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Effects of Facing Types and Construction Procedures on the Stability of Reinforced Earth Wall

전면벽 및 축조순서가 보강토옹벽의 안정성에 미치는 영향

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요 지

모형 보강토 옹벽을 실내에 축조하여 벽체의 연속성과 강성이 벽체의 거동 및 안정성에 미치는 영향을 조사하였다. 완전 연속 전면판과 일반적으로 사용되는 블록식 비연속 전면판을 설계하여 모형실험에 적용하였다. 따라서 각각의 전면판에 따라 서로 다른 축조방법과 축조순서가 채택되었다. 모형 보강토옹벽은 상용의 지오그리드 보강재와, 주문진 표준사를 사용하여 강성지반 상에 축조하였으며 토압계, 변위계 및 보강재 상에 부착된 변형율계 등을 사용하여 거동을 추적하였다. 두 벽체에 대한 시험으로부터 연속 강성 벽체를 가진 보강토 옹벽이 일반적인 블록식 전면판 보강토 옹벽에 비해 안정적인 거동을 보임을 확인하였다.

Abstract

A small-scale reinforced earth wall was constructed in a laboratory to investigate the effect of wall rigidity and of construction sequence on the wall. A full continuous wall facing and a discrete wall facing were designed and constructed for tests. These two different facing systems should adapt different construction procedures due to their different facing shapes. The model wall was built with geo-grid reinforcement, sand, and facings on rigid surface. The model wall was instrumented with earth pressure gages, LVDTs, and strain gages. The experimental results have shown differences in wall behavior related to construction sequence and types of wall facing. It is found in this study that the reinforced earth wall built with full continuous facing is safer than the reinforced earth wall built with the discrete wall facing.

Keywords : Construction procedure, Continuity, Reinforced earth wall, Rigidity, Wall facing

1. Introduction

Recently, many types of reinforced earth wall with geo-grid reinforcement and block facing have been proposed due to its simple and economic construction procedures. However, wall deformations generated during the construction procedure are comparatively larger than those of conventional gravity retaining wall and excavated cut wall such as soil nailed wall (Jones, 1994). This is due to the use of different construction procedure and construction materials. The reinforced earth walls are built usually from bottom to top. The

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soil nailed walls are built from top to bottom. Usually, it is well known that the reinforced earth walls are more endurable to large deformations than conventional gravity walls. However, the deformations of the wall provide instability to the wall system somehow. In this study, the behavior of a reinforced earth wall built with full continuous facing was investigated in detail and compared to that of the wall built with discrete block facing.

Cardoso and Lopes (1996) divided construction procedures of the reinforced earth structures into two typical types. The first one is the so-called common type of reinforced earth wall built from bottom to top with block-type facing, reinforcement and backfill soil. In this type of the wall, tension in the reinforcement is generated from the beginning of construction. On the other hand, construction of the other type of the wall may start with the use of panel-type facing with aid of props in front of the wall first. After setting up the propped facing, the wall is backfilled and reinforced from bottom to top. Then the props are to be removed from the wall after backfilling. Therefore, the tension in the reinforcement is to be generated when the wall moves due to removal of the props. Different wall behavior can provide different pattern and amount of wall deformation.

In this study, a small-scale model wall reinforced with geogrid adapting different construction sequences was investigated in order to validate usage of full continuous facing wall designed for reducing wall deformation effectively compared with conventional reinforced earth wall.

2. Tests of Model Reinforced Earth Wall

2.1 Test Equipments and Instrumentations

A schematic diagram of the testing apparatus used for the tests is shown in Fig. 1. The model wall was constructed by adopting two different construction sequences. The similitude law is not effective in this test. Therefore the tests have some limitations in modeling the wall and in analyzing the test results. However, instead of the size limitations, the model can provide useful information about the reinforced earth wall with different types of wall facings.

Major test equipments consisted of steel frames and soil retainer. The steel frames include vertical and horizontal loading machines attached on them. The size of the steel frames is 2.0 m long, 3.0 m high, and 0.8 m wide. The soil retainer used for making the model wall being filled with the Jumunjin standard sand was 1.2m long, 0.8 m high and 0.8 m wide. The bottom of the soil retainer was rigid steel slab. The vertical load is applied to the wall by a 200 kN (20 tonf) capacity of linear servo-motor and screw gear. Either a constant loading rate or a constant pressure system is available in this loading machine. Total displacements of the wall were monitored by five LVDTs as shown in Fig. 2. Gages and instrumentations used for measuring data are summarized in Table 1.

A load cell was used in order to measure vertical loads applied to the model wall. Earth pressure gauges were

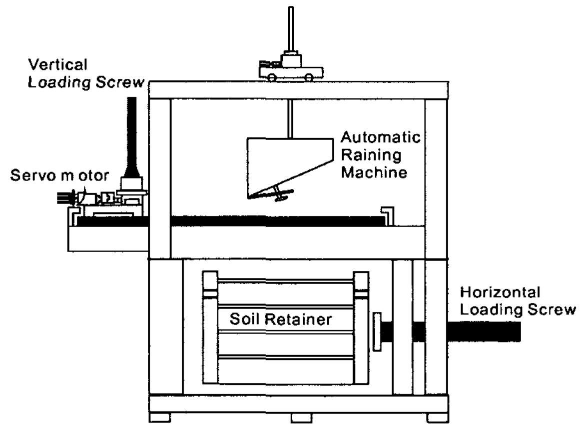


Fig. 1. Test equipments and loading system

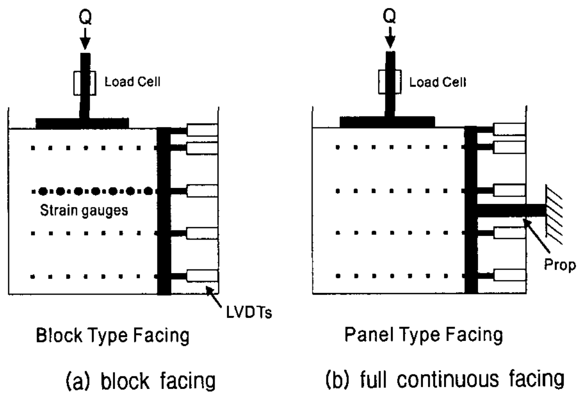


Fig. 2. Sectional view of model walls

Table 1. Specifications of Instrumentations for Tests

Gages	No. Gages	Model No.	Capacity
Load cell	1 EA	KD-CD	200 kN
LVDTs	5 EA	KTC 225	200 mm
Strain gages	34 EA	YFLA-10 (Tokyo Sokki)	N/A
Earth pressure cell	5 EA	KD-2E (Tokyo Sokki)	200 kPa
Data logger	1 EA	UPM60 - Static	60 channels

also embedded behind the wall to monitor change in earth pressure in the process of loading and wall deformation. Strain gauges were also attached to the surface of the reinforcement in order to monitor the generated tensile strains. The measured signals were transmitted to readout box and personal computer for saving and analyzing the obtained data. The model wall was loaded vertically to failure. The failure of the wall was determined when the wall was deformed horizontally to 10% of the wall height (H=0.8 m).

2.2 Properties of Backfill Soil and Reinforcements

Standard Jumunjin sand was selected as the soil used for the backfill of the model wall. Properties of the Jumunjin sand and of the reinforcement are shown in Table 2. The used reinforcements for all tests were geogrid type reinforcements and were obtained from commercial production. The dry Jumunjin sand was compacted to 77% of relative density by free falling method.

2.3 Design of Model Tests

All tests were focused on investigation of effects of reinforcement length, facing types, and load intensity on the wall behavior, especially the wall deformation. All the tests were not repeated due to the scale of the tests. Thus, the tests results could not be unique and could include intrinsic errors due to construction complexities. The vertical load was applied to the wall after the wall completion. The loads were applied to the wall with 0.6 m wide loading plate and loading intensities were varied. The obtained data from earth pressure gauges were too irregular, in case of the wall with discrete block facing, to be valuable data. Thus they were not considered in the analyses. The used facings (0.05 m thick) were made of recycled and pressed polyurethane board and have 5%

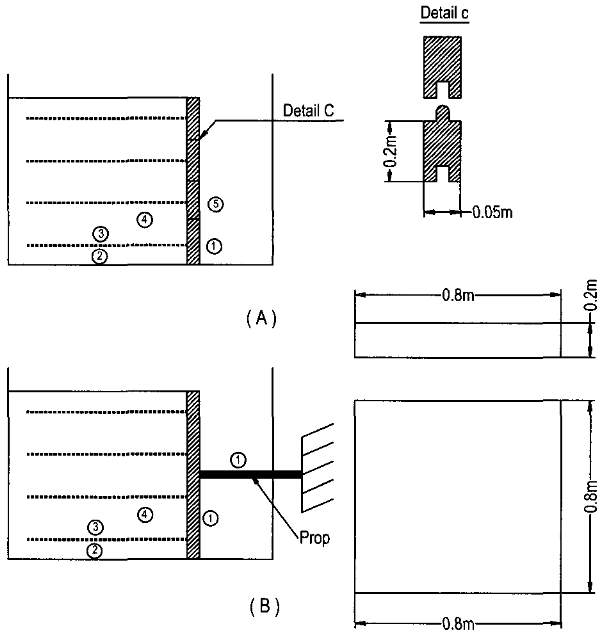


Fig. 3. Construction sequence and the wall facing board in details: (a) block facing, (b) full continuous facing

Table 2. Material properties of Jumunjin sand and geogrid reinforcement

Jumunjin sand					Reinforcement		
G_s	γ_{max} (kN/m^3)	γ_{min} (kN/m^3)	D_r (%)	φ (°)	TensileStrength T_{max} (kN/m)	T^* (kN/m)	ε^{**} (%)
2.65	16.17	13.3	77	45	80	25	13

N.B) *T= tensile strength at 5% elongation of reinforcement; ** ε =elongation at failure of the reinforcement of glass fiber. The size of the full continuous facing was 0.8 m wide, 0.8 m high and 0.05 m thick. The size of the block facing was 0.8 m wide, 0.2 m high and 0.05 m thick. The block facings were inter-connected using small long rail and long hole made on the top and bottom of each facing board as shown in Fig. 3. However, each block facing moves freely by making the rail to have half-circular section. Longitudinal ribs of the reinforcements were connected to the facing using small steel hooks. Material characteristics of the facing are presented in Table 3. All tests were performed following the design parameters as shown in Table 4.

The model wall was constructed by following two different construction sequences independently. The block-facing wall was built from bottom to top with block-facing, extensible reinforcement and backfill soil. On the other hand, construction of the continuous full facing wall started with setting full facings and props up first. After setting the propped facing up, the wall is backfilled and reinforced from bottom to top. Then the props are to be removed from the wall after backfilling. Thus the construction sequences adopted in this test were drastically different in these two wall types. In the full continuous facing wall, the facing was not hinged at the bottom of the wall resting on a rigid foundation.

Table 3. Material characteristics of wall facing

	Full cont. facing	Block facing
Young's modulus (kN/m^2)	6.27E6	6.27E6
Section area (m^2)	0.04	0.04
Moment of Inertia (m^4)	1.04E-5	N/A
Unit weight (kN/m^3)	5.88	5.88

Therefore the wall facing moves freely at the bottom of the wall. In order to reduce frictional resistance generated between the wall sides and the soil retainer, transparent papers were cut and aligned along the sides of the board.

3. Analyses of Test Results

3.1 Wall Deflections

Fig. 4 illustrates how the horizontal wall deflections are different with changing the types of wall facing and the construction sequences. In case of the wall with the block-facings, contour of the horizontal wall deflection was somehow different from that of the conventional reinforced earth walls built in the field that generated typically maximum wall deflection around upper one third of the wall height. This difference might be due to the difference in the shape and size of the model wall facing compared with the conventional block facings found in the field.

The horizontal wall deflections generated in the block-facing wall were 10 to 17 times those of the full continuous facing wall immediately after the wall construction was completed. Furthermore, the horizontal wall deflections of block facing wall were 4 to 5.7 times those of the full continuous facing wall when the vertical load was applied up to 39.2 kPa (4 tf/m^2). Thus, difference in wall deflections between the two types of wall facing decreased when the vertical load was applied. Nevertheless, the horizontal wall deflections of the full continuous facing were still smaller than those of the block-facing wall. Generated additional net wall deflections measured

Table 4. Design parameters used for test.

Wall Types & Reinforcement Length			Loading conditions			
Test no.	Facing type	Length (L)	Plate width (m)	Loading intensity (kN/m^2)		
1	FHP	0.9H	0.6 (0.75H)	10.0	19.6	39.2
2	FHP	0.7H	0.6 (0.75H)	10.0	19.6	39.2
3	FHP	0.5H	0.6 (0.75H)	10.0	19.6	39.2
4	BP	0.9H	0.6 (0.75H)	10.0	19.6	39.2
5	BP	0.7H	0.6 (0.75H)	10.0	19.6	39.2
6	BP	0.5H	0.6 (0.75H)	10.0	19.6	39.2

N.B) FHP: full continuous facing, BP: Block facing, H: wall height (H=0.8m)

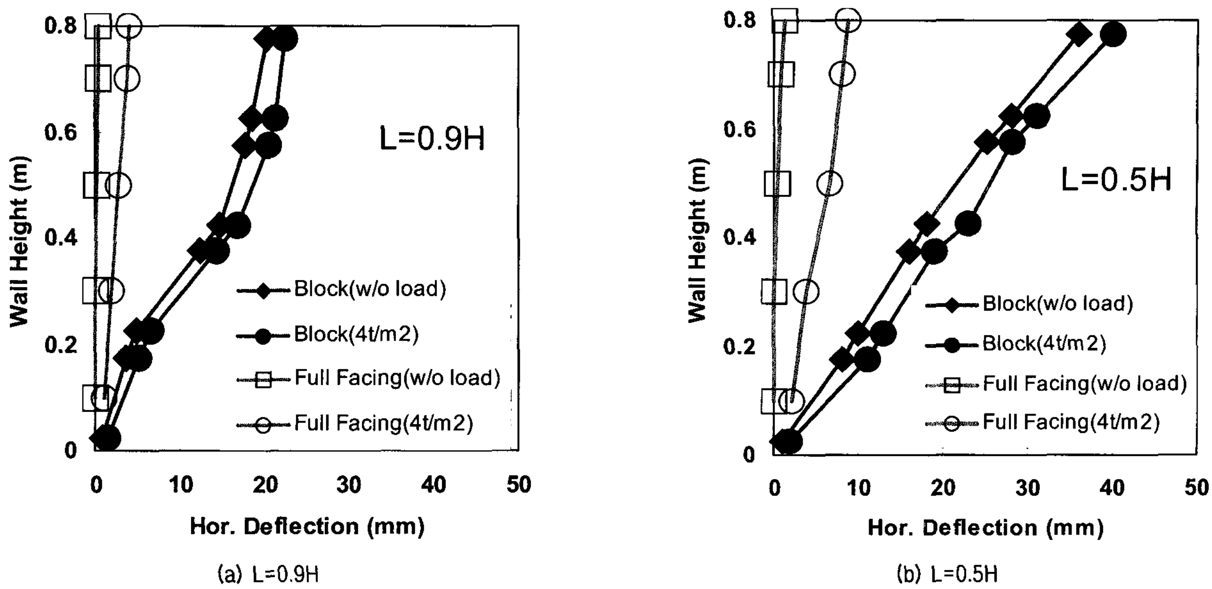


Fig. 4. Comparison of horizontal wall deflections

after applying the vertical loading increased in similar proportion in both facing walls. However, the net increase of wall deflection in the block-facing wall tended to increase relatively smaller than those of the full continuous facing wall. This may be due to enough generation of wall deflection during wall construction in case of the block facing wall.

3.2 Tensile Force Distribution in Reinforcements

The typical generated tensile forces in the reinforcement are shown in Fig. 5 to Fig. 8 for block facing and full continuous facing, respectively. Intensities of vertical loads were varied from 9.8 kPa (1 tonf/m^2) to 39.2 kPa (4 tonf/m^2) and were applied to top of the wall. As shown in the figures, the generated tensile forces in the reinforcement of the block facing wall were generally greater

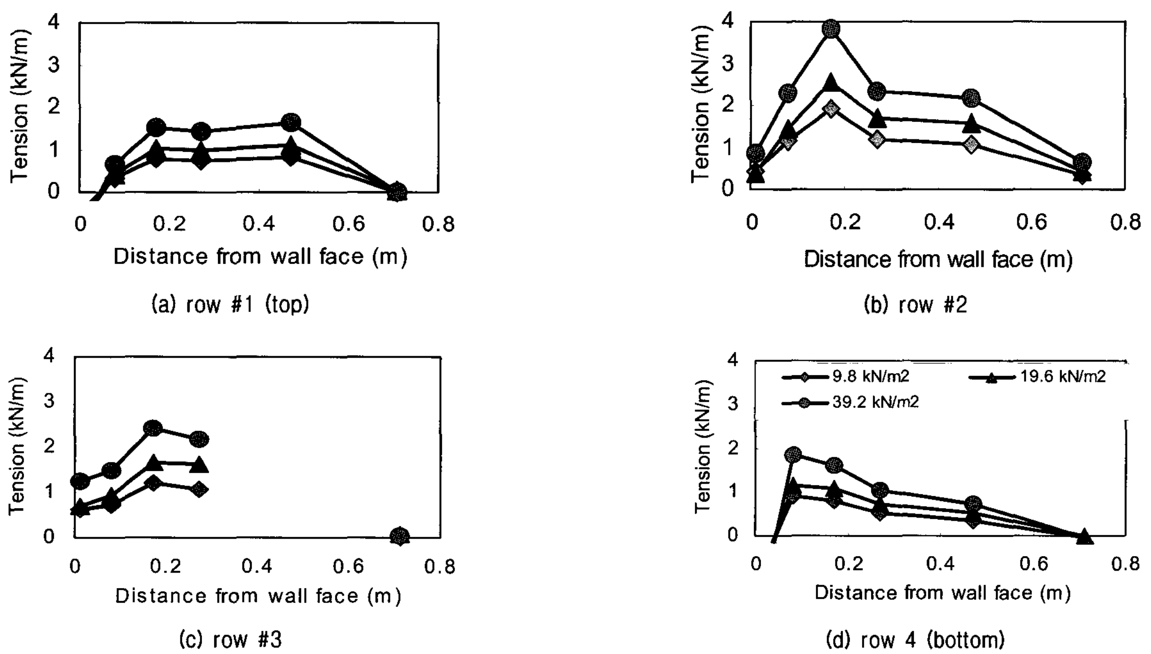
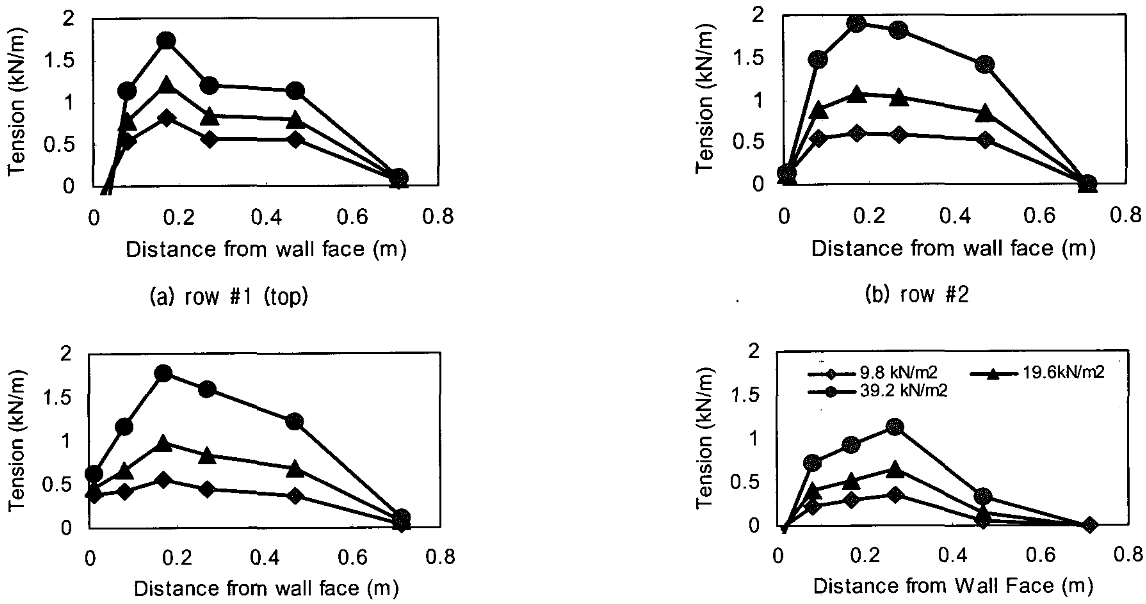


Fig. 5. Typical generated tensile force distribution in case of block facing (L=0.9H)

than those in the reinforcement of the full continuous facing wall. In the full continuous facing wall, the generated tensile forces in upper (two) reinforcement were greater than those in lower (two) reinforcement and tended to decrease with depth. In addition, in case of the full continuous facing wall, the maximum tension was found in reinforcement length (L) of 0.7H (not shown here). The generated tension in the reinforcement of the full continuous facing wall increased relatively very small when the wall was vertically loaded after the props were removed, compared with the block-facing wall. On the other hand, the generated tensile forces in the block-facing wall were larger in lower reinforcement than those of upper reinforcement. In addition the maximum tensile forces in each reinforcements of the block-facing wall represented greater values in the middle row of reinforcements than the upper most and lower most reinforcement. This may be due to the differences in mode of wall movement: the block facing wall moves in horizontal translation mode, but the full facing wall moves in



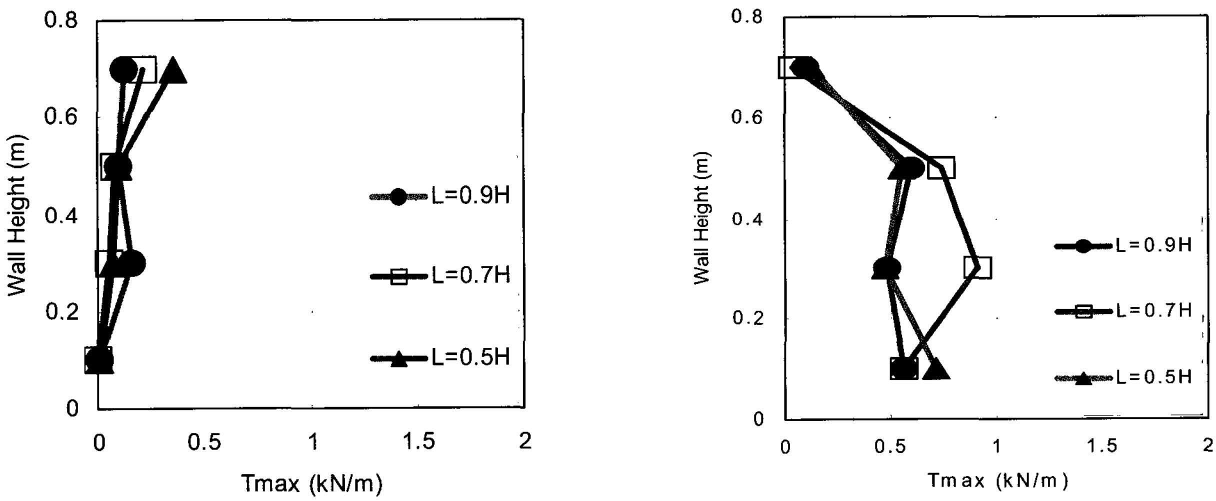
(a) row #1 (top)

(b) row #2

(c) row #3

(d) row 4 (bottom)

Fig. 6. Typical generated tensile force distribution in case of continuous full facing (L=0.9H)



(a) full continuous facing

(b) block facing

Fig. 7. Comparison of maximum tensile force generated in reinforcement after completion of wall construction (without loading)

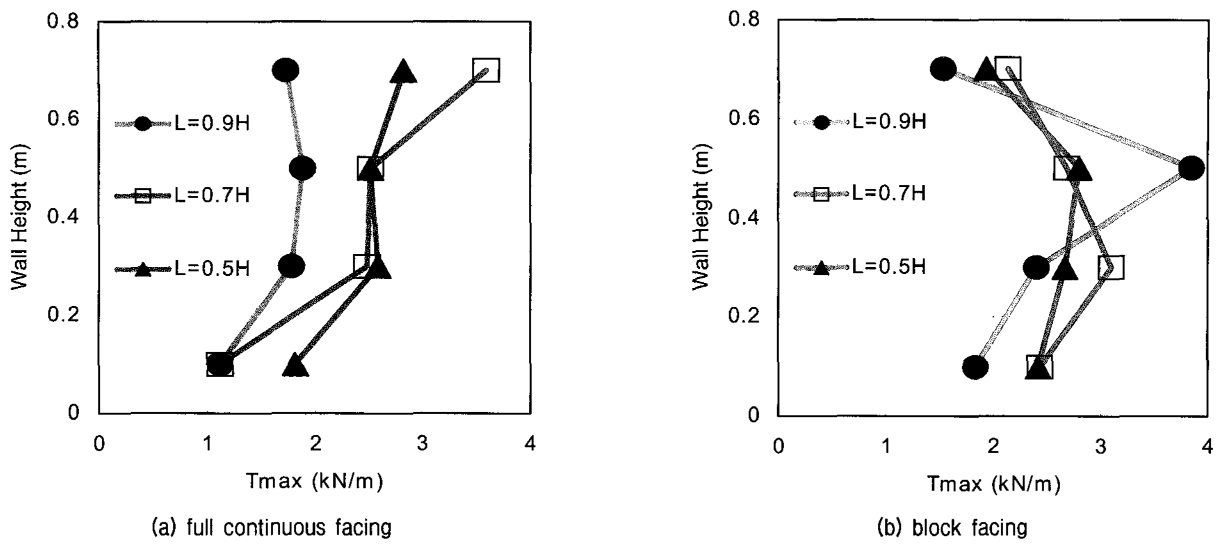


Fig. 8. Comparison of maximum tensile force generated in reinforcement after vertical loading

rotational mode mostly.

In case of the full continuous facing wall, the locus of maximum tensile force in the reinforcements tended to be generated close to the facing rather than the Rankine failure surface when the reinforcement length (L) was longer than 0.7H.

3.3 Earth Pressure Distribution

The earth pressure gages installed on the back face of the wall facing measured the earth pressure changes with depth. However, the earth pressures could be measured

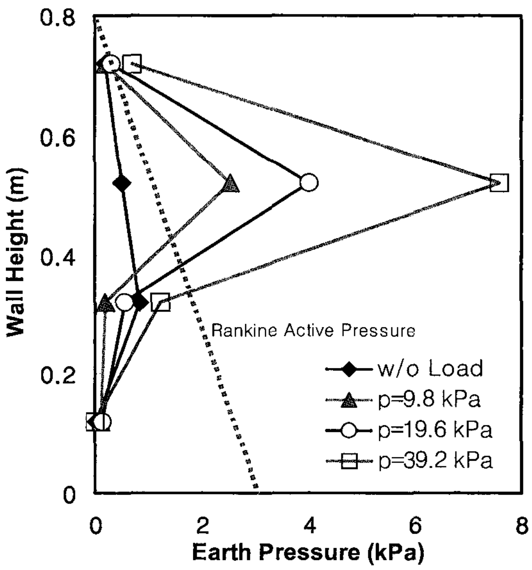


Fig. 9 Earth pressure distribution in case of the wall built with full facing

only in case of the wall with full continuous facing. This is due to the difference of construction sequence in the wall built with full continuous facing. The wall displaces and rotates immediately after the props in front of the wall were eliminated. The measured earth pressure distribution with depth in case of the wall built with full continuous facing is represented in Fig. 9. The measured earth pressure distribution immediately after the wall completion is much smaller than that of the Rankine's active case. This may be due to installation of earth pressure gages between the reinforcement, causing measurement of local earth pressure in the gages. Therefore, the walls built with the full continuous facing and the props have merits for reducing wall deflections, earth pressures and maximum tensile forces compared with the wall built with discrete wall facing. In addition, the earth pressure was much higher around the mid of the wall when the wall was loaded vertically. This phenomenon can be explained easily by adopting elastic theory.

4. Summary and Conclusions

This study has presented positive possibilities of reducing wall deflection when the reinforced earth wall is equipped with full continuous facing. In this study, a small-scale reinforced earth wall was constructed in a laboratory to investigate effects of continuity and rigidity of the wall facing and of the following construction sequence on the wall. A full continuous wall facing and a block-type discrete wall facing were designed and introduced for the tests. These two different facing systems adopted different construction procedures. The model walls were built with geo-grid reinforcement, sand, and facings on rigid surface. The model wall was instrumented with earth pressure gages, LVDTs, and strain gages.

The following findings are obtained from this study only and cannot be applied to general cases:

(1) The horizontal wall deflections generated in the block-facing wall were 10 to 17 times those of the full continuous facing wall immediately after the wall construction was completed. Furthermore, the horizontal wall deflections of block facing wall were 4 to 5.7 times those of the full continuous facing wall when the vertical load was applied up to 4 tf/m^2.

(2) The generated tensile forces in the reinforcement of the block-facing wall were generally greater than those in the reinforcement of the full continuous facing wall. The generated tension in the reinforcement of the full continuous facing wall increased relatively very small amount when the wall was vertically loaded after the props were removed, compared with the block-facing wall. This may be due to the differences in mode of wall movement: the block facing wall moves in horizontal translation mode, but the full facing wall moves in rotational mode mostly.

(3) The earth pressure changes were measured only in case of the wall with full continuous facing. The measured earth pressure distribution immediately after the wall completion is much smaller than that of the Rankine's active case. Therefore, the walls built with the full continuous facing and the props have merits for reducing wall deflections, earth pressures and maximum tensile forces compared with the wall built with discrete wall facing.

It is concluded finally from the study that the reinforced earth wall system built with full continuous facing may be the safest reinforced earth wall ever compared with the wall built with the block type discrete wall facing since it can reduce wall deflection drastically compared with the conventional block-facing wall. Therefore, it is recommended that study for the wall system, for example, full size of the full continuous facing wall, be necessary for further wide usage in the field in the future.

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