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Feasibility study of an earth-retaining structure using in-situ soil with dual sheet piles

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Abstract. Classic braced walls use struts and wales to minimize ground movements induced by deep excavation. However, the installation of struts and wales is a time-consuming process and confines the work space. To secure a work space around the retaining structure, an anchoring system works in conjunction with a braced wall. However, anchoring cannot perform well when the shear strength of soil is low. In such a case, innovative retaining systems are required in excavation. This study proposes an innovative earth-retaining wall that uses in situ soil confined in dual sheet piles as a structural component. A numerical study was conducted to evaluate the stability of the proposed structure in cohesionless dry soil and establish a design chart. The displacement and factor of safety of the structural member were monitored and evaluated. According to the results, an increase in the clearance distance increases the depth of safe excavation. For a conservative design to secure the stability of the earth-retaining structure in cohesionless dry soil, the clearance distance should exceed 2 m, and the embedded depth should exceed 40% of the wall height. The results suggest that the proposed method can be used for 14 m of excavation without any internal support structure. The design chart can be used for the preliminary design of an earth-retaining structure using in situ soil with dual steel sheet piles in cohesionless dry soil.

Keywords: Earth-retaining structure using in situ soil; dual steel sheet pile; numerical analysis; cohesionless dry soil; preliminary design chart

1. Introduction

Earth-retaining structures should be installed to minimize the level of relaxation induced by deep ground excavation (Cakir 2014). Depending on the form of the wall structure, earth-retaining structures can be specified as sheet pile walls, bored pile walls, and continuous pile walls, among others. The type of earth-retaining structure can be selected in accordance to various criteria such as the type of soil, soil characteristics, the excavation depth and width, stability, and constructability. To design an optimal earth-retaining structure, all these criteria must be carefully considered. Recently, the seismic behavior of earth-retaining structure has been considered for design (Ismeik and Shaqour 2015, Cakir 2017).

In classic earth-retaining structures using wales and struts, a number of difficulties are often encountered, including a confined work space from internal supporting structures, time-consuming installation processes, and relatively high construction costs. If the water table is high, then braced-wall excavation requires closer attention (Xiang *et al.* 2018).

To verify the feasibility of sheet piles as earth-retaining wall structures, many studies have employed numerical analysis techniques. Susumu *et al.* (1993) demonstrated the difference between large and negligible deformations in similar types of sheet pile quay walls through an FEM analysis. Nyby (1981) focused on the interaction between soil and sheet piles by considering the frictional resistance between them based on the interface element through an FEM analysis. Crawford *et al.* (2002) conducted numerical analyses and experimental tests to predict the bending strength of Larssen steel sheet piles.

Experimental studies have used sheet piles for retaining walls. Jamshidi *et al.* (2010) conducted an experimental study to evaluate dynamic deformation characteristics of sheet pile retaining walls with fiber-reinforced backfill. Sheet piles have been applied to various types of soil conditions. Sheet piles have been used as earth-retaining wall structures for sandy soil (Tefera *et al.* 2006, Nago *et al.* 1984, Adalier *et al.* 1998, Bransby *et al.* 1975, Qu *et al.* 2016). Finno *et al.* (1989), and Stewart *et al.* (1994) showed that sheet piles can be used for earth-retaining wall structures in the clay layer.

In particular, cofferdams using dual sheet piles have been examined in Japan since the 1970s. The cofferdam concept is about preventing water flow during construction in rivers or seas to obtain a dry work space (Kouichi *et al.* 1988, Taisaku *et al.* 1995, Masatoshi 1974). However, the space between two sheet piles must be filled with gravel and concrete to resist water pressure and achieve self-support.

To cope with problems associated with the workability of earth-retaining structures, self-supporting earth-retaining wall (SSR) systems have been proposed. The SSR system

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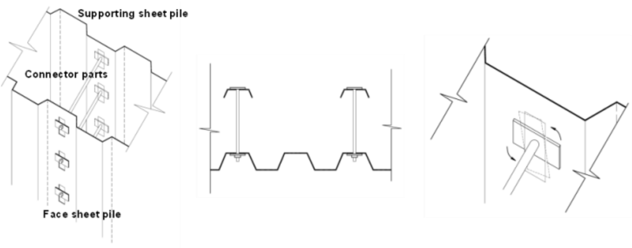
represents a type of gravity structure consisting of twin parallel lines of piles driven below the excavation level and tied head of soldier piles and landslide-stabilizing piles by beams. The SSR system reduces earth pressure from the unification of two parallel lines of piles (Kim 2008). The SSR system is known to increase workability because it requires no internal structural support such as wales and struts. Shin *et al.* (2015) suggested a cost-effective SSR system using the H-pile. Sim *et al.* (2009, 2015) suggested a self-supporting earth-retaining structure with stabilizing piles. To cope with problems concerning ground movements, such as subsidence and horizontal displacement, a self-supporting dual soldier-piled wall system has been proposed. Subsidence, horizontal displacement, a tilting angle on the wall crest, and the bending moment active on the soldier pile can be significantly reduced by using dual soldier-piled walls (Lee *et al*., 2007). Dai (2002) focused on the behavior of double row piles by using the resistance of sliding mass acting on anti-slide piles. Cai *et al*. (1999) developed a 2D FEM program to analyze the behavior of retaining structures of double-row piles. Cui *et al*. (2006) focused on the numerical simulation of deep foundation pit excavation with double-row piles. Although a self-supporting earth-retaining structure is effective for shallow excavation in sandy soil, it is difficult to apply the structure to deep excavation in saturated soil.



(a) Conceptual map (b) Connector parts (c) Connecting method

Fig. 1 Composition of an earth-retaining structure using in situ soil with dual sheet piles

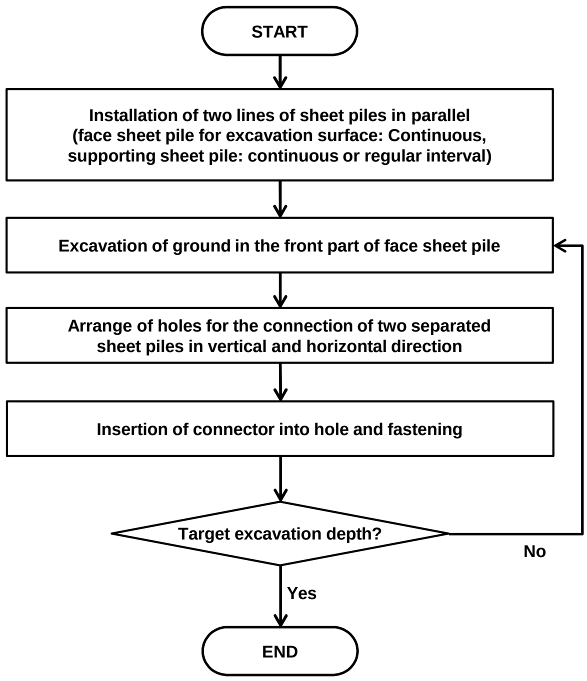


Fig. 2 Construction sequence of an earth-retaining structure using in situ soil with dual sheet piles

2. Development of an earth-retaining structure using in situ soil

This study proposes an innovative self-supporting earth-retaining structure that uses in situ soil confined in dual sheet piles as a structural component. A numerical study was conducted to investigate the relationship between depth of excavation and the clearance distance and establish a design chart for the proposed earth-retaining structure in cohesionless dry soil. Displacement and the factor of safety for structural members were monitored and evaluated. The results suggest that the proposed design chart can be used for the preliminary design of earth-retaining structures using in situ soil with dual steel sheet piles in cohesionless dry soil.

2.1 General description

An earth-retaining structure using in situ soil is a temporal self-supporting earth-retaining wall system. Fig. 1 shows the composition of the proposed earth-retaining structure. The proposed system is composed of three components: a face sheet pile forming an excavation surface, a supporting sheet pile embedded in the soil, and a connecting bar. Two lines of steel sheet piles are installed in parallel with some clearance distance.

The supporting sheet pile embedded in the ground parallel to the face sheet pile can be continuous or placed at a regular interval, as shown in Figs. 1(a) and 1(b). The face sheet pile forms an excavation surface, and the supporting sheet pile is embedded in the soil and must be inserted into the ground by being driven vertically to the target depth. Then the soil in front of the face sheet pile is excavated to a certain depth. The hole can be drilled for two separated sheet piles by using a drilling machine, or a sheet pile with pre-drilled holes at regular intervals can be used. The face sheet pile forming an excavation surface must be connected to the supporting sheet pile during excavation to unify separated walls and contain in situ soil between two sheet piles. Therefore, the connecting beam is inserted into the hole and fastened to combine two separated sheet piles.

During excavation, the connecting bar must be installed at regular intervals in vertical and horizontal directions. For saturated soil, the connecting bar must be fastened with a waterproof packer. In the case of dry soil, this packer can be omitted. Connector parts require some material with the stiffness capability to transmit the tensile force to walls. Fig. 1(c) shows the connecting method of the earth-retaining structure using in situ cohesionless dry soil with dual sheet piles. It can be easily connected using a rotating connector. Therefore, earth pressure can be supported by sheet piles and in situ soil between dual sheet piles without internal support structures such as wales and struts. The construction process of the earth-retaining structure using in situ soil with dual sheet piles is shown in Fig. 2.

2.2 Novelty of proposed retaining structure

The proposed earth-retaining wall using in situ soil with dual sheet piles can be applied to various types of ground conditions allowing the installation of sheet piles because this innovative earth-retaining structure uses steel sheet piles. Since sheet piles are watertight, the proposed structure can be applied to dry soil as well as to saturated soil. A work space can be obtained within the excavation area using this self-supporting earth-retaining structure. This approach is not affected by the shape of a sheet pile as long as the sheet pile forms a continuous excavation surface. In addition, the construction cost can be reduced sharply because of the use of in situ soil as the structural material and the recycling of perforated sheet piles. This method can be applied to temporal earth-retaining structures for underground structures of skyscrapers, launching areas of TBM subways, the construction of opencut tunnels or shallow cable tunnels, and underpass and harbor facilities, among others. This innovative earth-retaining structure is expected to increase performance by improving stability and workability in comparison to the classic braced-wall excavation support system. In addition, implementation of various smart geophysical techniques will further enhance reliable monitoring and maintenance of such innovative earth-retaining structures (Kwon and Cho 2005 and 2009, Kwon and Ajo-Franklin 2013, Noh *et al.* 2016, Ham *et al*. 2017).

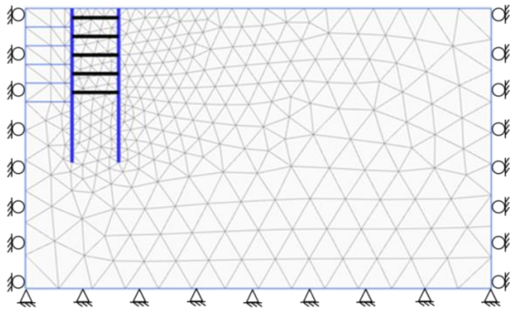
Table 1 Material properties of cohesionless dry soil (Jeong and Seo 2013, Plaxis 2014)

Parameters	Cohesionless dry soil
Coefficient of lateral earth pressure at rest, K_0	0.5
Cohesion, c_{ref}	1.0 kN/m²
Friction Angle, ϕ	30°
Dry unit weight, γ_{unsat}	17.0 kN/m³
Saturated unit weight, γ_{sat}	20.0 kN/m³
Elastic Modulus, E	13.0E3 kN/m²
Poisson's ratio, ν	0.3
Shear Modulus, G	5000 kN/m²

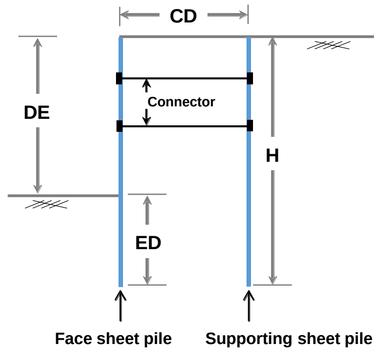
Table 2 Material properties of structural components

Identification	Plate (SP-III)	Plate (SP-IV)	Connector
Axial stiffness, EA (kN/m)	3.93E6	4.99E6	3.930E6
Flexural rigidity, EI (kN m²/m)	3.46E4	7.95E4	-
Spacing, $L_{spacing}$ (m)	-	-	1.0
Sectional modulus, Z (m³/m)	0.00134	0.002271	-
Cross-sectional area, A (m²/m)	0.0191	0.02425	-

cf) Here the elastic modulus of the steel plate is 2.06E8 kPa. Note that SP-III and SP-IV denote the type of steel sheet pile manufactured by Hyundai Steel Product



(a)



(b)

Fig. 3 Numerical model and boundary conditions for the feasibility study (a) FEM mesh and (b) Terminologies

3. Numerical analysis for feasibility study

3.1 Numerical model and boundary conditions

A feasibility study of the proposed earth-retaining structure was conducted through a numerical analysis using PLAXIS 2D AE (PLAXIS, 2014). Fig. 3(a) presents the 2D half-section model constructed for an excavation width of 10 m. The plane strain condition was assumed for the simulation of a long trench. Ground was modeled using 15-nodes and 12-stress-point triangle element. Earth-retaining structure and excavation area are discretized with finer elements. The bottom is fully fixed to the vertical and horizontal direction and the left and right sides of model are fixed to the horizontal direction as shown in Fig. 3(a).

Material properties assumed in the analysis are shown in Table 1. Conventional cohesionless soil following the linear elastic-perfectly plastic Mohr-Coulomb model was assumed as the basis for the feasibility study. Although ideal dry soil is not realistic, it was assumed to derive a preliminary design chart. In this regard, future research should conduct a comprehensive numerical study to construct a design chart for saturated ground and cohesive soil, among others. The simulation stage was identical to the construction process presented in Fig. 2. To investigate the relationship between the height of the wall (H), the depth of excavation (DE), the embedment depth (ED), and the clearance distance (CD) and establish a design chart for the proposed earth-retaining structure in cohesionless dry soil, a parametric study was conducted. The terminology is illustrated in Fig. 3(b). Material properties of structural components of the proposed earth-retaining structure are shown in Table 2.

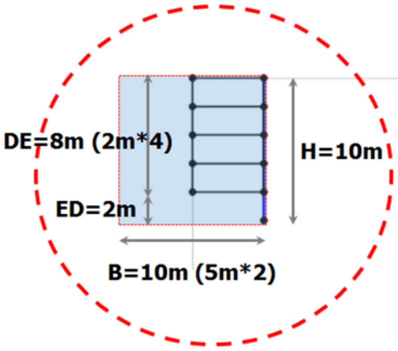


Fig. 4 Geometric conditions for the feasibility study

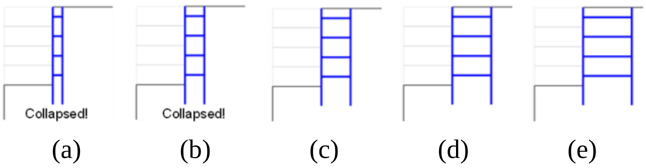


Fig. 5 Feasibility study of an earth-retaining structure using in situ soil with dual sheet piles (a) CD=1 m, (b) CD=2 m, (c) CD=3 m, (d) CD=4 m and (e) CD=5 m

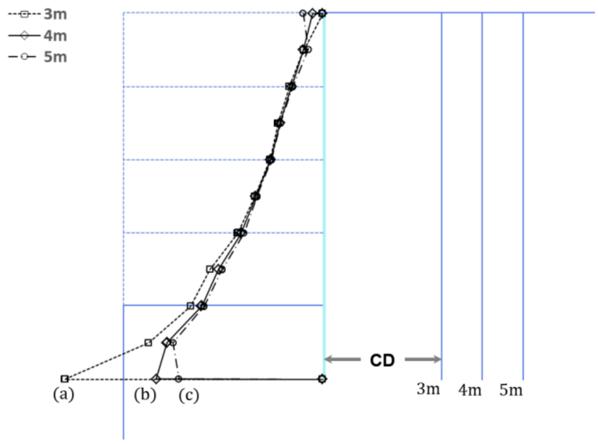


Fig. 6 Horizontal earth pressure distribution of the face sheet pile (a) CD=3 m (maximum σ'_{xx}= 141.6 kPa), (b) CD=4 m (maximum σ'_{xx}= 90.08 kPa), and (c) CD=5 m (maximum σ'_{xx}= 81.65 kPa)

3.2 Preliminary study

A feasibility study was conducted to realize the proposed earth-retaining structure system. For the study, the target depth of excavation, the height of the wall, and the embedded depth were predefined. As shown in Fig. 4, the depth of each excavation was 2 m, the target excavation depth was 8 m, and embedded depth was 2 m. Therefore, the total height of the wall was 10 m. The interval of the connector between two layers of sheet piles in the vertical direction was 2 m starting from 1 m below the ground surface, and the interval of the connector in the horizontal direction was 1 m. To find the clearance distance for an excavation depth of 8 m, the clearance distance was increased from 1 m to 5 m.

Based on the numerical study, when the clearance distance was less than 2 m, the excavation depth could not exceed 6 m under the given condition. However, an increase in the clearance distance from 3 m to 5 m allowed for an excavation depth of 8 m to be safely obtained, as shown in Figs. 5(c), 5(d), and 5(e). This implies that the space around the excavation site was wide enough for deep excavation work. If the space around the construction site is limited, then the design of sheet piles requires a modification. The relationship between the clearance distance and the excavation depth should be further examined for a deeper excavation depth.

Fig. 6 shows the Cartesian effective stress (σ'_{xx}) on the face sheet pile when the excavation depth reached 8 m and the clearance distance ranged from 3 m to 5 m (Figs. 6(a)-(c)). The horizontal stress increased with an increase in the depth of excavation. The maximum horizontal stress was found at the bottom of the face sheet pile. The maximum horizontal stress increased with an increase in the depth of excavation. When the excavation depth was 8 m, the maximum horizontal stresses decreased from 141.6 kPa to 81.65 kPa under an increase in the clearance distance from 3 m to 5 m. These numerical results clearly indicate that the level of earth pressure on the face sheet pile decreased with an increase in the clearance distance. This implies that an increase in the volume of soil confined between sheet piles increased the self-weight of the retaining structure and stabilized the structure against sliding and overturning.

3.3 Modification of design

As discussed in the previous section, the design of sheet piles must be modified to obtain deeper excavation within a confined space. In this study, the embedded depth of the face sheet pile and the supporting sheet pile increased because an increase in the embedded depth amplified the mobilization of passive earth pressure. Based on the feasibility study, the embedded depth of the sheet pile increased the stable excavation depth for a clearance distance less than 2 m.

For the design modification of the earth-retaining structure using in situ soil with dual sheet piles, three different designs were considered: the extension of the embedded depth of the face sheet pile, that of the supporting sheet pile, and that of both sheet piles. The embedded depth increased by 1 m for the three different designs, and the convergence of numerical calculations was estimated.

When the clearance distance was 1m, there was a failure even when the embedded depth(ED) increased to 40% of the wall height, as shown in Fig. 7. It implies a need to secure a minimum clearance distance to establish a self-supporting retaining structure with the proposed method.

When the clearance distance was 2 m, the extension had to be longer than 3 m for the face sheet pile and/or the supporting sheet pile to obtain a stable excavation depth of 8 m, as shown in Fig. 8. Although the calculation converged in this case, a large horizontal displacement could not be avoided at the top of the wall. In sum, it was possible to increase the excavation depth by modifying the sheet pile design. The results suggest that for a conservative design, the clearance distance should exceed 2 m and the embedded depth (ED) should exceed 40% of the wall height to secure

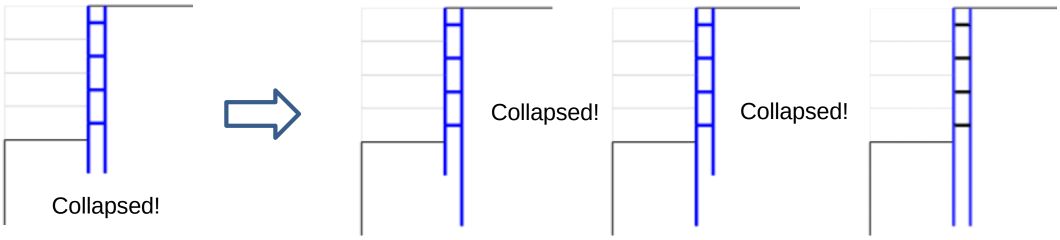


Fig. 7 Design modification for a clearance distance of 1 m

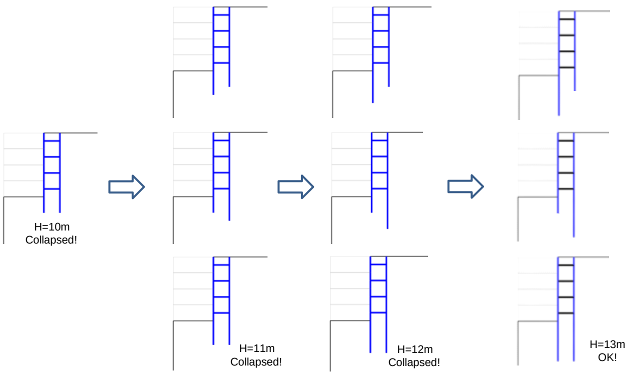


Fig. 8 Design modification for a clearance distance of 2 m

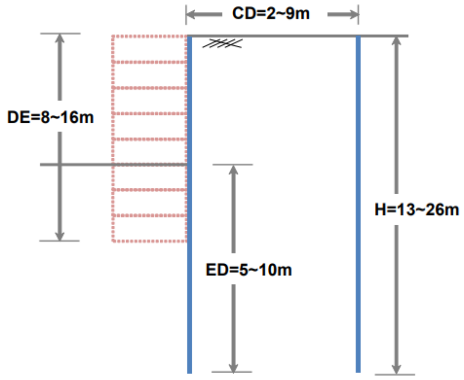


Fig. 9 Variables in numerical modeling

the stability of the earth-retaining structure in cohesionless dry soil.

4. Guidelines for an earth-retaining structure using in situ cohesionless dry soil and dual sheet piles

4.1 Numerical modeling

To derive a preliminary design chart for an earth-retaining structure using in situ cohesionless dry soil with dual sheet piles, comprehensive numerical analyses were conducted. As shown in Fig. 9, ED, H, and CD varied according to DE. Here DE increased from 8 m to 16 m at 2 m intervals. In each case, ED and CD varied depending on the optimal design. Based on the results, ED to H was maintained at a ratio of about 40%. Table 3 provides a summary of the numerical results.

4.2 Evaluation of structural stability

A numerical study was conducted as shown in Table 3 by using PLAXIS 2D AE, a 2D finite-element method. First, the conversion of calculations was evaluated. If the calculation process does not converge, then a failure state can be assumed. Second, the factor of safety of sheet piles against shear and bending was evaluated. Third, horizontal displacement at the top of the earth-retaining wall crest was obtained.

As shown in Table 3, an increase in ED required an increase in CD to obtain a converged and stable result. More specifically, an increase in ED from 8 m to 14 m required an increase in CD from 3 m to 7 m. In particular, the results suggest that stiffer sheet piles should be used for a deep excavation depth of more than 10 m because SP-III

Table 3 Summary of the numerical study

Case	DE (m)	H (m)	ED (m)	ED/H (%)	CD(m)		Sheet pile
					Examined	Stable	
1	8	13	5	38	1,2,3,4,5	3 onward	SP-III
2	10	16.5	6.5	39	2,3,4,5,6	5 onward	SP-III
3	12	8	8	40	5,6,7,8,9	7 onward	SP-IV
4	14	9	9	39	5,6,7,8,9	7 onward	SP-IV
5	16	10	10	38	5,6,7,8,9	All failed	SP-IV

cannot stabilize the earth-retaining structure. Although the proposed self-supporting earth-retaining structure can be used for 14 m of excavation with SP-IV, the method cannot be used for a deeper excavation depth of more than 16 m because 9 m of CD could not stabilize the earth-retaining structure with in situ soil.

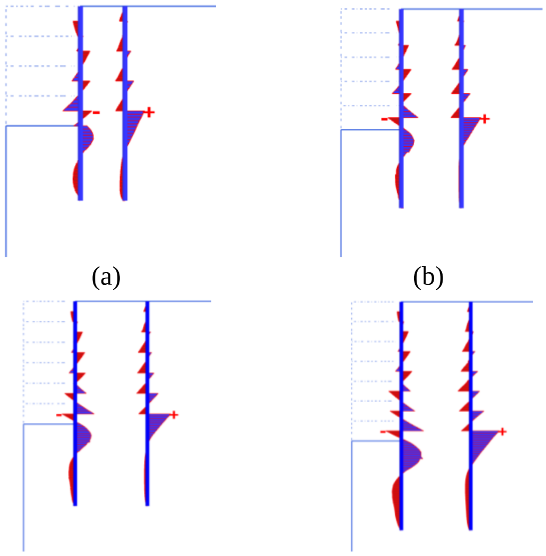
To estimate the structural stability of the sheet pile structure, the factor of safety of sheet piles against the shear force and bending moment was evaluated. Factors of safety for the shear stress and bending stress are effective indicators of the structural stability of steel structures (Song *et al.* 2013). If the factor of safety exceeds a certain threshold based on given design criteria, then the design of the earth-retaining structure using in situ soil with dual sheet piles is acceptable.

The section modulus (Z) and cross-sectional area (A) of the sheet pile are tabulated in Table 2. The maximum shear force and bending moment were determined from the horizontal reaction force and earth pressure acting on a beam simulating the steel sheet pile. When the allowable shear stress and bending stress were 100 MPa and 180 MPa, respectively, the stability of the steel sheet pile structure could be analyzed based on the factor of safety. The

Table 4 Assessment of the structural stability of dual sheet piles

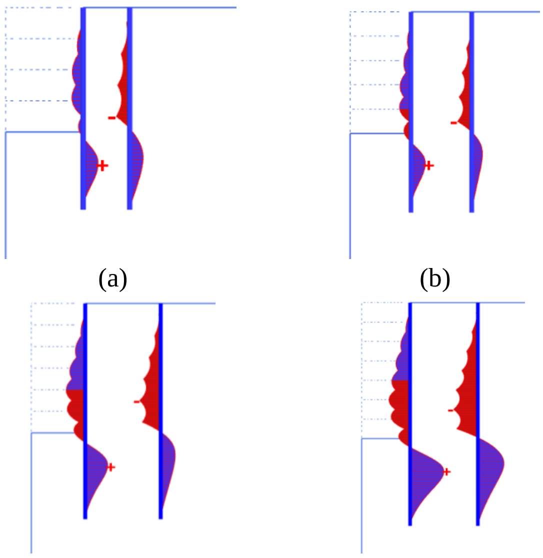
Cases	S_{max} (kN/m)	$\sigma_{shear}^{allowable}$ (MPa)	M_{max} (kNm/m)	$\sigma_{bending}^{allowable}$ (MPa)	FOS_{shear}	$FOS_{bending}$	Sheet pile type
1	66.24		48.16		28.83	5.01	SP-III
2	81.84		59.47		23.34	4.06	SP-III
3	114.4	100	104.6	180	21.20	3.91	SP-IV
4	144.9		174.8		16.74	2.34	SP-IV
5	N.A.		N.A.		N.A.	N.A.	N.A.

cf) Based on steel structure design standards by the allowable stress design (KSSC 2003)



(a) (b) (c) (d)

Fig. 10 Shear force diagram (a) Case 1 (S_{max}= 66.24 kN/m), (b) Case 2 (S_{max}= 81.84 kN/m), (c) Case 3 (S_{max}=114.4 kN/m) and (d) Case 4 (S_{max}= 144.9 kN/m)



(a) (b) (c) (d)

Fig. 11 Bending moment diagram (a) Case 1 (M_{max}= 48.164 kNm/m), (b) Case 2 (M_{max}= 59.47 kNm/m), (c) Case 3 (M_{max}=104.6kNm/m) and (d) Case 4 (M_{max}= 174.8 kNm/m)

maximum shear stress (σ_{shear}^{max}) can be obtained from the maximum shear force (S_{max}) derived from an FE analysis and the cross-sectional area of the double steel sheet pile (A) as follows

$$\sigma_{shear}^{max} = \frac{S_{max}}{A} \tag{1}$$

The factor of safety for the shear stress (FOS_{shear}) can be defined as follows

$$FOS_{shear} = \frac{\sigma_{shear}^{allowable}}{\sigma_{shear}^{max}} \tag{2}$$

In addition, the maximum bending stress ($\sigma_{bending}^{max}$) can be obtained from the maximum bending moment (M_{max}) and the sectional modulus (Z) as follows:

$$\sigma_{bending}^{max} = \frac{M_{max}}{Z} \tag{3}$$

The factor of safety for the bending stress ($FOS_{bending}$) can be defined as follows

$$FOS_{bending} = \frac{\sigma_{bending}^{allowable}}{\sigma_{bending}^{max}} \tag{4}$$

As shown in Table 4, the shear force and bending moment increased with an increase in ED. In addition, the factor of safety for the shear stress and bending stress decreased with an increase in ED. As shown in Table 4, the factor of safety for the shear stress far exceeded 1, suggesting that the sheet pile was safe against to shear. However, the factor of safety for the bending stress was greater than 1, suggesting the need to evaluate this factor in accordance with active design criteria.

Figs. 10 and 11 show the results for shear force and bending moment diagrams of sheet piles at the final excavation stage. The maximum shear force was found at the supporting sheet pile near the base of excavation. The factor of safety for the shear force was high enough. That is, the face sheet pile and the supporting sheet pile were safe against the shear force. The maximum bending moment was found at the face sheet pile where passive earth pressure was activated. The results suggest that the factor of safety for the bending moment should be checked in accordance with given design criteria.

Table 5 shows the distribution of lateral movements of the earth-retaining structure at the final stage of numerical calculations. An increase in ED increased the maximum lateral displacement. The allowable lateral displacement for cohesionless soil was estimated as 0.2% of ED based on NAVFAC DM-7.2 (1986). When ED was less than 12 m, the maximum lateral displacement fell within the range of allowable lateral displacement. However, NAVFAC DM-7.2 has been applied to urban excavation and areas with adjacent structures located near retaining structures under construction. The results suggest that for an area with no adjacent structure under construction, 14 m of deep excavation can be carried out using the proposed structural system. In addition, to reduce the lateral movement of the earth-retaining structure, heads of face and supporting sheet piles can be combined with the fixed bar. Fig. 12 shows the distribution of lateral displacement along the sheet pile structure at the final excavation stage.

Table 5 Maximum lateral movement of the earth-retaining structure

Cases	$\delta_{h(max)}$ (cm)	$\delta_{h(allowable)}$ (cm)	Excavation depth (m)	Remarks
1	0.99	1.6	8	For well-constructed strutted excavations in dense sand, horizontal displacement should be less than 0.2% of the excavation depth (NAVFAC DM-7.2, 1986)
2	1.48	2	10	
3	1.76	2.4	12	
4	16.1	2.8	14	
5	N.A.	N.A.	N.A.	

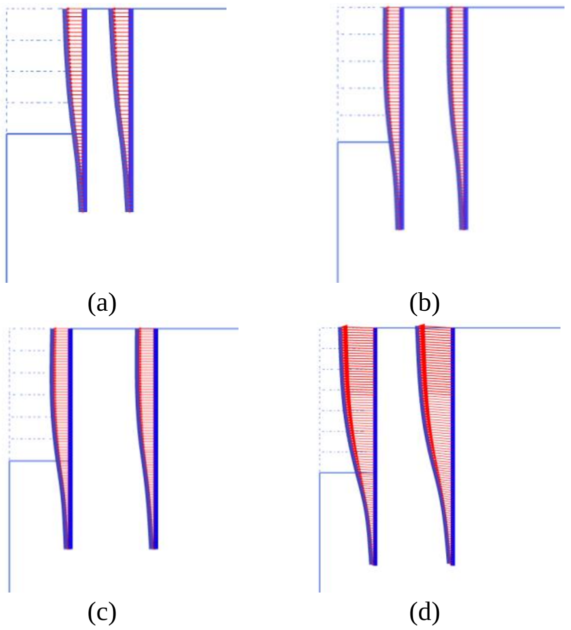


Fig. 12 Distribution of lateral displacement along sheet piles (a) Case 1 ($\delta_{h(max)}$= 0.99 cm), (b) Case 2 ($\delta_{h(max)}$= 1.48 cm), (c) Case 3 ($\delta_{h(max)}$= 1.76 cm) and (d) Case 4 ($\delta_{h(max)}$= 16.1 cm)

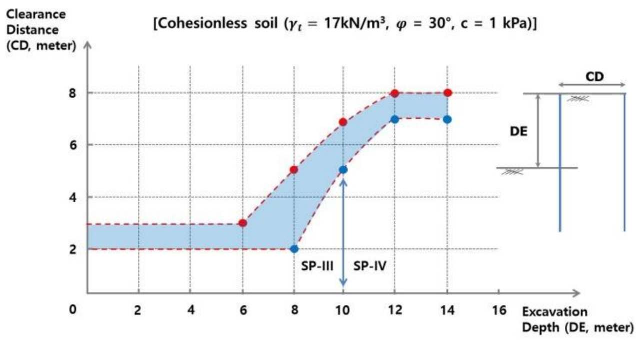


Fig. 13 Preliminary design chart for an earth-retaining structure using in situ cohesionless dry soil with dual sheet piles

4.3 Preliminary design chart

Based on the comprehensive numerical analysis, a preliminary design chart for an earth-retaining structure using in situ cohesionless dry soil with dual sheet piles was constructed (Fig. 13). The design chart shows a rough estimate of CD according to a depth of excavation up to 14 m in cohesionless dry soil with soil unit weight of 17kN/m^3, a friction angle of 30°, and a negligible cohesion value of 1 kPa. This design chart can be derived by using the sheet pile tabulated in Table 2. Because this study proposes an innovative self-supporting earth-retaining structure, the soil property was assumed in the analysis as simple cohesionless soil, and no ground water was considered. In this regard, a comprehensive numerical study is needed to derive a design chart for clayey soil. In addition, future research should consider the ground water condition and verify the proposed earth-retaining structure in the context of field construction. Complementary to a numerical approach, physical modeling using geotechnical centrifuge can also be deployed to investigate the interactions among the retaining structure, earth pressure, and groundwater (e.g., Kwon *et al*. 2013). To optimize the design of the earth-retaining structure using in situ soil and dual sheet piles, a detailed design process should be followed after the preliminary design suggested in this study. After installation of the earth-retaining structure, various smart geophysical techniques can be also implemented for performance monitoring (e.g., Kwon and Cho 2005 and 2009, Kwon and Ajo-Franklin 2013, Noh *et al.* 2016, Ham *et al.* 2017).

5. Conclusions

The classic braced wall uses struts and wales to minimize the ground movement induced by deep excavation. However, the installation of struts and wales is a time-consuming process and confines the work space. To secure the work space behind the retaining structure, an anchoring system is placed with the braced wall. However, such anchoring cannot perform well when the shear strength of soil is negligible. Such a case requires an innovative retaining structure for excavation. This study proposes an innovative earth-retaining wall using in situ soil confined in dual sheet piles as a structural component.

A numerical study was conducted to investigate the feasibility of the proposed structural design. According to the results, an increase in the clearance distance reduced the earth pressure on the face sheet pile, and a minimum clearance distance between the face sheet pile and the supporting sheet pile was required. The results suggest that the excavation depth can be increased by modifying the sheet pile design. For a conservative design to secure the stability of the earth-retaining structure in cohesionless dry soil, the clearance distance should exceed 2 m, and the embedded depth should exceed 40% of the wall height. The proposed method can be used for 14 m of excavation without any internal support structure.

Based on the numerical analysis, a design chart was constructed for the preliminary design of an earth-retaining structure using in situ cohesionless dry soil with dual sheet piles. Future research should investigate the behavior of the proposed structural design in clayey soil and examine seepage and surcharge effects for better field application.

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