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Effects of Relief Shelves on Stability of Retaining Walls

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ABSTRACT : Attaching shelf to retaining structure leads to a decrease in the total lateral earth pressure. This decrease enables the retaining structures to become more stable, to have small displacement, and to exhibit lower bending moments, the relief shelves effects are analyzed using FEM in order to understand how they stabilize cantilever wall in this study. Several models are varied by changing location and width of shelves to realize earth pressure and displacements of retaining wall. The displacement is getting smaller because earth pressure acting on shelf increases as shelves locations are lower and width is longer. The ground settlement variation effects caused by relief shelves are studied also. The ground settlement increases abruptly where shelf location is between of 0.5H and 0.625H, and settlement decreases suddenly where shelf width is between b/h=0.375에서and b/h=0.500. The shelf significantly reduces earth pressure and movement of the wall. This decrease in the lateral pressure increases the retaining structure stability.

Keywords : Special retaining structures Relief shelves, Earth pressure Lateral displacement

1. Introduction

Concrete retaining walls are widely used to resist earth pressure worldwide. Several types of retaining walls such as counterfort walls, buttress walls and retaining walls that rest on piles. The relief shelf wall can be alterative method to resist earth pressure, and can save concrete wall size causing economics and construction period. Farouk (2015) suggested cantilever retaining wall with relief shelf is possibly most economical method as well as reinforced soil wall. The relief shelf can reduce high lateral earth pressure specially in the case of high wall, and be able to conserve ovearl stability. If there is a construction near the wall and if the soil reinforcement cannot be applied, the use of this type of wall can be the most effective tool toward cost reduction and overall safety improvement. Few studies have been carried out on the real behavior of this type of wall. Therefore, studying the effectiveness of this type of retaining wall is required for its use in practical application. For the purpose of quantifying how much earth pressure and lateral displacements decrease, the shelves width and location are varied in this study. The parametric study using FEM was performed. The effect on lateral earth pressure, displacement, and ground settlements are analyzed. The position of the shelf logically affects the wall top movement. This effect is studied here using the FEM solution. Different single shelf positions are studied to investigate the position that obtains the minimum top movement of the wall. The shelf length is categorized as short and long to extend over the possible failure surface. It is found that long shelf increases stability of wall.

2. Literature Review

Fuchen & Shile (2008) studied the effect of adding one or more relief shelves to a counterfort wall to increase the stability of retaining wall. They extended the relief shelves up to the theoretical rupture surface. He found that the relief shelves reduces the lateral earth pressure on the wall and increase the stability of the overall retaining structur, and illustrated theoretically the method of stability analysis of a counterfort wall with two relief shelves. Raychaudhuri (1973) found the magnitude of the reduction in the total active earth pressure and its distribution due to the provision of a relief shelf in a retaining wall. He presented the reduction factors in charts for various locations and widths of relief shelves. Raychaudhuri (1973) suggested that Coulomb's theory for earth pressure would be applicable to this type

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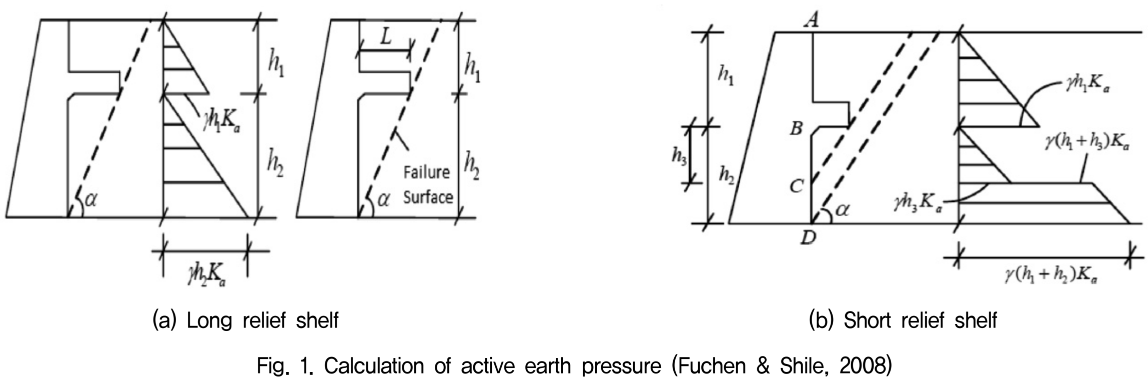
of wall and performed experimental studies to verify the stability of the wall, but he could not determine the earth pressure behind the wall due to the simple model that he used. Yakovlev (1974) experimentally studied in detail the effect of the relief shelves. He performed several experiments with one relief shelf to investigate different factors, such as the distribution of pressure over the height of the wall as a function of the position and the dimensions of the platform under the effect of a variably distributed load on the backfill surface; the distribution of the pressure on the platform as a function of the intensity and the location of the load; the nature of the change in pressure on the wall and on the shelf in the presence of forward movements of the wall; the size of the sliding wedge and the position of the sliding surface for walls with platforms; and the stress of the backfill behind the wall. Yakovlev (1974) studied the position of the internal and external sliding surfaces and the width and embedded depth of the shelf. For the same embedded depths of a shelf, the dimensions of the sliding zone increase with increasing platform width. Phatak & Patil (1975) discussed a theoretical concept for computing the earth pressure due to the effect of relief shelves. Phatak & Patil (1975) corrected an error in Raychaudhuri's (1973) solution. Raychaudhuri (1973) considered the effect of the relief shelf by deducting the weight of the soil above the relief shelf from the failure wedge; however, the change in the center of gravity for the failure wedge was not taken into consideration. Fig. 1(a) shows suggested distribution of the lateral pressure when the relief is extended to the rupture surface, while Fig. 1(b) shows their suggested distribution when the shelf width is not extended (Fuchen & Shile, 2008). For the case of the shelf extension, they suggested that the distribution of the earth pressure starts at zero under the shelf and increases linearly with depth. Yoo et al. (2012) measured the earth pressure acting on a wall with one shelf that is extended to the theoretical rupture surface. They constructed their model and simulated the excavation stage with slope angles of 50 and 90, and subsequently, they installed the wall and inserted the compacted backfill. They also attempted to verify the results from the finite element method (FEM) using the Mohr-Coulomb model. For their solution from the FEM, they installed the wall on a defined thickness of soil media. This thickness had settled and permitted the footing to rotate, even if by a small amount. These results should increase the lateral pressures, as shown in their FEM; however, the use of the Mohr-Coulomb soil model results in a slight increase in the lateral pressure due to the unloading-reloading conditions as they modelled the construction stages starting from the excavation stage to the backfilling stage.

3. Modeling Analyses

There are two objectives in this paper. The first is to compare the distributions of the lateral earth pressures for cantilever retaining walls with relief shelves. This is achieved by applying the FEM solution from PLAXIS2D using hardening soil model. This comparison should clarify the effectiveness of providing shelves for the cantilever retaining walls. The second objective is to conduct a parametric study to qualify the effect of several factors, such as, shelf location, shelf width, on the earth pressure distribution and wall deformation. To achieve the objectives of this study, numerical models are made and analyzed using PLAXIS 2D.

The models are prepared to ensure the effects of shelves location and width on earth pressure as shown in Table 1.



(a) Long relief shelf (b) Short relief shelf

Fig. 1. Calculation of active earth pressure (Fuchen & Shile, 2008)

Location of shelves are varied from wall bottom; 0.125H (100mm), 0.375H (300mm), 0.500H (400mm), 0.625H (500mm), 0.750H (600mm), 0.875H (700mm). The shelves are classified as long width and short width. The long width means it extends to slip surface of retaining wall while short means that width does not extends to slip failure surface. The analysis conditions on width and location are shown in Table 1.

The retaining structure material is reinforced concrete, which is modeled using a linear elastic model with a Rigidity (EA) of 80,000 kN/m, specific weight of 25 kN/m^3, and Poisson's ratio (ν) of 0.15. The hardening soil model was adopted to simulate the soils. The parameters of the base soil are as follows: The backfill parameters are as follows: φ is equal to 30, dilatancy angle (ψ) is 1, γ is 18.0 kN/m^3. The stated soils parameters are listed in Table 2. The wall is analyzed for the cases of cantilevers with a single relief shelf. Seven models are constructed to clarify the effectiveness of adding shelf and to the cantilever retaining wall. Seven models are constructed with different shelf locations and different shelf widths to qualify the effect on the resulting earth pressure distribution, top movement of the wall that is acting on the wall. The modeling is 2 dimensional plane strain condition. Wall and shelves are beam plate elements, and strength reduction is considered between plate and soil element. The load of 50 kN/m^2 is applied to compare displacement difference considering dead and live load.

4. Results and discussions

4.1 Effects of providing shelves on earth pressure

First, the effectiveness of the provided shelves should be discussed. Fig. 2 shows the resulting distributions of the lateral earth pressures in the cases of a cantilever with shelf. It can be observed that providing relief shelves to the retaining structure significantly reduces the lateral earth pressure. The distribution of earth pressure is similar to the that of ordinary cantilever wall, except discrete pressure behavior showing zero value beneath shelf. This discrete pressure is the result of the effect of shelf. The lateral pressure returns to its initial value from zero directly under the shelf and increases linearly with a slope that is less than the slope in the cantilever case. The lateral pressure directly above the shelves also exhibits an increase in the pressure for the same reason. It can be observed that the pressure beneath shelf starts at zero and returns to the path of the cantilever case. This means that the shelf increase the stability, especially when providing shelf. The effect of providing shelves at a level near the wall

Table 1. Model variation

		Width of relieving shelves					
		170	200	230	300	400	500
Height of Relieving platform	700	-	5-1	-	5-2	5-3	5-4
	600	-	4-1	-	4-2	4-3	4-4
	500	-	3-1	-	3-2	3-3	3-4
	400	2-a	2-1	2-b	2-2	2-3	2-4
	300	-	1-1	-	1-2	1-3	1-4

Table 2. Material properties for analysis

	Unit	Backfill soil	Wall
Unit weight (γ)	kN/m^3	18	25
Void ratio (e)	-	0.45	
Young's modulus (E)	kPa	35,000	
Rigidity (EA)	kN/m		80,000
Stiffness (EI)	kN/m^2	1.067	
Poisson's ratio (ν)	-	0.3	0.15
Shear resistance angle (φ)	Degree	30	
Cohesion (c)	kPa	1	
Dilatancy angle (ψ)	Degree	1	
Constitutive model	-	Mohr-Coulomb model	Elastic model

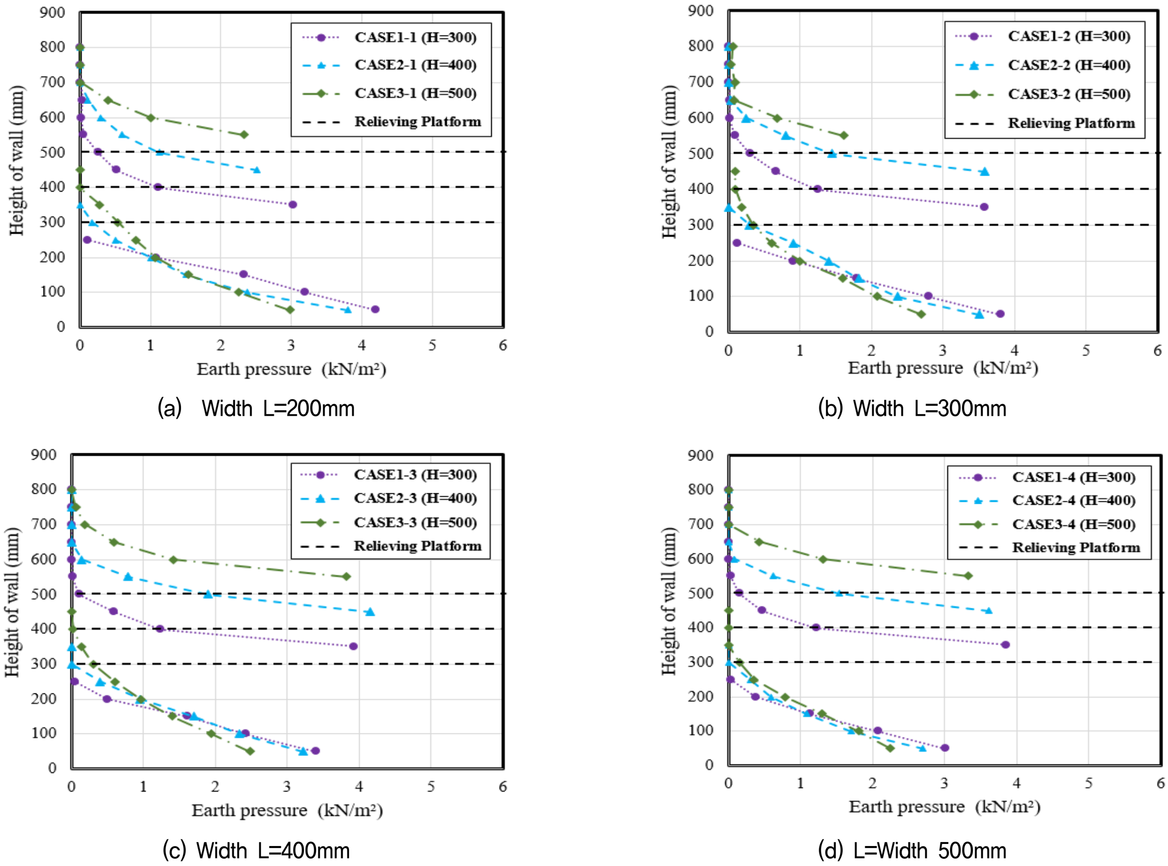


Fig. 2. Effects of shelves on earth pressure at each shelf width

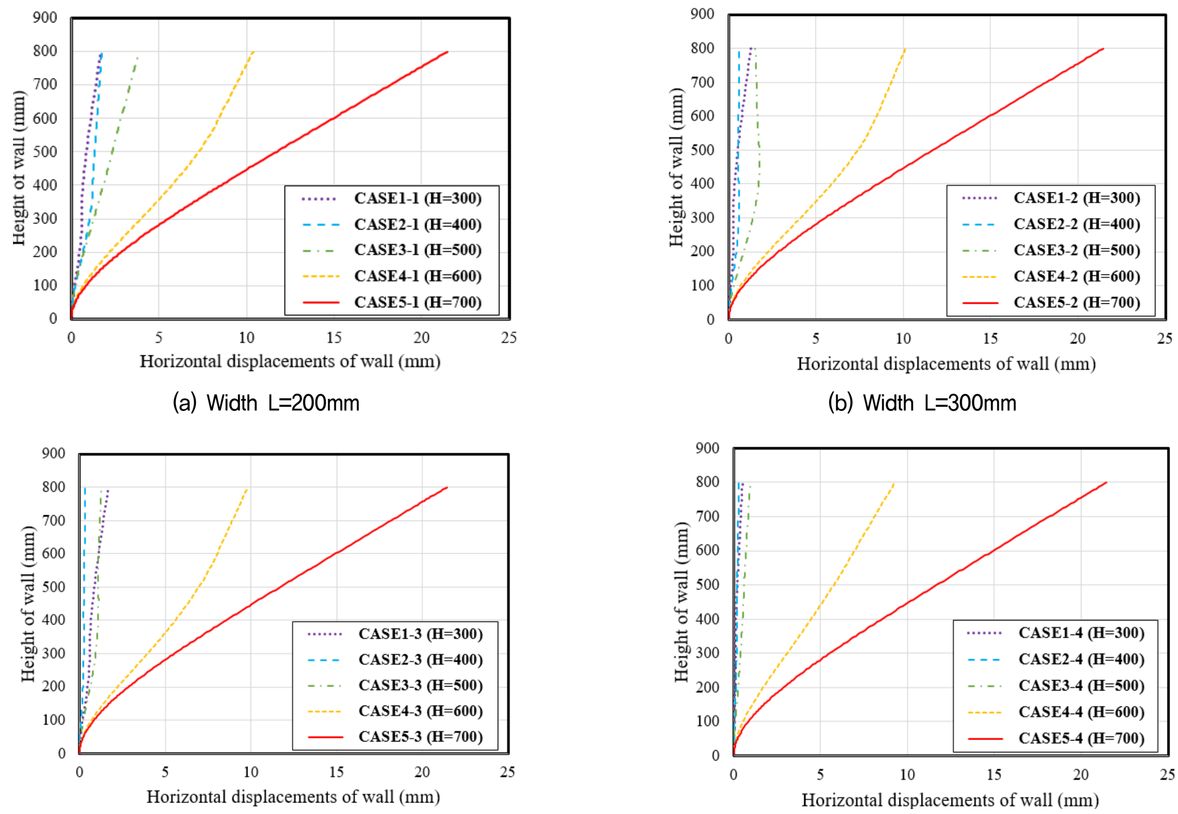
top is smaller than the effect of that which results from using a shelf at the lower level, this is, the effect of extending the shelf to the rupture surface that is increasing the stability. Lateral earth pressure decreases as width of shelves increases assuming shelves are at same depths as shown in Fig. 2.

4.2 Effects of shelf position on lateral displacement

The position of the shelf logically affects the wall top movement. This effect is studied here using the FEM solution. Different single shelf positions are studied to investigate the position that obtains the minimum top movement of the wall. The effect of the shelf position is also studied for the maximum bending moment. Fig. 3 investigates the effect of the depth shelves on displacements. The case at which shelves are located at lower position, the lateral displacements are smaller Also, as width of shelves increases, the displacement decrese, and the CASE 2 has smallest displacement. Therefore, the use of a lower depth ratio results in a lower wall top movement with an appropriate bending moment of the wall and of the shelf.

4.3 Effects of shelf width on displacements at CASE 2 (400mm height)

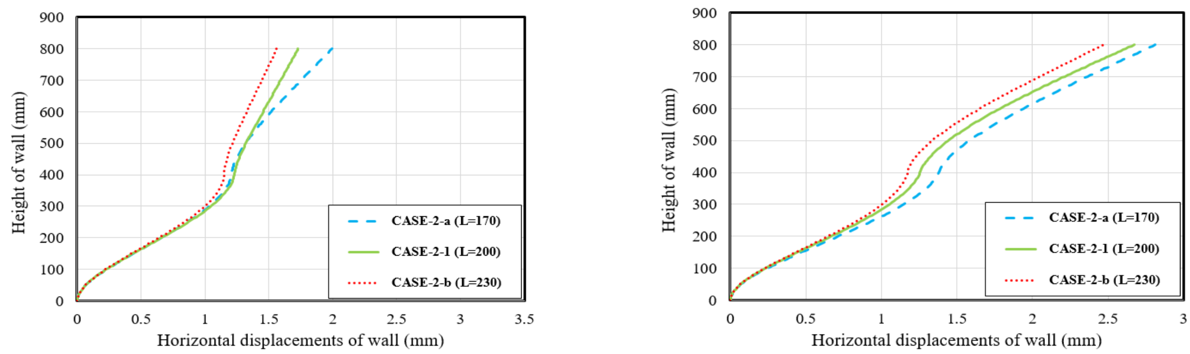
The shelf width is varied between 170, 200, 230. Single shelf is studied using different widths. As the theoretical solutions, the rupture surface has a slope angle of θ, which is equal to (45+φ/2). Fig. 4 presents the influence of the width for a single relief shelf at height of 400mm. It can be observed that which is not extended to the rupture surface, results in a higher lateral pressure below the shelf. For the case of 200mm and 230mm widths that are extended to the rupture surface, the distributions are similar. In the same manner, as when using a single shelf, 170mm shelf width results in a distribution characterized by higher values of the lateral earth pressure. Now, the movement of the wall is also permitted in the solution of the FEM to find the distributions of the lateral earth pressures. The logical solution from the FEM are compatible with these conclusions. In addition, the same distributions of the lateral pressures using the FEM were presented by Yoo et al. (2012), but they neglected the FEM solutions because the distributions of the FEM were not compatible with their measurements, which



(a) Width L=200mm (b) Width L=300mm

(c) Shelf length L=400mm (d) Shelf length L=500mm

Fig. 3. Wall displacement with shelf location at every width case



(a) Before loading (b) After loading

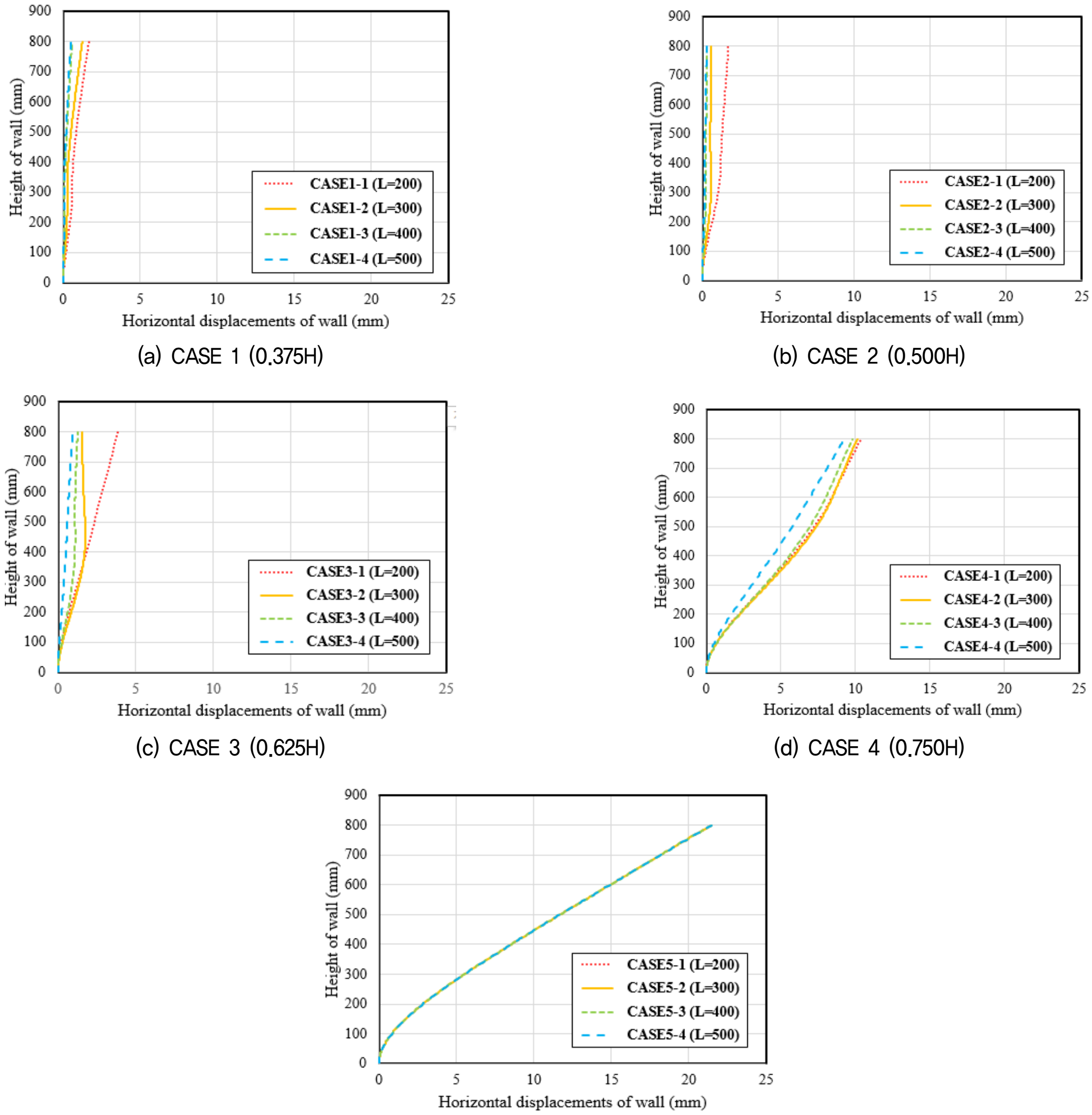
Fig. 4. Lateral displacements at 400mm height

were investigated using simple and fixed walls as previously discussed. The effect of the shelf width on the wall top movement is investigated as width varied ad 170, 200, 230 mm single shelf. Increasing the width of the shelves significantly decreases the wall top movement. This decrease is the result of the decrease in the acting lateral pressure and of the increase in the shelf deflection, which rotates the wall into the backfill. Displacement increase after loading especially above shelf as shown in Fig. 4.

4.4 Effects of Shelves location and width on displacements at each CASE

The shelves widths are varied as 200, 300, 400, 500mm. The displacements are analyzed in order to clarify effects of shelves location and width while shelves widths are varied as each shelve location.

CASE 1 is the case shelf is at nearest from the bottom, and lateral displacements decrease with increase of shelves width as shown Fig. 5. CASE 1-1 shows 1.7mm of maximum lateral displacement, and CASE 1-4 shows 0.65mm of lateral



(a) CASE 1 (0.375H) (b) CASE 2 (0.500H)

(c) CASE 3 (0.625H) (d) CASE 4 (0.750H)

(e) CASE 5 (0.875H)

Fig. 5. Wall displacement with shelf width at every case

displacement. When shelve width increase 150% from 200mm to 500mm (from CASE 1-1 to CASE 1-3), the displacement decreases 62%. CASE 3 shows same trend as CASE 1 such that displacement decreases with increase of shelve width increase. CASE 3-1 shows 5.0mm displacement while CASE 3-4 shows 3.46mm. Lateral displacement decrease of 31% as shelve width increase 150% as shown in CASE 3-1. CASE 4-1 shows 10.4mm displacement while CASE 4-4 shows 8.11mm. Lateral displacement decrease of 22% as shelve width increase 150% as shown in CASE 4-1.

CASE 5-1 shows 21.4mm displacement while CASE 5-4 shows 19.2mm. Lateral displacement decrease of 11% as shelve width increase 150% as shown in CASE 5-1. Displacements increase with decrease of shelve width increase in all the CASES. Also, as location of shelves are lower earth pressure decrease effect is effective and displacement are getting smaller. The decrease rate shows maximum value of 62% at CASE 1.

4.5 Effects of shelve width on ground settlement

Ground settlements are shown in Fig. 6 through numerical analysis. The settlements are analyzed with change of shelf location at each relieving shelf width.

The settlements increase rapidly at 0.50H height, and then increase steadily at same rate in all cases. The ground settlements are getting smaller as shelve width increase while decrease rate is largest when shelve widths are at between 300mm and 400mm.

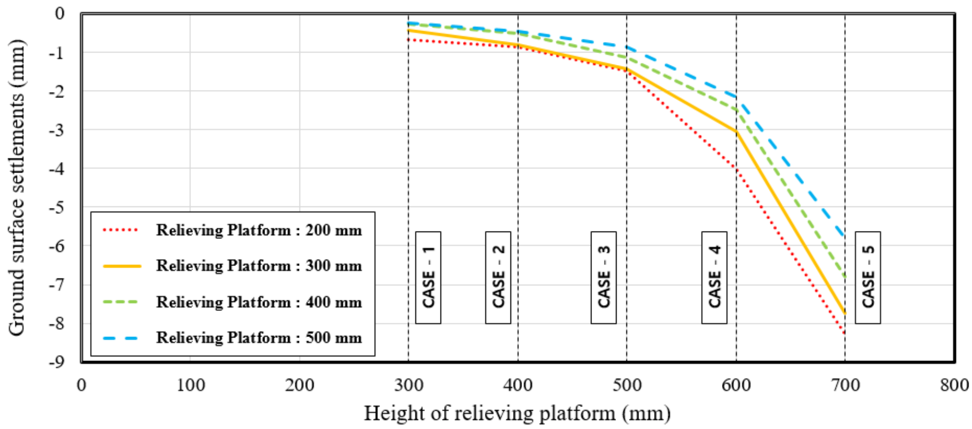


Fig. 6. Ground settlement with shelf location at each case

5. Conclusions

This paper presents a brief study of the effect of attaching shelf to a cantilever retaining wall. It was shown that few researchers have studied this special type of retaining wall. Attaching shelf to retaining structure leads to a decrease in the total lateral earth pressure. This decrease enables the retaining structures to become more stable, to have small displacement, and to exhibit lower bending moments. The shelf significantly reduces earth pressure and movement of the wall. This decrease in the lateral pressure increases the retaining structure stability. A parametric study was conducted to investigate the effectiveness of the shelf width and the shelf position on the lateral earth pressure distribution, top movement of the wall, and maximum bending moment. It is demonstrated that providing the cantilever retaining wall with a shelf with a certain shelf width is recommended to be extended to the rupture surface. The extension of the single shelf to the rupture surface leads the shelf to be rested on the stable soil; therefore, the fixed-end moment, from a fixed-hinged supported shelf, of the shelf is considered during the calculation of the acting maximum moment on the wall.

The summary of conclusions are as follows:

(1) The displacement is getting smaller because earth pressure acting on shelf increases as shelves locations are lower and width is longer. This phenomenon occurs because earth pressure action on shelf does not transfer to lower soil.

(2) The horizontal earth pressure acting on retaining wall increase as shelf location gets lower, but total earth pressure acting on wall decrease since shelf blocks transfer of earth pressure.

(3) The ground settlement increases abruptly where shelf location is between of 0.5H and 0.625H, and settlement decreases suddenly where shelf width is between b/h= 0.375에서and b/h=0.500.

Therefore, it is considered that shelf location is most effective at 0.50H where it is central part of wall.

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