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FINITE ELEMENT METHOD MODELLING OF STEEL SHEET PILE STRUCTURE ON DEEP FOUNDATION EXCAVATION

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ABSTRACT

Evaluation modelling of the OT-22 steel sheet pile wall with type H-350 steel strutting reinforcement in the excavation for the foundation structure with a depth of 7.50 meters was carried out to get the value of the safety factor and wall stability. The evaluation stages include subgrade investigation using the SPT method, data collection of profile steel properties used, interpretation of soil data, staged-construction modeling using the Finite Element Method (FEM) computer application, and analysis of modeling results. From the research that has been done, the value of maximum bending moment (M_{max}) is 223.8 kNm/m', the magnitude of the axial force that occurs in the strut members is 22.51 kN, 121.91 kN, and 66.10 kN respectively. The value of maximum lateral displacement (U_x) is 62.4 mm. From these results, it can be concluded that the lateral displacement (U_x) that occurs is much larger than allowable displacement (U_{all}) 39 mm. Thus, it is necessary to modify the existing sheet pile wall system, such as to change the dimensions of the steel sheet pile, changing the dimensions of the steel strutting, or changing the distance of the steel strutting.

Keywords: deep excavation; steel sheet pile; steel strutting; finite element method (FEM); lateral displacement.

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INTRODUCTION

The construction of tall buildings in the vertical direction in big cities is a necessity, with the increasing price of land and limited land. The construction of a vertical basement basement to meet the needs of service rooms and parking areas is an unavoidable choice. (Widjaja & Makarim, 2020) Construction of a basement in its implementation is not easy, considering the excavation process requires a suitable soil retaining system and careful excavation planning, especially in densely populated areas where the distance between buildings is quite close, the groundwater level is high, in areas with very soft soil conditions, (Taqwa, Hutabarat, et al., 2019) and earthquake-prone areas. (Berangket & Prakoso, 2018)

In the process, the development towards the bottom using the method of deep excavation or deep excavation. (Wadino et al., 2018). It is a challenge to find the right excavation method and retaining system so that it does not have a negative effect on the buildings around the excavation and the construction of cement construction can be carried out quickly.

Excavation work is important in geotechnical science, given that there are many factors that influence excavation work for cement, including soil properties, groundwater conditions and control, excavation dimensions, support systems, and facilities around the excavation.

The movement that occurs in the retaining wall due to deep excavation carried out for the construction of cement and leaks that can occur in the retaining wall are very critical factors that need to be considered. Soil excavation that causes changes in stress and strain in the soil can result in deformation of the soil. The deformation that occurs can be very dangerous, both for the workers in the excavation, as well as the buildings around the excavation site. (Fahriani, 2011; Finno et al., 2005; Laefer, 2001). Especially if the soil around the wall is embankment soil which is still undergoing consolidation. (Fadli et al., 2021; Taqwa, Chayati, et al., 2019)

To reduce the impact due to deformation that occurs, excavation support systems are widely used in the excavation process. This support system can be in the form of sheet piles, soldier piles, secant piles, continuous bored piles, and diaphragm walls. (Firmasyah, 2015; Kartikasari & Abdurrozak, 2018; Kenawi & Ibrahim, 2017; Rustiani & Lyman, 2017).

This study aims to obtain the value of the safety factor and stability of the OT-22 steel sheet pile wall with type H-350 steel strutting reinforcement in excavations for foundations with a depth of 7.50 meters above soft clay using the Element Method model. Until. (Lutfi et al., 2014).

In planning cliffs, complete data is needed to be able to produce precise calculations. So that the planned retaining wall will be stronger and last longer (Taqwa FML et al, 2017). Subgrade reinforcement also affects the condition of the building above it. Included in planning roads so that good planning results will be obtained and can be continued with construction (Syaiful S, Rusfana H, 2022).

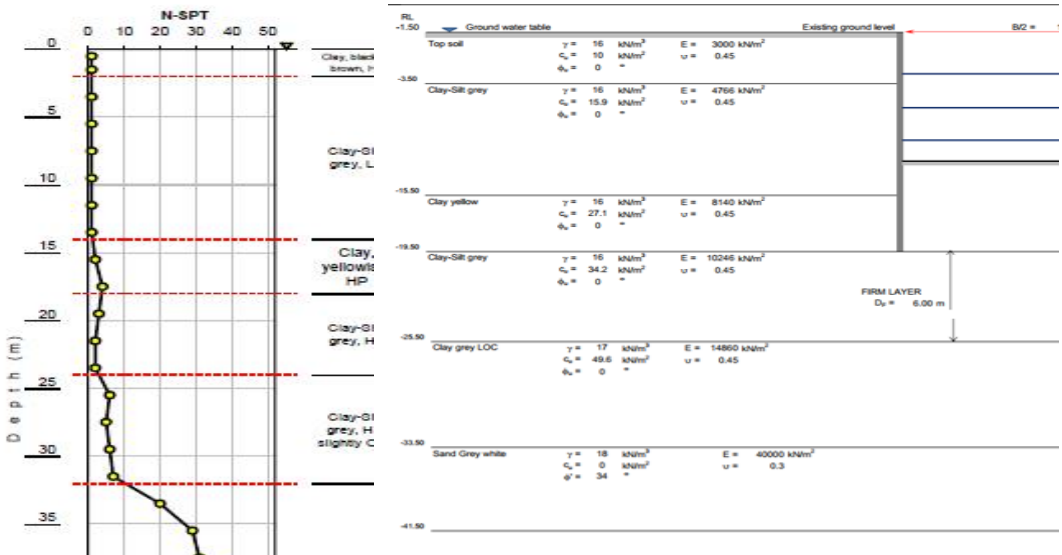
RESEARCH METHODS

Research stages

The stages of the research include subgrade investigation using the SPT method, data collection of profile steel properties used, interpretation of soil data, phased construction modeling with the finite element method (MEH) computer application, and analysis of modeling results.

This deep excavation foundation is a substructure with a design excavation height of 7.5 m from the ground surface. To overcome unexpected conditions in the field in the form of excess excavation (over cut) by operator error in digging with an excavator or poor control by field supervision, the design excavation height is the design excavation height plus an estimated over cut permit of 0.3 meters, so the design excavation height (H0) is 7.8 meters.

Soil investigation was carried out using the SPT (Standard Penetration Test) test with a test depth of 50m. Based on the results of observations and measurements the ground surface is at an elevation of 1.5m from the datum line and the water level is the same as the ground surface. The results of the soil test are shown in Figure 1.



No	Soil Layer	Depth (m)	γ (kN/m^3)	c_u (kN/m^2)	ϕ_u / ϕ' (°)	E (kN/m^2)
1	Top Soil	0.0 – 2.0	16.0	10	0	3,000
2	Clay-Silt grey	2.0 – 14.0	16.0	7.5 – 24.3	0	2,246 – 7,286
3	Clay yellow	14.0 – 18.0	16.0	24.3 – 29.9	0	7,300 – 8.980
4	Clay-Silt grey	18.0 – 24.0	16.0	30.0 – 38.4	0	8,986 – 11,506
5	Clay grey LOC	24.0 – 32.0	17.0	38.4 – 60.8	0	11,500 – 18,220
6	Sand grey-white	32.0 – 40.0	18.0	-	34	40,000

Figure 1. Soil profile and interpretation of soil data Source: Lab Documentation. Soil Mechanics, 2019.

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Based on the picture above, it is shown that at a depth of 0 – 24m is a soft-clay soil type with an NSPT value between 0-5, at a depth of 24m – 32m is a medium-clay soil type with an NSPT value between 5 – 10, while a depth of 32m – 50m is sand with an average NSPT value of 30.

Deep Digging Geometry

The geometry of the excavation and the support system is shown in Figure 2 below.

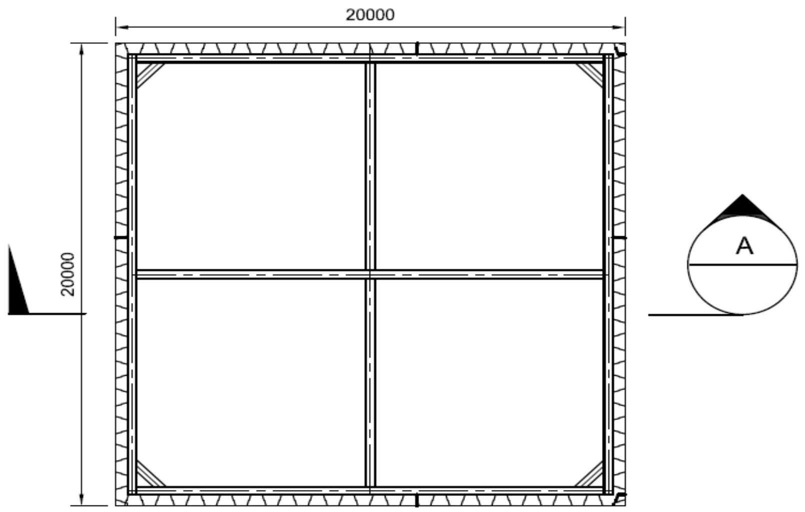

Figure 2. Top view of the foundation excavation plan

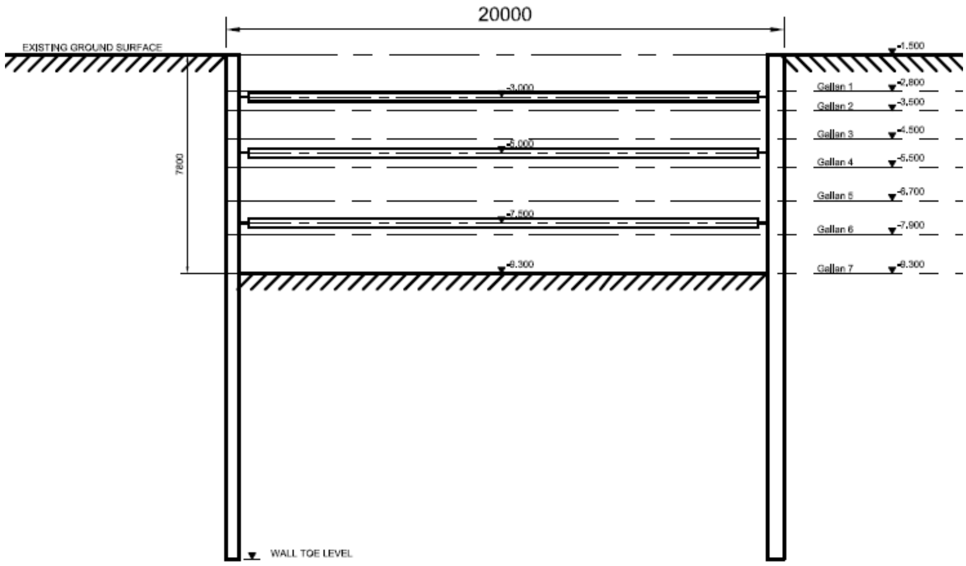

Figure 3. Sections of the foundation excavation plan

Deep Excavation Structure System

The deep excavation structure consists of retaining walls, namely steel sheet piles along with horizontal beams (wale) and strutting, namely H steel profiles. The design wall length is 18 m. Steel material properties are shown in table 1 below.

Table 1. Material properties of sheet pile and steel strutting

Structure		Sheet Pile	Strutting
Profile		OT 22	H350 x 350 x 12 x 19
Area	(A)	187.3 cm^2/m	173.90 cm^2
Moment of Inertia	(I)	53584 cm^4/m	13600 cm^4
Cross-sectional modulus	(S)	2200 cm^3/m	
Distance between	d		10m
Long	L	18m	10m

Source: Lab Documentation. Soil Mechanics, 2019.

The stages of deep excavation construction are as follows:
a. Phase 0: Initial conditions
b. Phase 1: Digging to a depth of 1.3m

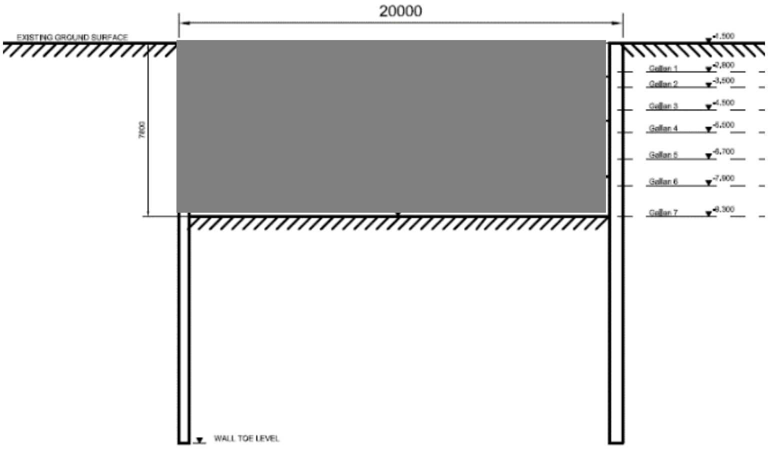

Figure 4. Excavation plan phase 1

a. Phase 2: Excavation to a depth of 2.0m and installation of level 1 . struts

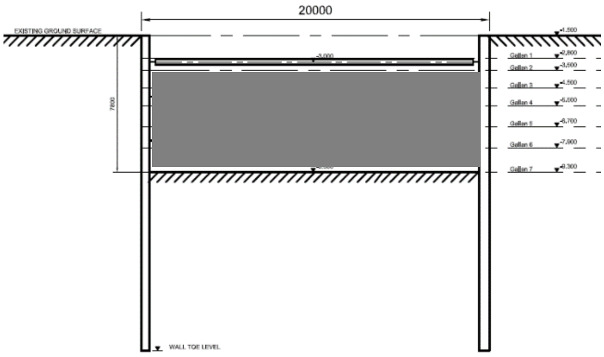

Figure 5. Excavation plan phase 2

b. Phase 3: Digging to a depth of 3.0m

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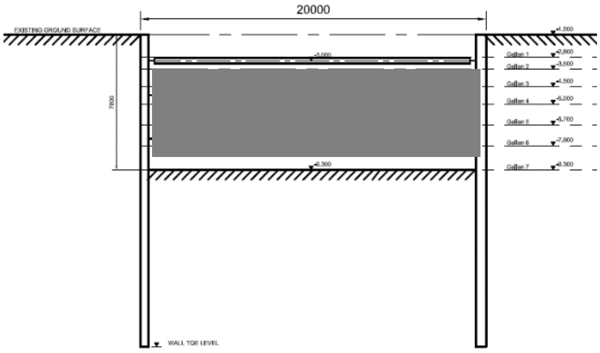

Figure 6. Excavation plan phase 3

c. Phase 4: Digging to a depth of 4.0m

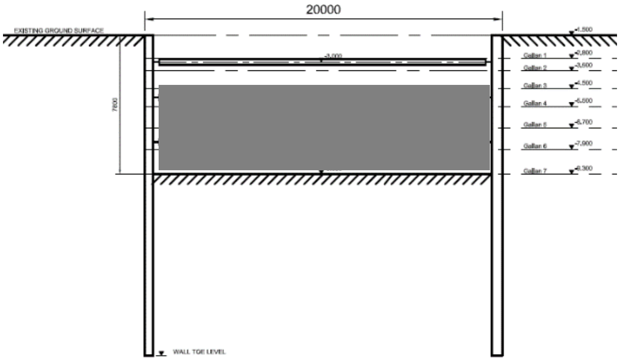

Figure 7. Excavation plan phase 4

d. Phase 5: Excavation to a depth of 5.2m and installation of level 2 strut

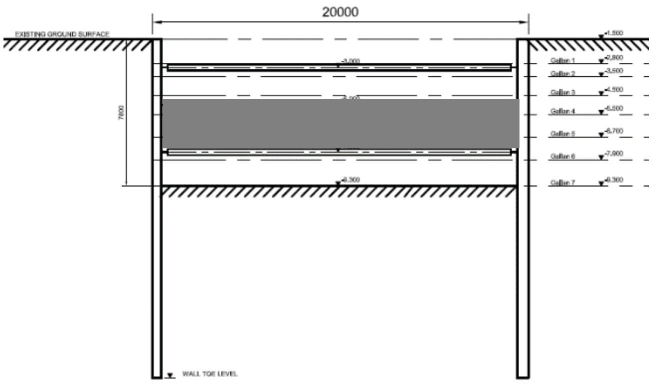

Figure 8. Excavation plan phase 5

e. Phase 6: Digging to a depth of 6.4m

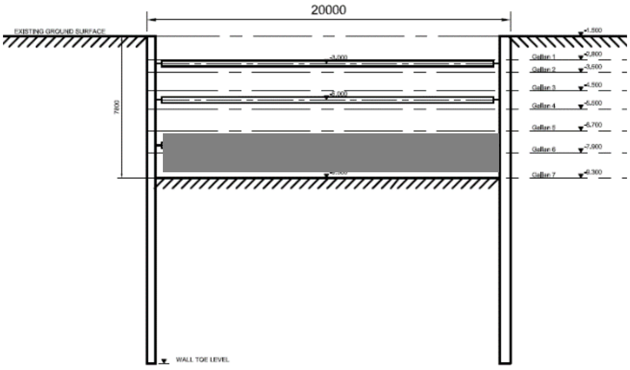

Figure 9. Excavation plan for phase 6

f. Phase 7: Excavation to a depth of 7.8m and installation of level 3 struts

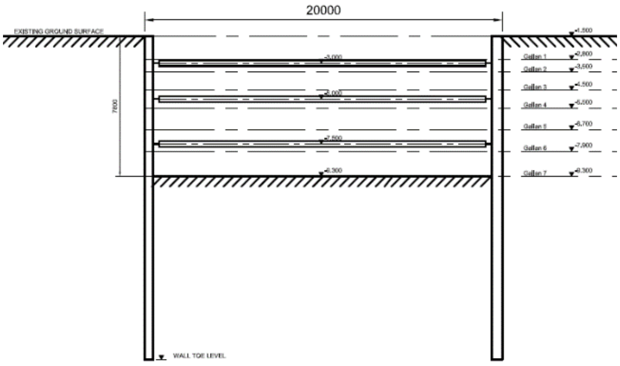

Figure 10. Excavation plan phase 7

Finite Element Modeling

The finite element model of soil, sheet pile and strutting elements is shown in Figure 12. The construction load is assumed to be 10 kN/m^2.

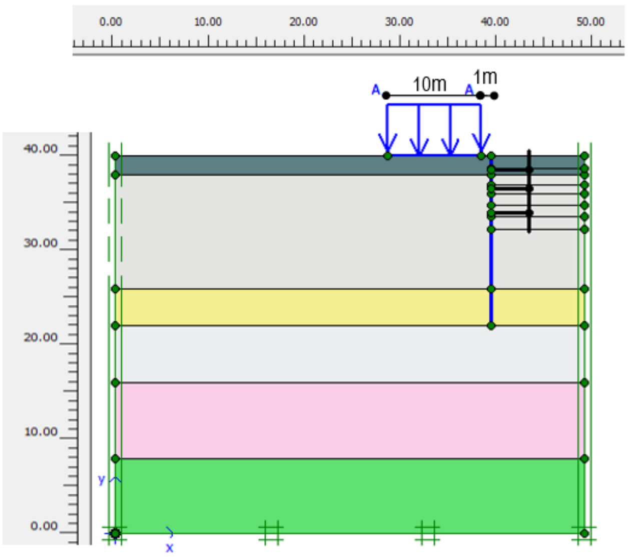

Figure 11. Finite Element Method Model

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Ground support system parameters

The parameters of the ground support system are shown in table 2 below.

Table 2. Steel strutting properties

Parameter	Name	Value	Unit
Type of behaviour	Material type	Elastic	
Normal stiffness	EA	3478000	kN
Spacing out of plane	L	10	m
Maximum force	Fmax,com	$1*10^{15}$	kN
	Fmax, tens	$1*10^{15}$	kN

Source: Lab Documentation. Soil Mechanics, 2019

The Mohr-Coloumb soil model parameters are shown in table 4 below.

Table 3. Properties of soil materials

Parameter		Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Unit
Material model	Model	MC	MC	MC	MC	MC	MC	
Type of material behaviour	Type	Undrained	Undrained	Undrained	Undrained	Undrained	Drained	
Soil unit weight	□$_{unsat}$	16	16	16	16	17	18	kN/m^3
Horizontal permeability	k_x	1.E-09	1.E-09	1.E-09	1.E-09	1.E-09	1.E-03	m/s
Vertical permeability	k_y	1.E-09	1.E-09	1.E-09	1.E-09	1.E-09	1.E-03	m/s
Young modulus	E_{ref}	3000	2246	7300	8986	11500	40000	kN/m^2
	E_{inc}	-	420	420	420	840	-	kN/m^2
Poisson ratio	□	0.45	0.45	0.45	0.45	0.45	0.35	
Cohesion	c_{ref}	10	7.5	24.3	30	38.4	-	kN/m^2
	c_{inc}	-	1.4	1.4	1.4	2.8	-	kN/m^2
Friction angle	□	0	0	0	0	0	34	º
Dilatancy angle	□	0	0	0	0	0	4	º
Strength reduction factor inter	R_{inter}	0.5	0.5	0.5	1	1	1	

Source: Lab Documentation. Soil Mechanics, 2019

RESULTS AND DISCUSSION

Finite Element Method analysis results

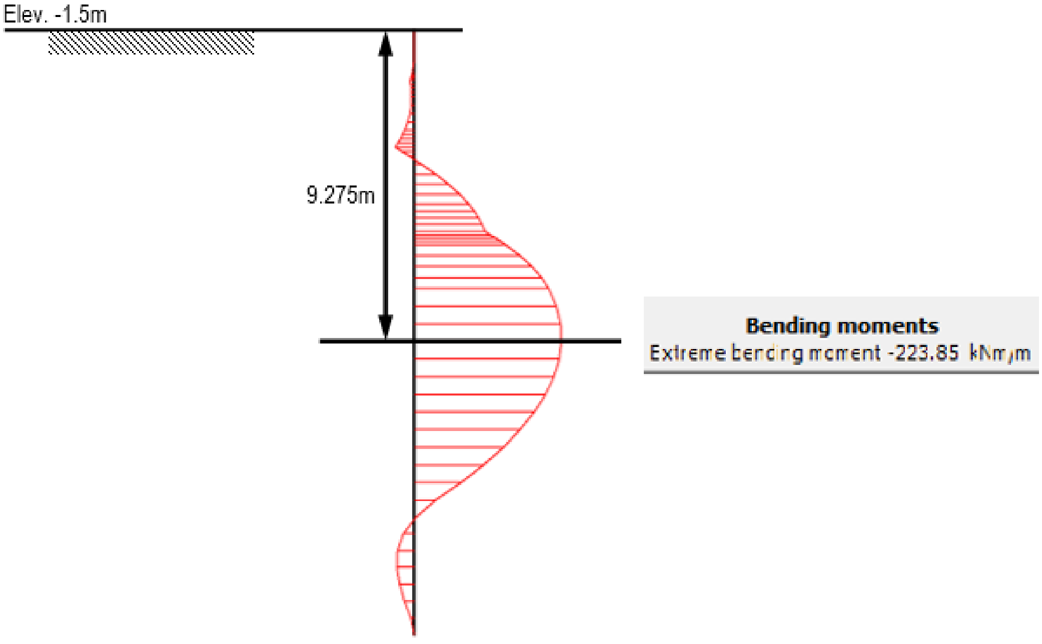

Figure 12. Maximum moment that occurs in the sheet pile system

The picture above shows that the maximum moment on the sheet pile is 223.85 kNm/m at a depth of 9.275m from the ground surface. So the required sheet pile modulus (Section modulus (Sreq)) = 1.5M / fy = (1.5) (223.85 x 106) / 335 = 1002313.4 mm3.
Due to the required modulus of sheet pile cross-section (Sreq) of 1022.3 cm3/m < much smaller than the modulus of cross-sectional sheet pile OT22 (S = 2200 cm3/m) therefore the use of sheet pile OT22 is declared safe.

Lateral displacement at the end of construction

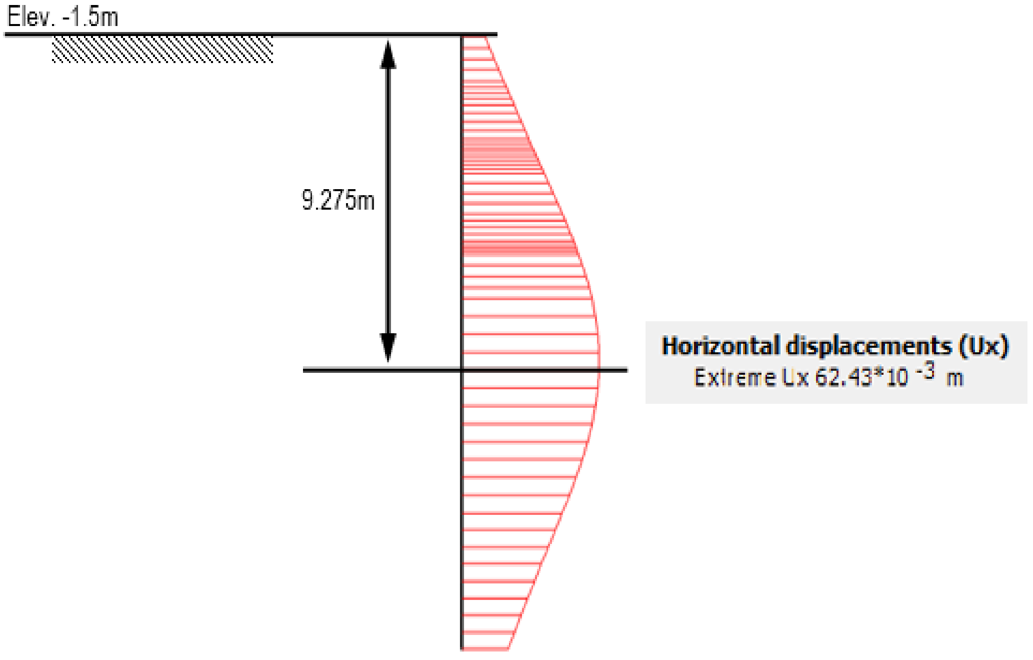

Figure 13. Lateral movement occurring at the end of construction

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The maximum lateral displacement in sheet pile is 62.43 mm, which occurs at a depth of 9.275m from the ground surface. much greater than the permissible lateral displacement of permit = 0.5% x H0 = 0.5/100 x 7800 mm = 39 mm. The axial force that occurs on each support, is shown in the table

Table 4. Axial strut forces at the final stage of construction

Fixed-end Anchor	Depth [m]	F [kN/m]
1	- 3,00	-22.509
2	- 5,50	-121.909
3	- 7,50	-66.098

Modification of the Sheet Pile Wall Model

Based on the results of plaxis analysis at the final stage of construction, the maximum lateral displacement (Δmax) in sheet piles is 62.43 mm, much larger than the permitted lateral displacement of permit = 39 mm.

So to reduce the lateral displacement that occurs in sheet piles, some modifications are made to the model, and they can be shown in the table below.

Table 5. Modification of reinforcement dimensions and parameters

No	Method	U_x modif (mm)	Ux awal (mm)	% reduce
1	Changing Sheet Pile Dimensions (OT22 OT26)	62.43	62.43	0
2	Changing strut Dimensions (OT22; H350 H450)	62.43	62.43	0
3a	Changing the strut spacing (OT22; H350; s = 10m 5m)	59.35	62.43	4.93
3b	Change the spacing and dimensions of the struts (OT22; H400; s = 10m 5m)	59.35	62.43	4.93
4a	Changing the length of the sheet pile depth to a stiffer soil layer (OT22; D = 18m 25m; H350; s = 10m)	61.79	62.43	1.03
4b	Changed the length of the sheet pile depth to a stiffer soil layer and strut dimensions (OT22; D = 18m 25m; H400; s = 10m)	61.79	62.43	1.03
4c	Change the length of sheet pile depth to a stiffer soil layer and strut spacing (OT22; D = 18m 25m; H350; s = 5m)	58.89	62.43	5.67
4d	Changed the length of the sheet pile depth to a stiffer soil layer and the sheet pile dimensions and strut spacing (OT26; D = 18m 25m; H350; s = 5m)	58.89	62.43	5.67

CONCLUSION

Based on the table above, it shows that changing the dimensions of the sheet pile or strut does not have a significant or no effect on reducing the maximum lateral displacement of the sheet pile. This is because the maximum lateral displacement in sheet piles occurs in the soil (below the bottom of the excavation) so that soil properties become one of the most decisive factors in reducing the maximum lateral displacement in sheet piles. Reducing the longitudinal distance between the struts also has a significant effect on the lateral displacement of the sheet pile because the active soil forces that occur on the walls are held by the struts to be smaller based on the distance between the struts, thereby increasing wall stiffness.

It can be concluded that the reduction of lateral displacement in sheet piles is generally influenced by the type and properties of the soil and the longitudinal distance between the struts. But the strut spacing reduction factor has a very small effect on the lateral displacement of the sheet pile compared to the soil factor of about 4.9%. In addition, the spacing strut reduction factor has limitations, namely it will reduce the workability of the excavator in digging where the free area for digging is reduced, this will have a direct impact on the duration of the project and will affect the project cost indirectly.

In addition to the above, the location of the foot of the sheet pile on a hard/rigid soil layer will affect the piling work where the tip of the sheet pile will be damaged when driving on a hard/rigid soil layer where the sheet pile thickness is thin.

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