Geotechnical Aspects of Underground Construction in Soft Ground – Yoo, Park, Kim & Ban (Eds)
 ISBN 978-1-138-02700-8

Analysis of the displacement caused by construction conditions at a rear side of sheet pile structures on soft ground

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ABSTRACT: This study is conducted in order to review the stability for the factors leading to displacement on the top of the sheet pile and RCD pile in P2 section of bridge crossing water way that is located in Pusan, Korea. Also, main factor leading to the displacement is analyzed in this study. As the result of the stability review, the embankment at a rear side of the sheet pile and equipment load on the embankment are estimated as the main factor leading to displacement on the top of the sheet pile and RCD pile in P2 section.

Keywords: construction step, horizontal displacement, RCD pile, sheet pile, soft ground, stability review

1 INTRODUCTION

The purpose of this paper is to review influence of embankment load at a rear side of the sheet pile which is main factor inducing the displacement of the sheet pile and RCD pile.

The site which excessive displacement occurred under sheet pile construction in order to build a bridge pier is located in Busan, Korea. Items and section for stability review to understand influencing factors of expected displacement has been selected after analyzing the existing results and then each influencing factor which has an effect on the sheet pile and RCD pile has been reviewed after considering construction step.

Midas GTS which is finite element analysis program is used to carry out the stability review on influencing factors of expected displacement. In-situ applying model such as clay, silty sand, weathered rock, soft rock and sea wall is Mohr-Coulomb model, and applying model of structures such as RCD pile, steel pipe pile, Sheet pile and H-pile is elastic model.

2 SOIL CHARACTERISTIC AND SELECTION OF THE SOIL PROPERTIES

The range of the natural moisture content is 31.3∼77.0%. Also, the range of the triaxial compression strength is 0.16∼0.89 kgf/cm^2 and in case of converting triaxial compression strength into undrained shear strength, the range of the undrained shear strength in in-situ clay is 0.04∼0.89 kgf/cm^2. The results of triaxial compression test and in-situ vane test for depth are given in Figure 1.

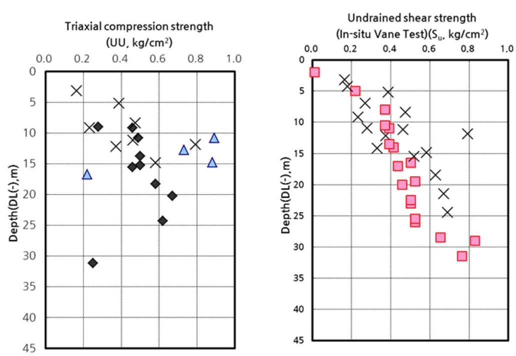


Figure 1. The range of the soil properties for depth.

The soil properties for stability review of this report are given in Table 1 and the range of the clay is given in Figure 2.

In case of embankment, the modulus of elasticity of A2 section which consists of reclamation soil is 3,000 t/m^2 and the equipment of A2 section is 1.3 t/m^2.

Table 1. Soil properties for stability review (Clay).

Layer	Unit weight (tf/m^3)	Cohesion (tf/m^2)	Internal friction angle (°)	Poissons ratio	Deformation modulus (tf/cm^2)	
Embankment	1.8	1.5	25	0.30	3,000	a
					48	b
Water way ∼ P2	1.7	0.16D + 0.40	0	0.33	100	c
					249	d
Below A2	1.7	0.133D + 1.067	0	0.33	247	e
					271	f
Reclaimed land	1.7	0.15D + 0.75	0	0.33	247	g
					271	h
Silty sand	1.9	5.0	27	0.30	3,000	i
Weathered rock	2.0	10	33	0.27	10,000	j

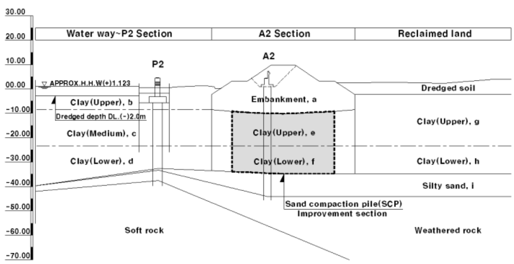


Figure 2. Cross section of soil layer for stability review.

3 STABILITY REVIEW CONSIDERING CONSTRUCTION STEP

3.1 *The review of the factors leading to displacement*

The factors leading to displacement at the construction site are 7 items (Refer to Table 2). Main factors in Table 2 are considered as basic loading step to review the stability. Except on main factors, increase in the loads in accordance with construction of the steel pipe piles for abutment, structure and steel box girder load is considered when the stability review for construction step based on stress-strain analysis is conducted and the effect on increase in the loads is checked after applying additional loading step.

3.2 *Selection of cross section for stability review*

Cross section has been selected after considering construction step that each factor leading to displacement is applied. Also, the number of cross section for stability review has been divided by total 19 steps and the stability review has been conducted.

Figure 3 is a cross section for the first step as modeling of P2∼A2 section before beginning the construction (November, 2004) and is initial condition for stress-strain analysis. Figure 4 is a cross section for the tenth step(final embankment of the sea wall).

Table 2. The factors leading to displacement (main factors).

No.	Main factors	Method of the stability review
1	Embankment load at a rear side of the sheet pile	• Modeling for embankment ground • Considered as load for construction step
2	Heavy equipment load at a rear side of the sheet pile	• Modeling for uniform load of heavy equipment • Considered as load for construction step
3	Working load of RCD pile on the sheet pile	• Modeling for uniform load of equipment in order to build RCD pile • Considered as load for construction step
4	Foundation bed excavation at a rear side of the sheet pile	• Modeling for depth of foundation bed excavation • Considered as load for construction step
5	Dredge of waterway	• Modeling for dredge of waterway • Considered as load for construction step
6	Embankment and heavy equipment load of entering road to sea wall	• Modeling for embankment ground of entering road • Modeling for uniform load of heavy equipment • Considered as load for construction step
7	Spreading of dredged soil in sea wall	• Modeling for dredge soil in sea wall • Considered as load for construction step

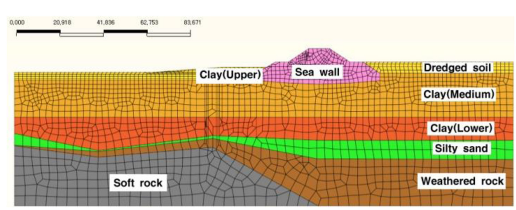


Figure 3. 1st step: In-situ condition (Before beginning the construction).

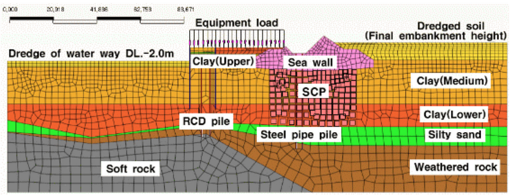
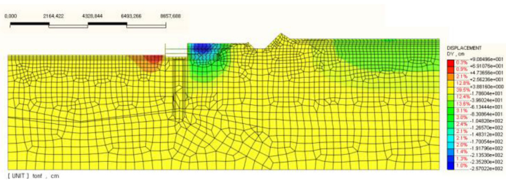
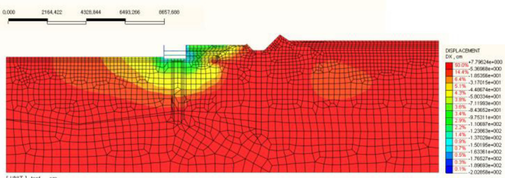


Figure 4. 10th step: Final embankment of the sea wall.



(a) Vertical displacement



(b) Horizontal displacement

Figure 5. The result of the stability review for 13th step(DL(−)3.5 m).

In the step, vehicle load and final embankment of the sea wall have been applied as uniform load and ground model respectively.

3.3 *The results of the stability review for real construction step*

Maximum vertical and horizontal displacement (13th step: Inner excavation of the sheet pile in P2 section, DL(−)3.5 m) on the top of the sheet pile are 27.6 cm and 202.9 cm respectively, and maximum vertical and horizontal displacement on the top of the RCD pile are 27.9 cm and 100.3 cm respectively after inner excavation of the sheet pile until DL(−)3.5 m. The result of the stability review for 13th step is given in Figure 5.

3.4 *Stability review for construction step of original design*

The height of inner filling in the center of the sheet pile is DL(+)4.0 m in real construction (3rd step) but DL(+)2.4 m in original design. Also, the height of the embankment at a rear side of the sheet pile is applied until the top of the pile (DL(+)4.0 m) in real construction (7th step) but the embankment at a rear side of the pile is not applied in original design. Furthermore, 7th (embankment at a rear side of the sheet pile) and 8th (application of equipment load at a rear side of the sheet pile) construction step in P2 section are not applied to original design. Therefore, except on above-mentioned steps, other steps for the stability review in original design are equally applied to real construction.

4 ANALYSIS

4.1 *Analysis on the factor leading to displacement*

The results of the cumulative horizontal displacement for real construction in P2 section are given in Table 3. The proportion of each step for cumulative displacement is estimated by the displacement of 13th step that is maximum displacement. Moreover, the proportion leading to displacement on the top of the sheet pile and RCD pile is very larger in 7th (embankment at a rear side of the sheet pile) and 8th (application of equipment load at a rear side of the sheet pile) step than in other steps, and the value of the average proportion in 7th and 8th step is respectively 60.92% and 78.82% for displacement on the sheet pile and the RCD pile.

4.2 *Comparison with the results of the stability review for construction step of original design and real construction*

The results of the cumulative horizontal displacement for construction step of original design in P2 section are given in Table 3. The proportion of each step for cumulative displacement is estimated by the displacement of 13th step that is maximum displacement. Comparison of horizontal displacement on the top of the sheet pile and RCD pile in accordance with applying embankment and equipment load at a rear side of the sheet pile is respectively given in Figure 6 and Figure 7.

Average cumulative horizontal displacement of 13th step on the top of the sheet pile and the RCD pile is respectively 18.7 cm and 8.0 cm, and the values of the displacement is respectively 9.20% (203.3 cm) and 8.56% (93.5 cm) for the displacement in the same step of real construction. As the result of this review, the embankment at a rear side of the sheet pile and equipment load on the embankment are estimated as the main factor leading to displacement.

4.3 *Comparison with the results of measurement in field and the stability review*

4.3.1 *The results measured in the site of P2 section*

The results of measured in the site of P2 section from April 2005 to August 2005 is given in Fig. 9. Maximum value of the displacement had sharply increased until 2.94 m since construction of embankment (May 2005) at a rear side of the sheet pile. Furthermore, a part of the displacement has been recovered since removal of embankment (16 Aug. 2005) at a rear side of the sheet pile.

Table 3. Estimating cumulative horizontal displacement for real construction step and original design: Displacement on the top of the sheet pile and the RCD pile in P2 section.

	Cumulative displacement (cm)							
	Real construction step				Original design			
	Sheet pile		RCD		Sheet pile		RCD	
Step	Water way	Sea wall	Water way	Sea wall	Water way	Sea wall	Water way	Sea wall
3 Construction of the sheet pile	0.0	0.0	–	–	0.0	0.0	–	–
4 Dredge of water way, DL(−)2.0 m	6.0	7.0	–	–	4.8	5.1	–	–
5 Construction of steel pipe pile for abutment in A2 section	6.3	7.3	–	–	4.9	5.2	–	–
6 Construction of RCD pile in P2 section	6.4	9.1	0.0	0.0	4.9	5.7	0.0	0.0
7 Embankment at a rear side of the sheet pile in P2 section (No application in construction step of original step)	77.6	74.7	41.7	44.8	4.9	5.7	0.0	0.0
8 Application of equipment load at a rear side of the sheet pile in P2 section (No application in construction step of original step)	134.0	128.8	70.8	75.6	4.9	5.7	0.0	0.0
9 Application of entering vehicle load to sea wall	149.1	144.9	76.6	81.5	6.1	6.8	1.0	1.1
10 Final embankment of sea wall	154.3	150.0	80.0	85.1	10.0	10.6	4.0	4.5
11 Inner excavation of the sheet pile in P2 section, DL(+)1.0 m	186.5	172.6	81.4	90.6	14.7	11.0	3.1	6.3
12 Inner excavation of the sheet pile in P2 section, DL(−)1.6 m	197.1	183.2	84.6	95.1	17.2	13.5	4.3	8.1
13 Inner excavation of the sheet pile in P2 section, DL(−)3.5 m	210.2	196.3	88.5	98.5	20.5	16.8	5.9	10.0
14 Removal of the embankment at a rear side of the sheet pile in P2 section, DL(−)2.0 m	151.8	139.0	56.8	65.5	10.4	6.7	0.2	4.1
15 Inner excavation & removal of the embankment at a rear side of the sheet pile in P2 section, DL(−)5.3 m	120.8	108.1	40.0	47.6	−6.6	−10.3	−7.7	−3.8
16 Construction of structure for abutment in A2 section	121.8	109.1	40.3	47.9	−6.5	−10.2	−7.7	−3.8
17 Construction of CJM	121.9	109.1	40.4	48.0	−6.5	−10.2	−7.7	−3.8
18 Construction of structure for pier in P2 section	–	–	41.9	49.5	–	–	−6.0	−2.1
19 Application of steel box girder load	–	–	44.6	52.2	–	–	−3.5	0.4

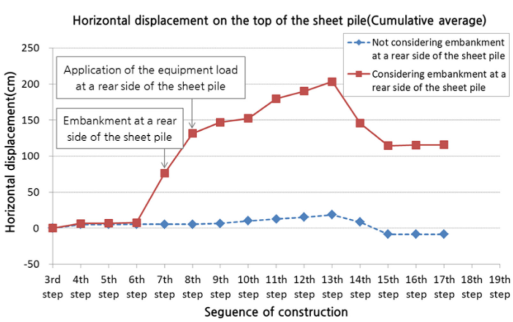


Figure 6. Comparison of horizontal displacement on the top of the sheet pile in accordance with applying embankment and equipment load at a rear side of sheet pile.

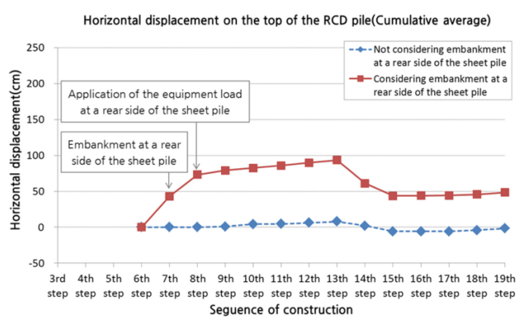
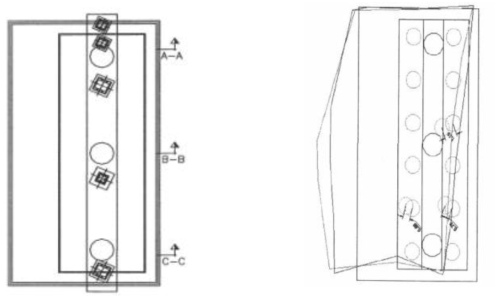


Figure 7. Comparison of horizontal displacement on the top of the RCD pile in accordance with applying embankment and equipment load at a rear side of sheet pile.

4.3.2 *Analysis on the results of measurement in field and the stability review*

Maximum horizontal displacement on the top of the sheet pile and RCD pile measured in field is given in Table 4 and Table 5. Also, the displacement on the top of the sheet pile and RCD pile estimated by the stability review for real construction steps is given in Table 3. As the result of the comparison with the values of the



(a) Up lane

(b) Measurement in up lane(2005.8.16)

Figure 8. Ground plan for a strain cross section of the sheet pile in P2 section.

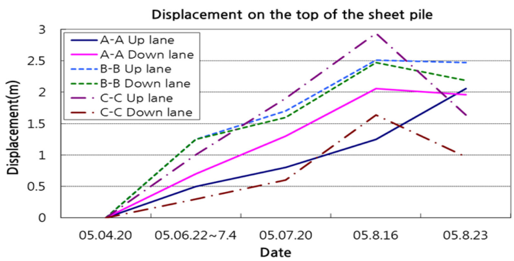


Figure 9. A graph for displacement on the top of the sheet pile in structure location of P2 section.

displacement, the variation of the displacement measured in field is similar to the variation estimated by the stability review but the values measured in field is larger than them estimated by the stability review relatively. The difference between the two values is caused by limitation of numerical analysis that cannot apply all loading steps and conditions of the site, and errors of soil parameters estimated by the ground investigation. Moreover, the displacement of the RCD pile greatly occur relatively because construction period for external load such as construction of RCD pile and embankment at a rear side of the sheet pile is overlapped, and external load such as embankment at a rear side of the sheet pile is applied to the RCD pile before curing of cast-in-place concrete.

5 CONCLUSION

This study is conducted in order to review the stability for the factors leading to displacement on the top of the sheet pile and RCD pile in P2 section of bridge crossing water way that is located in Pusan, Korea. Also, main factor leading to the displacement is analyzed in this study and the results are as follows.

– The factors leading to displacement at the construction site are 7 items such as embankment and heavy equipment load at a rear side of the sheet pile, working load of RCD pile on the sheet pile, foundation bed excavation at a rear side of the sheet pile,

Table 4. Horizontal displacement measured in field: Displacement on the top of the sheet pile in P2 section.

Maximum horizontal displacement (m)							
		A-A		B-B		C-C	
Date (2005)	Construction conditions	Up lane	Down lane	Up lane	Down lane	Uplane	Down lane
6/22 (Up lane)· 7/4 (Down lane)	Under Construction RCD pile	0.50	0.70	1.25	1.25	1.00	0.30
7/20	Inner excavation of the sheet pile, DL(−)1.6 m	0.80	1.30	1.70	1.60	1.90	0.60
8/16	Inner excavation of the sheet pile, DL(−)3.5 m	1.25	2.06	2.51	2.47	2.94	1.64
8/23	Inner excavation of the sheet pile, DL(−)5.3 m	2.06	1.96	2.47	2.19	1.64	0.97

Table 5. Horizontal displacement measured in field: Displacement on the top of the RCD pile in P2 section.

Maximum horizontal displacement (m)							
		A-A		B-B		C-C	
Date (2005)	Construction conditions	Up lane	Down lane	Up lane	Down lane	Up lane	Down lane
7/20	Inner excavation of the sheet pile, DL(−)1.6 m	–	0.00	1.13	0.00	0.65 0.78	0.00
8/16	Inner excavation of the sheet pile, DL(−)3.5 m	–	1.16 1.46	1.13	0.70 0.86	0.65 0.78	0.33 0.04
8/23	Inner excavation of the sheet pile, DL(−)5.3 m	Not measure displacement					

dredge of waterway, embankment and heavy equipment load of entering road to sea wall, spreading of dredged soil in sea wall. The stability review for 7 items is conducted in this study.

- As the result of the stability review for real construction step, the proportion leading to displacement on the top of the sheet pile and RCD pile is very larger in 7th (embankment at a rear side of the sheet pile) and 8th (application of equipment load at a rear side of the sheet pile) step than in other steps.
- As the result of the stability review for construction step of original design that does not apply the embankment at a rear side of the sheet pile and equipment load on the embankment, maximum horizontal displacement is very smaller than the displacement of real construction step. Therefore, the embankment at a rear side of the sheet pile and equipment load on the embankment are estimated as the main factor leading to displacement on the top of the sheet pile and RCD pile in P2 section.
- As the result of the comparison with the values of the horizontal displacement, the variation of the displacement measured in field is similar to the variation estimated by the stability review but the values measured in field is larger than them estimated by the stability review relatively. The difference between the two values is caused by limitation of numerical analysis that cannot apply all loading steps and conditions of the site, and errors of soil parameters estimated by the ground investigation. Moreover, the displacement of the RCD pile greatly occur relatively because external load such as embankment at a rear side of the sheet pile is applied to the RCD pile before curing of cast-in-place concrete.

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