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Ground Behavior Behind Soil Nailed Wall by Feed Back Analysis

역해석에 의한 쏘일네일링 벽체 배면지반의 거동 연구

Jeon, Seong-Kon* 전 성 곤

요 지

쏘일네일링 공법은 작업공간의 확보가 용이하고 네일길이가 어스앵커보다 비교적 짧아 도심지 지하굴착에 매우 이로운 장점이 있다. 이 공법이 도입된 이후 쏘일네일링 벽체의 거동에 관한 연구는 토조에 의한 모형실험과 이론적 연구가 진행되고 있지만 지반조건이 다층토로 구성된 현장에 대한 연구는 미흡한 실정이다. 본 연구는 국내 다층토 지반에 시공된 쏘일네일링 현장에서 시공중 측정된 수평변위를 토대로 한 역해석적 방법에 의해 배면지반의 이완영역거리와 이완영역계수를 고찰하였다. 연구결과에 의하면 쏘일네일링 벽체 배면지반의 이완영역거리는 최종굴착깊이의 증가에 따라 증가함을 보였으며, 그 비율은 최종굴착깊이의 94% 정도로 나타났다. 토사층과 암층이 혼합되어 있는 다층토 지반에서 토사층의 비율이 클수록 이완영역계수도 증가하였으나, 약 1.05 값에서 수렴하는 경향을 나타냈다. 벽체 최대수평변위에 대한 지표면 최대수직변위와의 관계는 역해석결과에서 지표면 최대수직변위가 최대수평변위의 80%이하로 나타났으며, Caspe방법에 의한 지표면 최대수직변위는 최대수평변위의 150~280%의 범위로 나타나 역해석결과보다는 매우 큰 값을 나타내 Caspe방법이 매우 보수적임을 확인하였다.

Abstract

The soil nailing is one of the useful support-system in urban excavation because of the presence of other structures in the vicinity. Since the soil nailing system was introduced, model experiments and theoretical studies have been performed to investigate behavior of soil nailed wall. However, there are few data in the case of multi-layered soil strata just like Seoul Metropolitan area in Korea. The feed back analyses are carried out using the measured wall displacement data for soil nailing construction sites with multi-layered strata in order to analyze the distance and the coefficients of extension zone of ground behind soil nailed wall. As a result, the distance of extension zone increased with increasing of the final excavation depth and the ratio of the distance to the final excavation depth was shown to be about 94% of the final excavation depth. Also, the coefficients of extension zone increased with enlargement of soil layer thickness and converged into constant value of 1.05. On the other hand, the maximum vertical displacements by the feed back analysis and Caspe's method were shown to be approximately 80%, 150~280% of the maximum horizontal displacement respectively.

Keywords : Displacement, Etenxion zone, Excavation, Feed back analysis, Measurement, Multi-layer, Soil nailing

1. Introduction

The basic concept of the soil nailing is reinforcing of existing ground by the introduction of steel reinforcement into the exposed face. Soil nailing resists bending and shear force developed by the skin friction

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between soil and nails. Especially, it controls the displacement of the walls.

In France, German and America where soil nailing method has been very much spread, the method is used when construction work is not much affected by ground water, soil layers are generally homogeneous, excavation depth is not deep and field condition is not affected by surrounding buildings.

However, there are few data in the case of deep and urban excavation and of multi-layered soil strata in Korea.

In this paper, the feed back analysis was carried out using the measured wall displacement data for 11 soil nailing construction sites with the multi-layered strata including various rock layers in order to analyze the distance and the coefficients of extension zone of ground behind soil nailed wall.

2. Site Conditions and Feed Back Analysis Modelling

2.1 Site Conditions

Site conditions and the measured data which are used in this paper are quoted from Jeon(1999).

The characteristics of sites are those of typically urban areas which used the advantage of soil nailing method because of ;

-.the boundary of adjacent land being near.

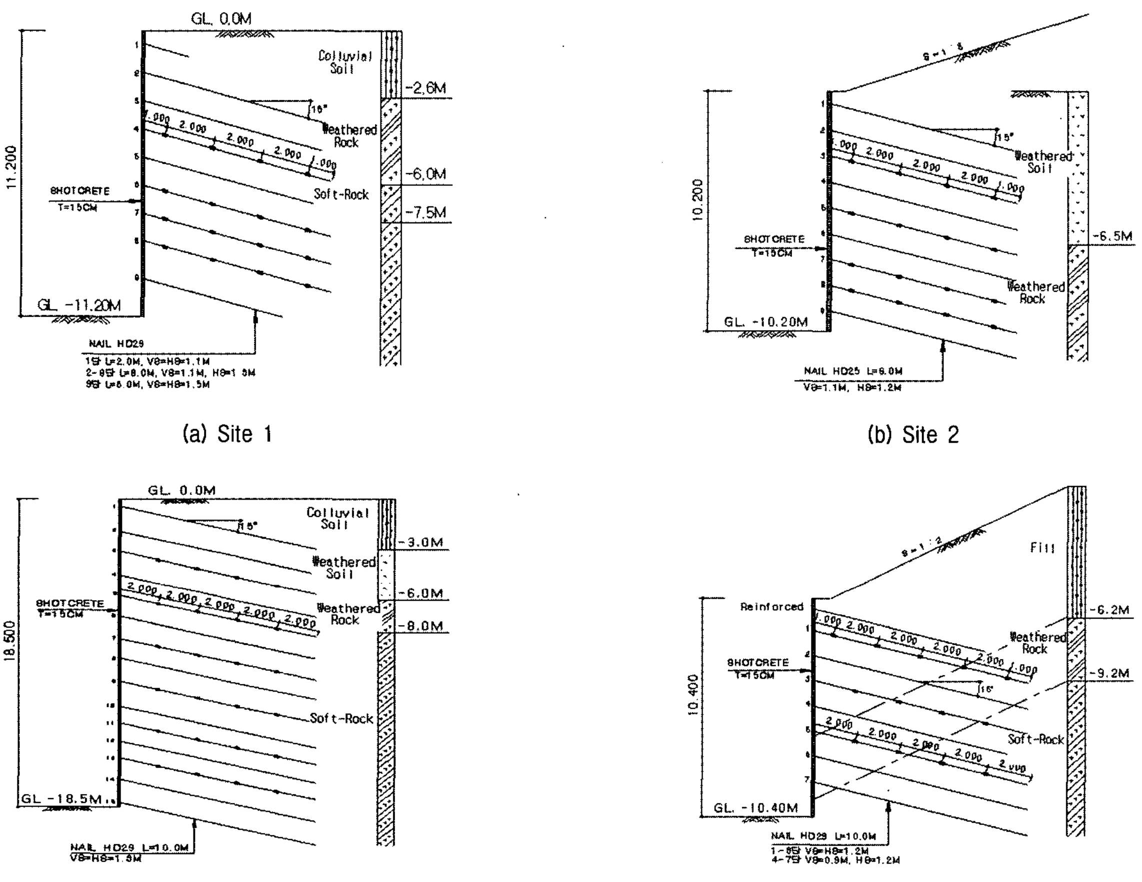
-.the difficulty in constructing earth anchor due to existing structures.

-.complex geometry of excavation plane.

-.ground loss being large when retaining wall is constructed on slope.

The construction step of soil nailed wall is proceeded in the order of excavation, nailing and facing.

The multi-layered ground of the site consists of fill,



(a) Site 1

(b) Site 2

(c) Site 5

(d) Site 10

Fig. 1. Cross section and soil profile of representative site(Jeon, 1999)

residual soil, weathered soil, weathered rock, soft rock, and hard rock as shown in Fig.1 and Table 1.

Ground was excavated by about 0.5m without berm at location of nail being installed or with berm of 2~5m

Table 1. Soil Profile

Profile (thickness ,m) \ Site	Site 1	Site 2	Site 3	Site 4	Site 5
Fill	Gravel and Silty Sand-Boulder Mixtures (0.4~7.2)	Boulder and Sand Mixtures (0.4~3.7)	Silty Sands, with Fine Gravel (0.3~1.4)	Silty Sands, with Waste Mixtures (0.3~2.9)	Boulder and Clay Mixtures (0.8~3.7)
Deposite Soil	Gravel and Silty Sands (0.9~7.5)	-	-	Silty Sand (0.5~3.9)	-
Residual Soil	Gravel and Silty Sands (1.0~5.9)	Silty Sand (1.9~2.4)	Sandy Clays (0.6~2.6)	Biotite Gneiss N-value 14/30~50/21 (1.0~5.2)	Well-Graded, N-value 30~50 (0.5~7.6)
Weathered Rock	(0.4~6.1)	(1.7~9.8)	(0.7~6.5)	(0.1~6.2)	TCR/RQD 4/0~6/0 (1.1~2.2)
Soft Rock	(below 8.0)	Andesite, Fcture and Joint Developed, TCR/RQD 6/0~41/22 (below 9.8)	Fracture and Joint Developed, (0.5~2.3)	Highly Weathered ,TCR/RQD 31/0~75/30 (below 8.6)	TCR/RQD 37/9~45/13 (0.5~1.5)
Hard Rock	-	-	Andesitic Tuff (below 8.2)	-	TCR/RQD 87/85~96/88 (below 7.5)
Ground Water Level (m)	G.L-1.05	-	G.L -2.4	G.L -4.6	-

Profile (thickness, m) \ Site	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Fill	-	Completely Weathered Soil with Rock Fragment (0.0~0.3)	Silty Sand, and Fine Gravel-Boulder Mixtures (0.8~3.2)	Boulder and Sandy Gravels (0.5~0.7)	-	Sandy Gravels, and Boulder Mixtures (8.6~8.8)
Deposite Soil	Gravel-Boulder-Clay Mixtures (5~12)	-	Find Sands, Silt, and Sandy Gravel Mixtures (10.9~12.1)	-	-	-
Residual Soil	Granite Weathered Residual Soils or Clayey Residual Soils (0.0~5.7)	Silty Sand (1.0~3.7)	-	Silty Sand (2.3~4.7)	Silty Sand, N Value 13~50 (0.0~6.5)	-
Weathered Rock	Rock Fragments and Dykes (0.0~2.0)	(0.5~5.3)	(1.5~4.2)	(4.1~6.2)	(6.5 below)	Banded Gneiss (1.5~1.6)
Soft Rock	Rhyolitic Tuff (below 9.8)	Fracture and Joint Developed, TCR 6.8 (below 8.9)	Gneiss, Fracture and Joint Developed, (below 17.2)	Fractured Zone (below 11.0)	-	TCR/RQD 20/0~100/0 (4.0~4.3)
Hard Rock	-	-	-	-	-	TCR/RQD 20/76~100/96 (below 11.6)
Ground Water Level(m)	-	G.L -9.6	G.L -1.8	G.L -0.7	-	-

at each steps.

Facing was made of wire mesh and shotcrete(t=150mm) and the retention walls composing the H-pile+C.I.P+L.W were constructed below the level of the final excavation depth in the 2 excavation sites case for reinforecment and cutoff purpose.

Nails were ribbed bar of HD-25mm or HD-29mm and were placed at an inclination of 15°~25° to the horizontal, and the inclination was adjusted if obstruction was present in the ground.

The borehole radius is 100mm and the inside of it was grouted with cement paste(σ_{ck} = 210kg/cm^2) to unificate nail and ground. And also weep holes are installed per 6m^2~8m^2 before excavation.

In order to check the stability of wall and adjacent structures, inclinometer, strain gauge and ground water level apparatus were installed, and readings were performed 2~3 times per week during construction period.

The inclinometer casings were located at about 1m from top of the wall and installed 2.0m~4.0m deeper than the final excavation depth, and these were measured more than once at each excavation steps.

To measure the developed tensile force of nail, vibrating wire strain gauges were installed with 1.5m~2.0m intervals along the length of nail.

2.2 Feed Back Analysis Modelling

The feed back analysis is performed by using FLAC program of the finite difference method. In feed back analysis, the ground behavior is assumed to depend on the Mohr-Coulomb criterion and the shotcrete stiffness of facing is applied to elastic modulus of concrete, and the nail is simulated as cable element which can be transferred to axial force. And the analysis was performed by stepwise excavation, and the effect of ground water was not considered because of drainage.

3. The Horizontal Displacement of the Wall

3.1 The Maximum Horizontal Displacement at Stepwise Excavation

The horizontal displacements of soil nailed wall at final excavation depth are shown in Fig. 2 with the results of the feed back analysis and measurements. Also, the maximum horizontal displacements at stepwise excavation depth by measurement data are plotted on Fig. 3(a).

The maximum horizontal displacements of the wall increased as the excavation depth increased and reached up to 0.3% of the excavation depth(H), however, small difference of the displacements is caused by the soil strata and site conditions.

Considering the ratio(L/H_f) of nail length(L) to the final excavation depth(H_f), in the case of the above 0.5, the maximum horizontal displacements increase linearly as excavation depth increases.

In the case of below 0.5 L/H_f ratio, the maximum horizontal displacements are larger than that of the above case. These results are not the effect of L/H_f ratio but due to a deep excavation depth of about 31m.

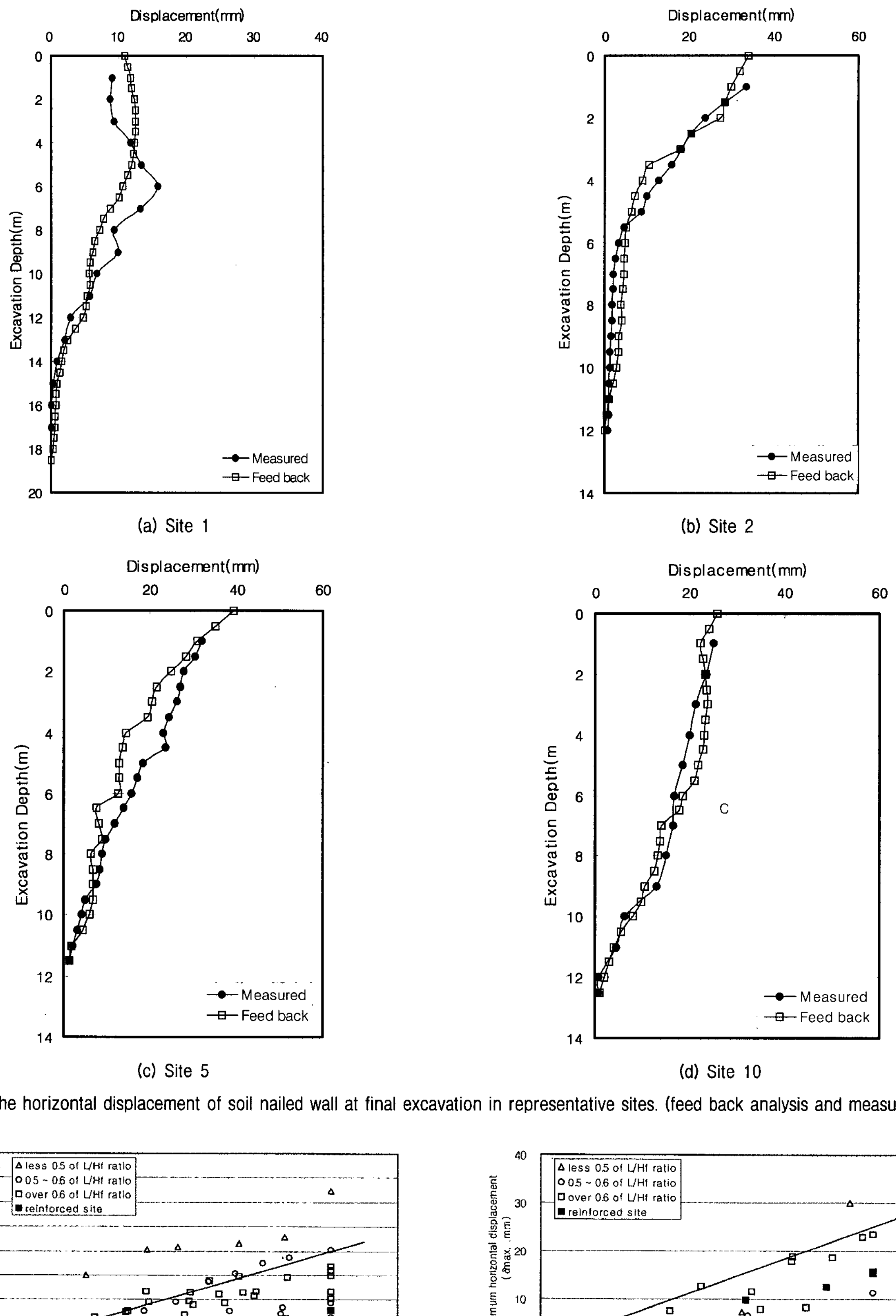
Furthermore, in the case of the reinforcing wall of H-Pile+C.I.P+L.W, the maximum horizontal displacements are shown below 0.2% of excavation depth as in Fig. 3(a).

If earth anchor or strut is installed, in this case, the shape of the horizontal displacements are parabolic and the point of maximum horizontal displacement moved towards the lower part of the wall as published by Lee et al(1993).

As a results, the occurring points of the maximum horizontal displacement are shown in the upper part of the soil nailed wall with excavation process.

On the other hand, as only the soil strata in the multi-layered ground is considered the maximum horizontal displacement increased about 0.3%H rate as the excavation depth increased in Fig. 3(b).

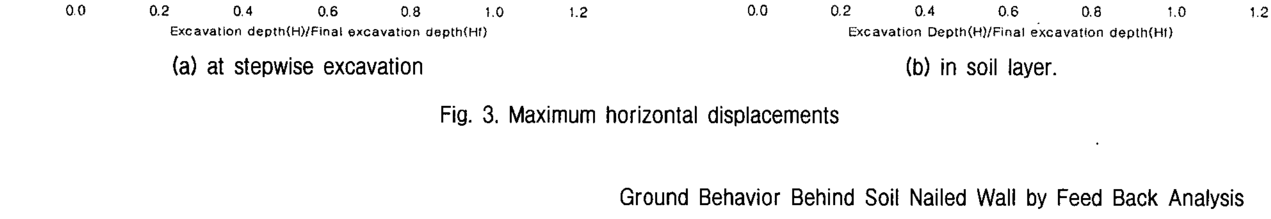
These results could be interpreted that the horizontal displacement occurred at the beginning of excavation in soil layer has effect until the final excavation step.



(a) Site 1 (b) Site 2

(c) Site 5 (d) Site 10

Fig. 2. The horizontal displacement of soil nailed wall at final excavation in representative sites. (feed back analysis and measurement)



(a) at stepwise excavation (b) in soil layer.

Fig. 3. Maximum horizontal displacements

3.2 The Inclined Angle of the Wall

The angle $\beta = \tan^{-1}(\delta_h/H_f)$ constitutes the final excavation depth(H_f) and the horizontal displacement(δ_h) of the top of the wall is the inclined angle of the wall, which are 0.04 to 0.25 as plotted in Fig. 4.

Fig.4 shows that the inclined angle of wall is observed below 0.24° in all sites. In the case of excavation depth is 30.5m, the inclined angle of wall is shown to be about 0.12°, because the thickness of rock layer is larger than 70% of excavation depth, and the length of nails installed in fill layer is long enough to restraint the horizontal displacement.

On the other hand, in spite of shallow excavation, the inclined angle of wall is larger than 0.2°, because the thickness of soil layer is larger than 50% of excavation depth and reinforcement effect of nail is small.

4. The Extension Zone of Ground

The wall deformation caused by excavations in soil nailed system is shown in Fig. 6.

On the other hand, the distance(λ) of the extension zone of ground behind the facing is as follows (project CLOUTERRE, 1991)

$$\lambda = H_f(1 - \tan\beta)\ \kappa \qquad (1)$$

where, κ =the coefficient of the extension zone.

In order to identify the influence of ground extension due to horizontal displacement of the wall in the multi-layered ground, the extension zone of ground behind soil nailed wall is estimated by feed back analysis based on the horizontal displacement of measurement as shown in Fig. 2.

where,

- δ_o : horizontal surface displacement behind the wall
- δ_h : horizontal displacement of the top of facing
- δ_v : vertical displacement of the top of facing
- λ : distance of the extension zone of ground behind the wall
- β : inclined angle of wall at the final excavation depth
- L : length of nail
- H_f : final excavation depth
- A_h : area of horizontal displacement of wall
- A_v : area of vertical displacement of ground surface

4.1 The Distance of the Extension Zone

According to the feed back analysis, the correlation between the final excavation depth(H_f) and the distance of the extension zone(λ) is presented to be about $\lambda \fallingdotseq 0.95H_f$ as shown in Fig. 6.

In the presence of structure behind soil nailed system, this correlation is used to evaluate a damage region

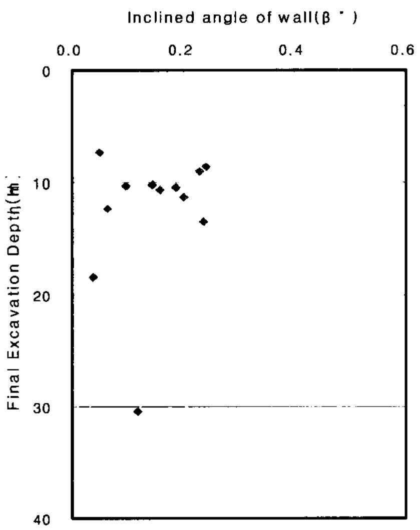


Fig. 4. The inclined angle of the wall at the final excavation

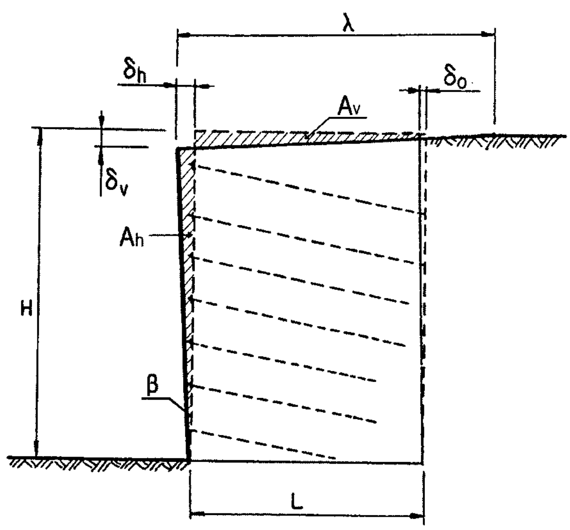


Fig. 5. Deformation of soil nailed wall

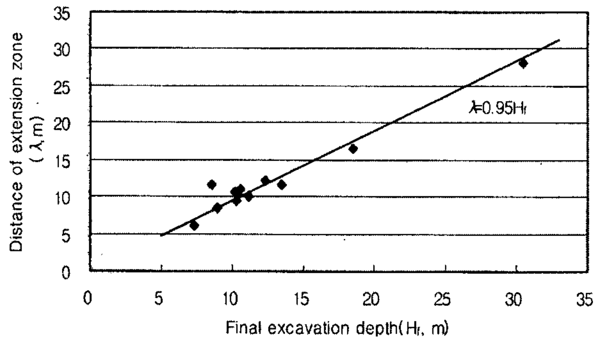


Fig. 6. Distance of the extension zone

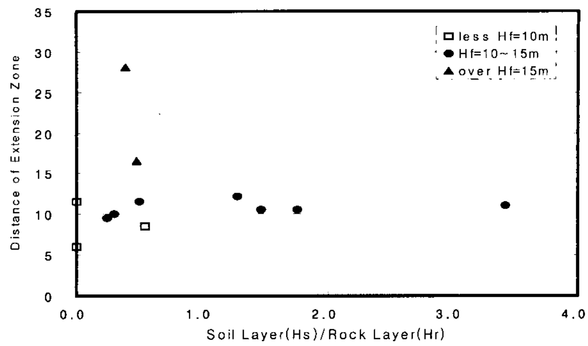


Fig. 7. Distance of the extension zone vs. Ratio of soil and rock strata

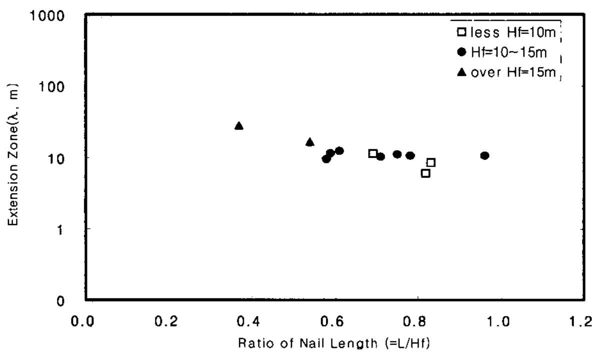


Fig. 8. Distance of the extension zone vs. the ratio(=L/H_f) of nail length

of structure due to cxcavation.

Also, from the results that were performed to investigate the relationship between the distance of extension zone and the ratio of the soil layer(Hs) to rock layer(Hr), it could be seen that the increase of thickness of soil layer does scarcely affect the distance of the extension zone as shown in Fig. 7.

In the case that excavation depth is over 15m, although the ratio of soil layer and rock layer is less than 0.48, the distance of extension zone is larger than the other sites because of the final excavation depth.

On the other hand, the relationship between the ratio(R=L/H_f) of nail length to the final excavation depth and the distance of extension zone shows that the distance of extension zone tends to decrease according to the increase of the ratio of nail length as shown in Fig. 8.

4.2 The Coefficient of the Extension Zone

The coeffecients of the extension zone(κ) in equation (1) proposed by project CLOUTERRE are investigated.

The coefficients of the extension zone are between 0.83~1.05 without considering the final excavation depth as in Fig. 9.

On the other hand, the coefficients of the extension zone(κ) were below 0.95 in the case of the ratio of the soil layer thickness(H_s) to the final excavation depth(H_f) less than 0.5, but increased as the rate of the thickness of soil layer increased in multi-layered ground including various rocks. These tendencies are converged around the value of 1.05 as shown in Fig. 10.

Comparison of the coefficient of the extension zone (table 2) proposed by project CLOUTERRE, the coefficients of rock strata of 0.85 almost coincide with the project CLOUTERRE' s, but in the case of soil layers of 1.05, these are smaller than the CLOUTERRE' s value.

The coefficients of the extension zone vary due to the thickness of soil layer in the case of multi-layered ground including rock. As shown in Fig. 10, it is advisable to predict the coefficient of the extension zone of multi-layered ground including rocks.

Table 2. The coefficient of extension zone (CLOUTERRE, 1991)

	Intermediate soils(rocks)	Sand	Clay
κ	0.8	1.25	1.5

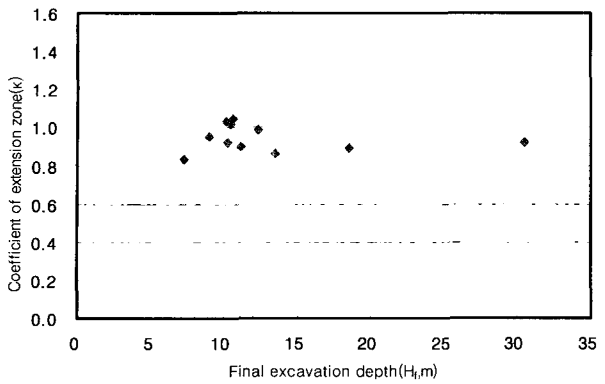


Fig. 9. Coefficient of extension zone vs. final excavation depth

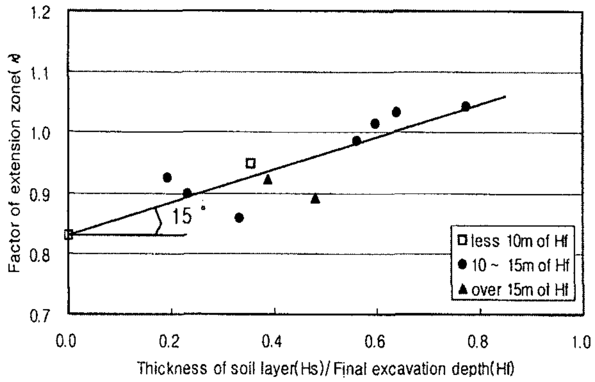


Fig. 10. Variation of the coefficient of the extension zone vs. thickness of soil layers

4.4 Relationship Between Vertical and Horizontal Displacements

In this study, in order to investigate the effect of the vertical displacement of wall caused by horizontal displacement occurred with excavation, the vertical displacement of ground surface proposed by Caspe's method (1966) and feed back analysis are compared as shown in Fig. 11.

From the relationship of the maximum vertical displacement of ground surface(δ_v) versus the maximum horizontal displacement of soil nailed wall(δ_h), it is obtained that the maximum vertical displacement of ground surface by feed back analysis is less than 0.8 δ h, and in the case of Caspe's method(1966), it has the range of 1.50~2.80 δ_h.

Caspe's results are larger than the ones of feed back analysis because it does not consider wall friction and poisson's ratio.

Also, in order to find the correlation of the area of horizontal displacement of wall (A_h) and the area of vertical displacement of ground surface(A_v) at final excavation for each sites, feed back analysis and Caspe's method(1966) are compared as shown in Fig. 12. The area of vertical displacement of ground surface(A_{vf}) by feeed back analysis is less than 0.6 A_h which is the area of horizontal displacement of wall, but in the case of Caspe's method, the area of vertical displacement of ground surface(A_{vc}) is 1.33 times larger than A_h.

From the above results, it could be seen that the Caspe's method is conservative.

5. Conclusions

The feed back analysis is performed to investigate the behavior of back ground extension zone in the multi-layered strata including various rock layers at 11 excavation sites. Based on the results, the following conclusions could be made.

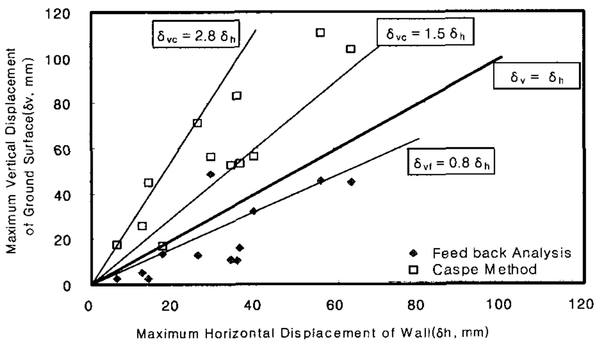


Fig. 11. Relationship of maximum horizontal displacement(δ_h) and maximum vertical displacement(δ_v)

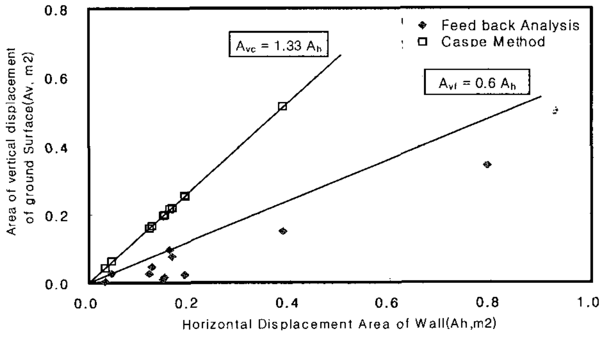


Fig. 12. Area of horizontal displacements of wall(A_h) vs area of vertical displacements of ground surface(A_v)

(1) The correlation between the final excavation depth (H_f) and the distance of the extension zone(λ) is about $\lambda \fallingdotseq 0.95H_f$

(2) The coefficients of extension zone increased with enlargement of soil layer thickness and were converged into the constant value of 1.05 in the case of multi-layer including various rock.

(3) The maximum vertical displacements of ground surface which were calculated by the feed back analysis and Caspe's method were shown to be approximately 80%, 150～280% of the maximum horizontal displacement respectively, and it could be seen that the Caspe's method is conservative.

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