam to keep the system working effectively can be further observed in the various front-to-rear spacing conditions. Utama (2021) provides various capping beam modes to observe the wall deformation behavior as shown in Figure 17. It can be observed that the further front to rear spacing, the double wall system will work less effectively. The spacing of 0.5 m until 1.2 m result in similar head movement, however the belly shape is different between the front and rear piles, indicating they are not working simultaneously as a retaining system. The discrepancies become the largest at 2.0 m spacing where front piles move about 4.7 cm, while rear piles move about 3.7 cm only. Without capping beam, the system cannot collaborate well. It loses connection to make rear pile able to take part in resisting soil movement. The larger the front to rear pile spacing, the less rear pile contributions to sustain earth pressures.

Both excavations were carried out in different soil layer conditions. CP 202 excavation was conducted in a silty clay – sand soil layer, whereas Taipei Guanyin case was conducted in a clay – gravel soil layer. Therefore, the performance of capping beam in CP 202 excavation requires further studies.

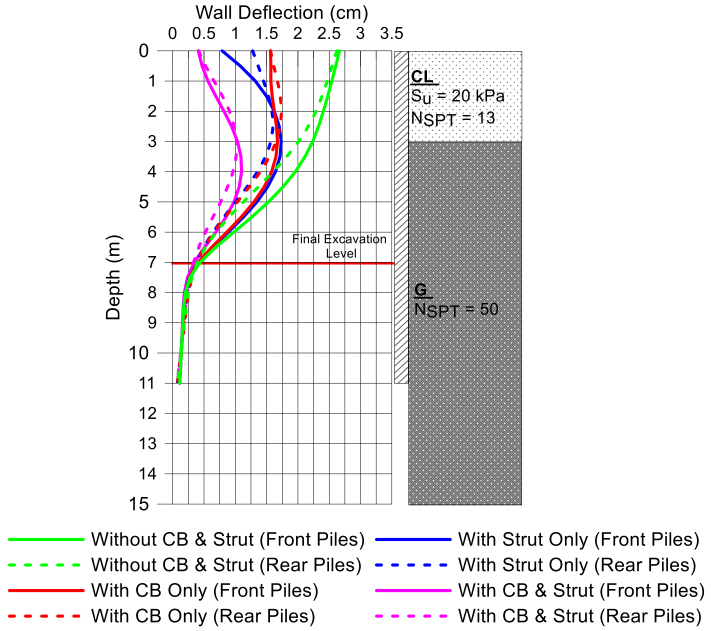


Figure 16. The comparison of wall deflection profile under different strut and capping beam conditions of the Taipei Guanyin Case (Utama, 2021)

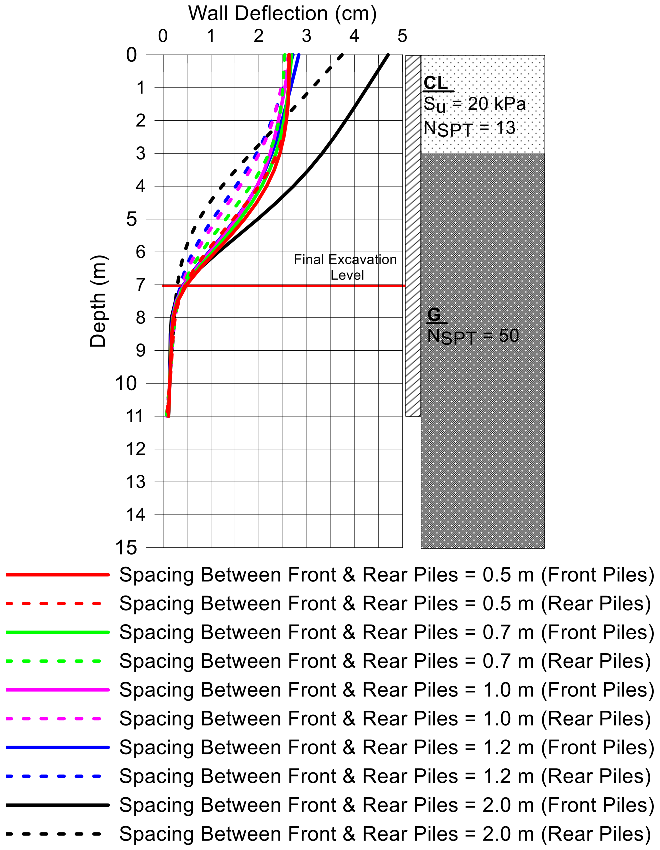


Figure 17. The comparison of wall deflection profiles under different front and rear pile spacings of the Taipei Guanyin Case without the capping beam (Utama, 2021)

5 CONCLUSION

In this case study, the effectiveness of diaphragm wall in double-wall condition is analyzed using Jakarta MRT CP202 project as the data source. The analysis utilized PLAXIS 2D model to obtain the wall deflection and bending moment, then compared the condition between the single-wall and double-wall conditions. The excavation of 3 MRT stations are modeled with its various site conditions. Based on the analysis model, it was found that double-wall system does not work effectively. The observed contribution of double wall is only reducing maximum wall deformation of 2 mm. It is contradictory with common knowledge that simply installing two rows of diaphragm wall can reduce the wall deformation. Moreover, the larger the spacing between the front and rear wall, the less effective the system to be. Capping beam becomes the essential component of the system to ensure both can collaborate in resisting soil pressures as studied by Utama (2021), however the effectiveness of capping beam itself in CP202 project need further studies. Considering the cost and time needed to install two rows of diaphragm wall, double-wall system is not recommended if no capping is installed at all. This study was done using Jakarta clay soil data and diaphragm wall as the ERSS in the top-down excavation method. Different excavation methods, soil conditions and ERSS system need further studies.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

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