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Structural Performance of Underground Composite Wall for Extension of Underground Parking Lot of Apartment Building

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Abstract*—The purpose of this study is to investigate the effects of composition of underground structural wall and H-pile in soil cement. For a building with three basement floors, the magnitude of the working stress is considered in consideration of one earth pressure condition. In addition, the composite effect of composing the underground structural wall and H-pile in soil cement is studied and the safety against the acting stress is evaluated. The effect of the composite effect is analyzed by performing comparisons with nonlinear sectional analysis results of walls with various thicknesses. The working earth pressure condition is the medium sandy soil. In the case where the dimension of the retaining wall does not change even if the wall thickness of the building wall changes, the thinner the wall thickness of the building wall, the higher the composite effect.

***Index Terms*—underground space extension, Earth pressure, Composite effect, H-pile in soil cement, underground structural wall.**

I. BACKGROUND AND OBJECTIVES

In recent years, there has been the increased utilization of underground space in apartment buildings due to the lack of available land and parking space. This has resulted in a variety of ways for the extension of underground space. These characteristics, in turn, have contributed to the growing importance of excavation and earth retaining works [4], [7]. The earth retaining method is to install temporary structures to resist lateral pressures such as earth pressure and water pressure during excavation work for ensuring the safety of the excavation. The currently used earth retaining methods include H-pile + lagging method, sheet-pile method, contiguous pile wall method (CIP or SCW), and underground slurry wall. These retaining walls resist the earth pressure during the underground excavation. However, after underground structural walls are constructed, the H-piles are removed or would be not reflected in the design even if they resist the actual earth pressure. However, since these temporary structures have considerably large stiffness, the proper utilization of them makes it possible to improve the structural performance of the basement walls, and thus to enhance the economical efficiency and safety [2].

In this regard, Seo et al. (2005) [3] investigated the behavior and design of underground composite walls combined with architectural retaining walls and H-piles, and confirmed that the resisting force increases by up to 2.8 times through the combination of the temporary H-piles into the basement walls, thereby reducing the cross-sectional area. Cho et al. (2009) [1] examined four different shear connectors connected to the interface between concrete surface and H-pile in an experimental and analytical evaluation on the composite effects of H-pile and concrete according to the shear connector details, and proved that they are suitable as a shear connection method for a composite basement wall because they exhibited shear resistance exceeding the value specified in ACI and PCI.

Therefore, an economical design through a reduction in wall thickness can be achieved by building an underground composite retaining wall [5]. In addition, it is possible to maximize space in the extension of underground space. In this regard, this study seeks to analytically investigate the composite effect as a method to maximize the underground space extension. In particular, this study is conducted regarding the thickness of the basement wall combined with H-pile with a focus on the composite effect.

II. CONSTRUCTION PROCEDURE FOR EXTENSION OF UNDERGROUND SPACE

Fig.1 illustrates the flow chart of the underground extension method for an apartment building with the first basement. First, a temporary support is installed in the basement for equipment to construct newly installed earth retaining system. At the same time, a supporter is installed to support the existing basement wall. Next, earth retaining work is performed, and the floor on the first floor above ground is dismantled. And H-pile to support temporary struts is installed, and then the temporary struts are installed every 2.5 meters. Next, the existing underground frame and support are dismantled.

The temporary strut is installed while proceeding to the part where excavation is to be performed, and a foundation work is conducted when the excavation is completed. Next, the basement is constructed by building the basement frame, when a composite wall is selected as an earth retaining wall. The composite basement wall is formed by connecting H-pile to the underground wall of the building with the use of shear connector. Thus, the H-pile, which was needed in the earth retaining work, can be combined with the basement wall to reduce the thickness of the wall. This, in turn, reduces the construction costs and has a significantly positive impact on environment through the recycling of waste [2].

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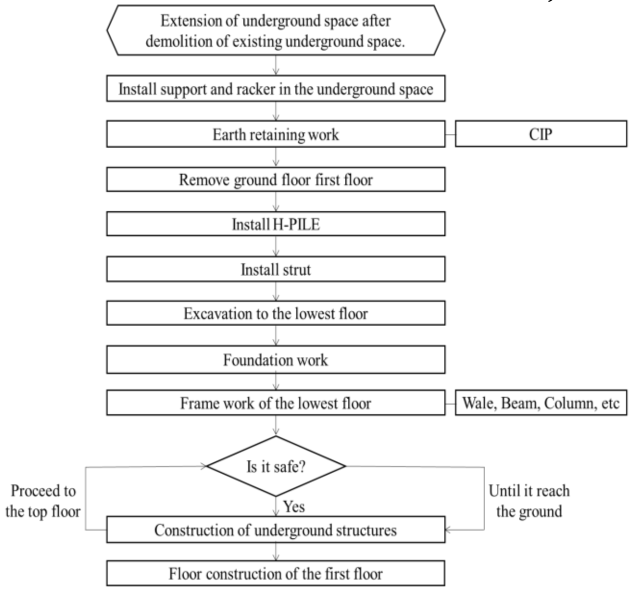


Fig. 1: Flow chart of underground extension

III. ANALYSIS ON THE COMPOSITE EFFECT OF RETAINING WALL AND H-PILE

A. Design of composite walls

The target wall considered in this paper is marked in Fig.2. Retaining wall is constructed by using CIP to resist earth pressure during the excavation. H-Pile of H-300 x 200 x 9 x 14 was installed at every 1200mm space in CIP. The thickness of basement wall is 300mm and its height between upper and bottom floors is 3,400mm. As vertical and horizontal reinforcements, HD10 bar with space of 300mm and HD13 bar with space of 200mm are used in the basement wall, respectively. The strength of H-Pile is 300 MPa and the compressive strength of concrete is 36 MPa, tensile strength of reinforcement is 400 MPa.

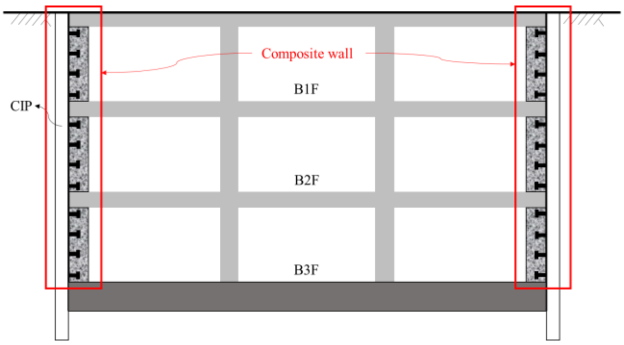
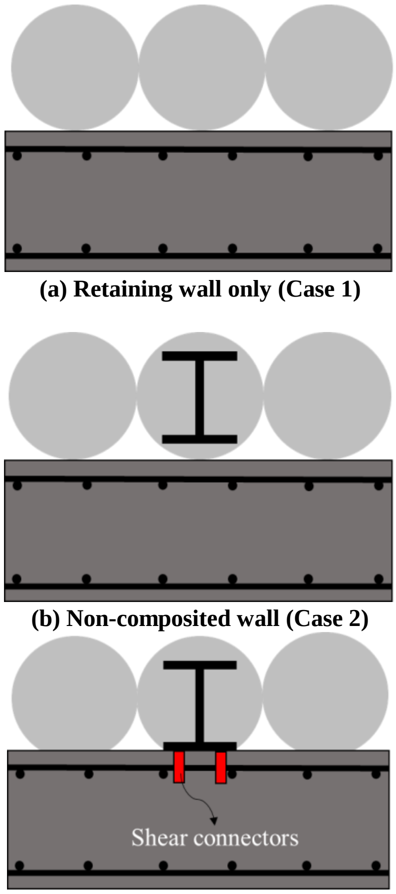


Fig. 2: Underground structure with composite wall

B. Nonlinear analysis of the composite wall

In order to evaluate the composite effect, three cases, which are general basement wall resisting sorely soil pressure without consideration of H-Pile (Case 1), the wall with non-composited H-pile (Case 2) and the wall composited with H-Pile by shear connectors, are considered in this paper as shown in Fig.3. Nonlinear sectional analyses were conducted for those three wall sections by using X-TRACT program [6].

The material properties of concrete, reinforcement and H-Pile are shown in Fig.4. The elastic modules of reinforcement and concrete are 199,900MPa and 28,400MPa, respectively. The elastic module of H-Pile is same to reinforcement. The width of the wall for all cases is 1,200mm.



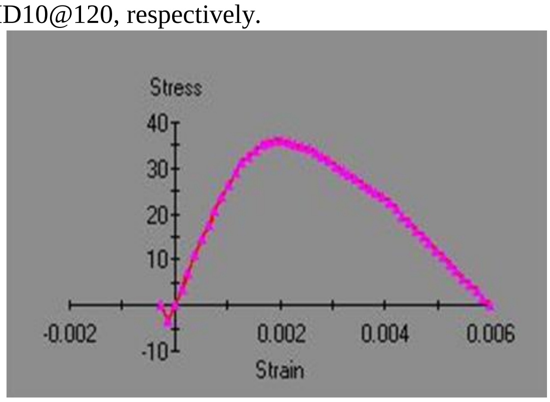
(a) Retaining wall only (Case 1)

(b) Non-composited wall (Case 2)

(c) Composite wall (Case 3)

Fig. 3: Design cases of composite wall

For each case, nonlinear sectional analyses were performed for walls with three different thicknesses, 300mm, 400mm and 500mm. If the wall thickness varies without changing the reinforcement ratio, the reinforcement ratio is to be changed. Therefore, the analysis was also performed for walls with keeping same ratio of vertical reinforcement (0.24%)when their thickness varies. The designed vertical reinforcements of walls with thickness of 400mm and 500mm are HD10@150 and HD10@120, respectively.



(a) Concrete

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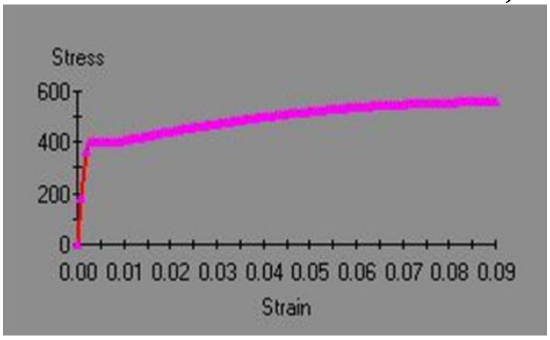
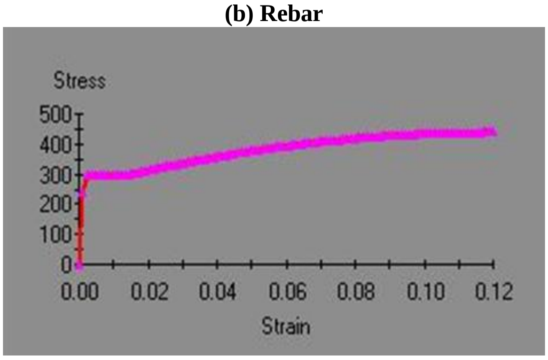


(b) Rebar

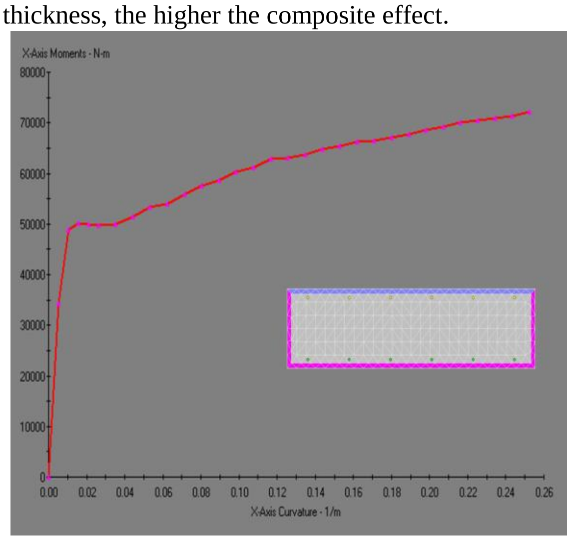


(c) H-PILE

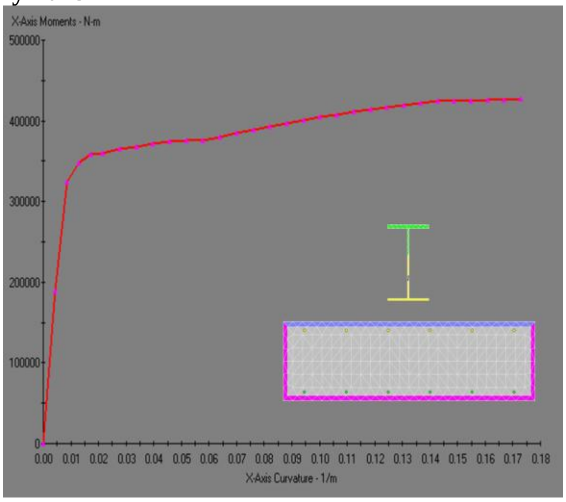
Fig. 4: Stress-strain curve of materials (MPa)

C. Analysis result

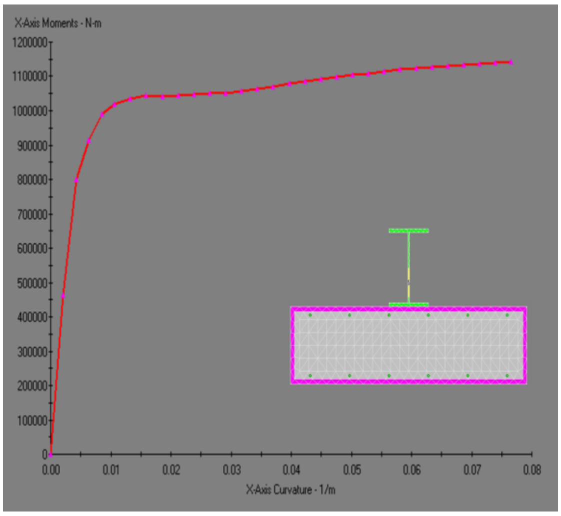
The analysis result for all cases is represented in Fig.5 as moment-curvature relationships. And the yield strength for all analysis result is summarized in Table 1. In addition, the strength of each case is expressed as a ratio for the comparison. In the case of wall thickness of 300mm, the strength of Case 3 with the full composition was 1.05 times and 7.2 times higher than Case 2 and Case 1, respectively. When the wall thickness was 400 mm, the strength of Case 3 was 1.04 times higher than that of Case 2 and 5.2 times higher than that of Case 1. Also, when the wall thickness was 500 mm, the strength of Case 3 was 1.03 times higher than that of Case 2 and 4.35 times higher than that of Case 1. The strength of Case 2 and Case 3 are shown in Figs. 6 and 7 as a ratio of Case 1 to wall thickness. It was confirmed that the thinner the wall thickness, the higher the composite effect.



(a) Retaining wall only



(b) Non-composited wall



(c) Composite wall

Fig. 5: Moment-curvature curve from nonlinear sectional analysis

When the wall thickness is 400mm and vertical reinforcement ratio, is 0.24%, Case 3 has 1.06 times more strength than Case 2 and 4.35 times more than Case 1. However, when compared with the case where the amount of the same vertical reinforcing bar is arranged even the wall thickness increases, in case 2, the rate of increase of strength was decreased from 5.1 times to 4.1 times, and in case 3, it decreased from 5.2 times to 4.4 times. When the wall thickness was 500mm, the yield strength of Case 3 was 1.03 times higher than that of Case 2 and the yield strength was 2.9 times higher than that of Case 1. As a result, it can be confirmed that the wall with same ratio of vertical reinforcement has a lower strength increase ratio than the wall with the same amount of vertical reinforcement when the wall thickness varies. It was confirmed that the thinner the wall thickness, the higher the composite effect, regardless of the increase of the wall thickness and the increase of the rebar amount.

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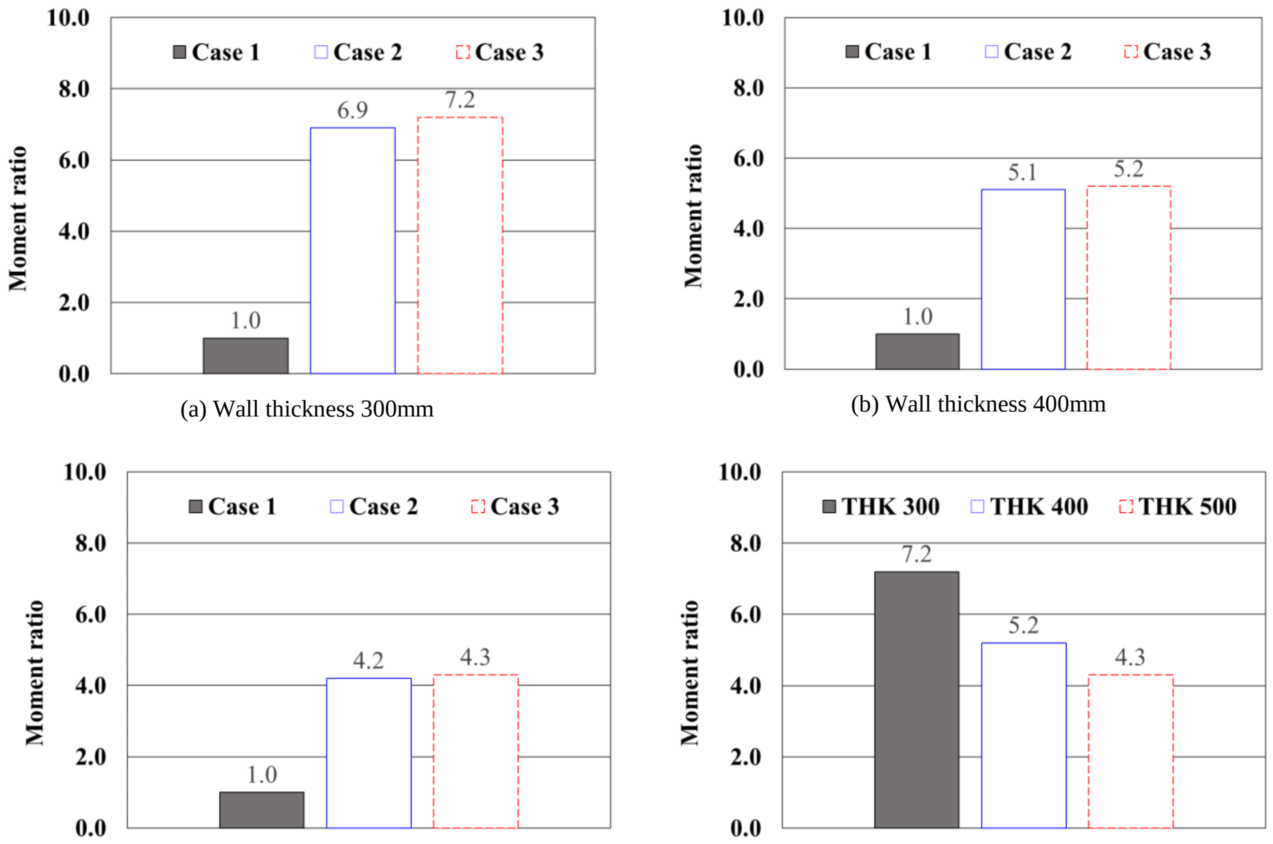
Table 1: Comparison of strengths corresponding to wall thickness and reinforcement ratio

Wall thickness (mm)	Ratio of vertical bars ρ_v	Yield moment (kN.m)			Moment ratio		
		Case 1	*Case 2*	*Case 3*	$\frac{Case\,2}{Case\,1}$	$\frac{Case\,3}{Case\,1}$	$\frac{Case\,3}{Case\,2}$
300	0.24	52.4	361.0	379.2	6.89	7.24	1.05
400	0.24	99.8	408.4	434.5	4.09	4.35	1.06
	0.18	76.1	384.7	398.4	5.06	5.24	1.04
500	0.24	173.3	481.9	495.7	2.78	2.86	1.03
	0.14	97.0	405.6	418.9	4.18	4.32	1.03



(a) Wall thickness 300mm

(b) Wall thickness 400mm

(c) Wall thickness 500mm

(d) Strength variations due to the composition

Fig. 6: Composite effect of walls with same magnitude of vertical reinforcement

IV. Conclusion

In this study, it was found that the strength of the wall increases when the underground wall and the H-pile are composited and the thickness of the wall can be reduced. As for the thickness change of the underground building wall, it is confirmed that the composite effect is increased as the wall thickness is decreased. It can be seen that the amount of shear connectors in the composite wall is not determined by the flexural behavior. In other words, the amount of shear connectors is seen to be determined by shear rather than dominated by flexural behavior, or to prevent widening between wall and H-pile.

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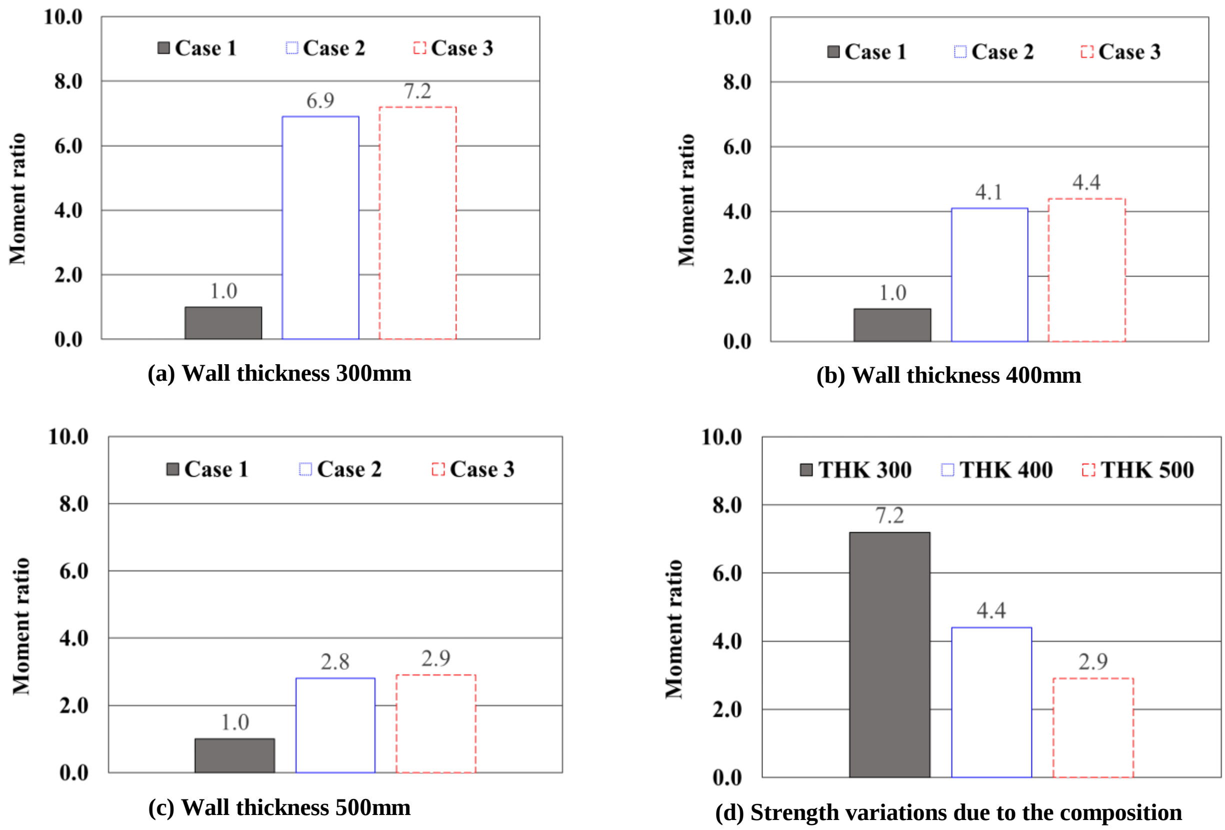

Fig. 7: Composite effect of walls with same ratio of vertical reinforcement

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