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Comparison of Nail Tensile Force by Feed Back Analysis and Measurements

현장계측과 역해석에 의한 네일의 인장력 비교 연구

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요 지

쏘일네일링 공법은 굴착이나 사면안정을 위해 가시설이나 영구용으로 국내에서 널리 이용되고 있다. 특히, 도심지 근접 굴착시 쏘일네일링 공법 적용시 고려사항은 벽체변위와 네일의 인장등 이다. 본 연구는 국내 여러 암반층을 포함하는 다층토 지반의 11개 쏘일네일링 현장에서 굴착단계별 네일의 인장력 거동을 계측자료와 역해석을 통하여 고찰하였다. 역해석 결과 네일의 최대인장력은 계측값의 50% 정도로 낮게 나타났고, 벽면에서 가상파괴활동면까지의 거리를 주동영역거리라 할때 CLOUTERRE 보고서와 Cartier & Gigan이 각각 제안한 최종굴착깊이(H_f)의 $0.3H_f$, $0.5H_f$에 비해 계측결과는 크게 나타났으며, 역해석은 이들이 제안한 범위내에 포함되었다.

Abstract

Soil nailing type of retaining structures has been widely used in Korea for the purpose of the temporary and permanent support in excavations and slope stability. The important factors in application of soil nailing systems in urban excavation site nearby the existing structures are the displacement of the wall and tensile force of the nails, etc. In this paper, the feed back analyses are carried out at 11 excavation sites to investigate the behavior of tensile force of nails at stepwise excavation in the multi-layered strata including various rock layers. The results of the feed back analysis are less than about 50% of the measured ones. The distance of active zone by measurements are shown almost larger than that of feed back analysis when the distance of active zone is defined from the surface of wall to the potential failure surface. And the results of feed back analysis are within the range proposed by the project CLOUTERRE and Cartier & Gigan (1983) which were $0.3H_f$ and $0.5H_f$ of the final excavation depth (H_f) respectively, but the values of the measurement were larger than these values.

Keywords : Active zone, Feed bak analysis, Measurement, Multi-layer, Nail, Potential failure surface, Stepwise excavation, Tensile force

1. Introduction

The origin of soil nail comes from techniques developed for rock bolting and reinforced earth technique.

Soil nailing consists of reinforcing the ground by passive inclusions, closely spaced, to create in-situ coherent gravity structure and thereby to increase the overall shear strength of in-situ soil and restrain its displacement. The basic design consists of transferring the resisting tensile forces generated in the inclusions into the ground through the friction mobilized at the interfaces.

Soil nailing is readily adaptable to otherwise difficult sites as long as no prior excavation work is needed and

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a light equipment can be used. In particular, it allows structures to be built on slopes where access is difficult. It can also be built in segments and, if necessary, on a curve or with benches.

A detailed discussion of the available design methods was provided by Elias and Juran (1991); CLOUTERRE (1991); Xanthakos, et al (1994); Byrne et al (1991). A particular emphasis has been made by different investigators (Mitchell et al., 1987; Elias and Juran,1991; Juran et al.,1990; Gassler,1993; CLOUTERRE,1991; Plumelle, 1993) on the evaluation method predictions with full scale experiments and measurements on in-service structures.

In recent years in Korea, Kim (1995) studied the behavior of soil nailed wall system both theoretically and experimentally.

In this paper, the feed back analysis carried out at 11 excavation sites to investigate the behavior of the soil nailed walls and the maximum tensile force of nails to the final excavation depth in the multi-layered strata including various rock layers.

2. Site Conditions and Feed Back Analysis Modelling

2.1 Site Conditions

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

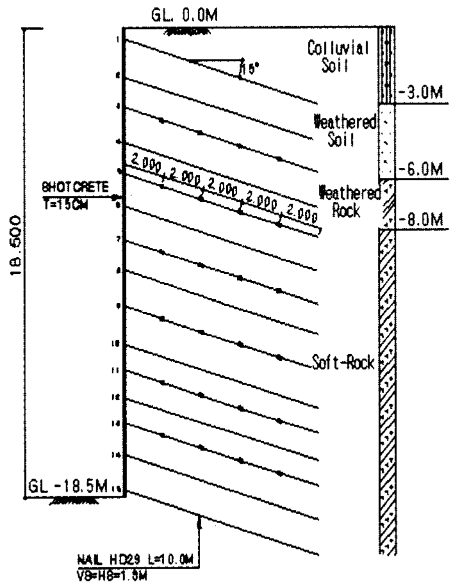
The construction of soil nailed wall is proceeded in the order of excavation, nailing and facing.

The multi-layered ground of the site consists of fill, residual soil, weathered soil, weathered rock, soft rock, and hard rock, generally located in Korea as shown in Fig. 1. Ground water table varied from 0.9m to 9.5m below the excavation depth.

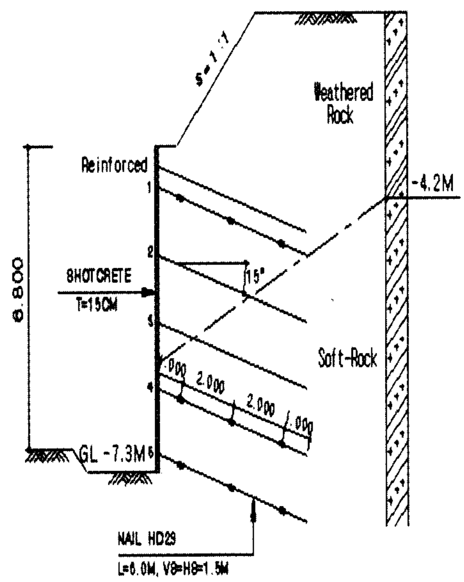
Ground was excavated to the depth of about 0.5m without berm at the location of nail being installed or with berm of 2～5m at each steps.

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

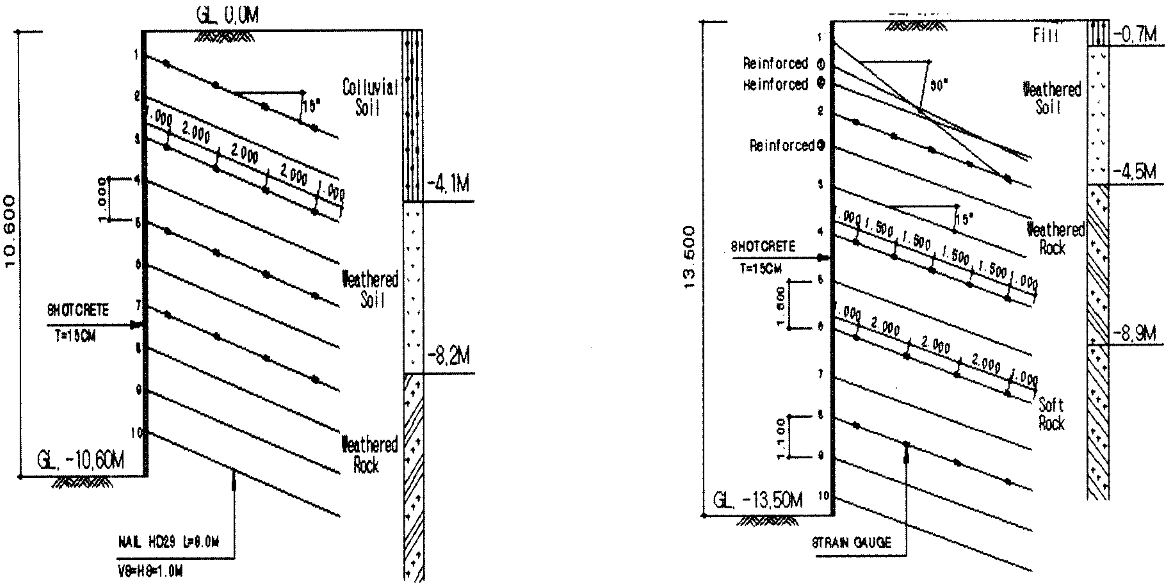


(a) Site 1



(b) Site 3

Fig. 1. Cross section and soil profile for typical sites (Jeon,1999)



(c) Site 6 (d) Site 7

Fig. 1. Cross section and soil profile for typical sites (Jeon,1999)

horizontal, and the inclination was adjusted if obstruction was present in the ground.

The borehole radius is 100mm and its inside was grouted with cement paste (σ_{ck} = 210kg/cm^2) to unificate nail and ground. Weep hole was also 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 reading was 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 (Geokon VK-4100) were installed with 1.5m~2.0m intervals along the length of nail. Adhesion of instrumentation was welded at the surface of nail, which was planed by using grinder.

2.2 Feed Back Analysis Modelling

The feed back analysis is perforned to investigate the horizontal displacement of soil nailed wall and the tension developed nail for each site condition by using FLAC program of the finite difference method.

In numerical analysis, the ground behavior is assumed depending on the Mohr-Coulomb criterion and the shotcrete stiffness of facing is applied to elastic modulus of concrete, and the nail is simulated cable element which can be transferred to axial force.

The typical modelling of section in numerical analysis is shown in Fig. 2; analyses were performed at stepwise excavation, and the effect of ground water was not considered because of drainage.

The horizontal displacements of soil nailed wall at final excavation depth by feed back analysis and measurements are shown in Fig. 3.

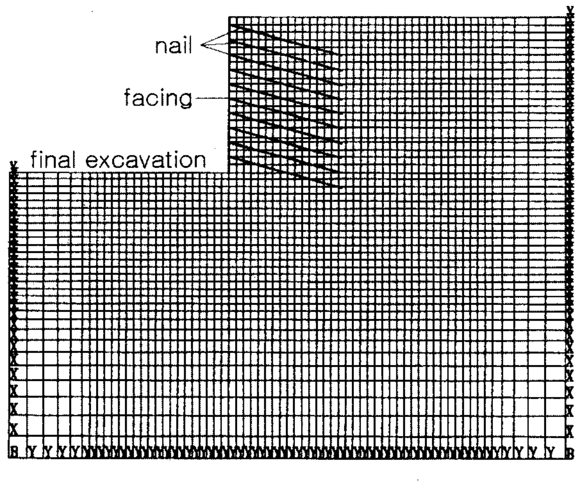
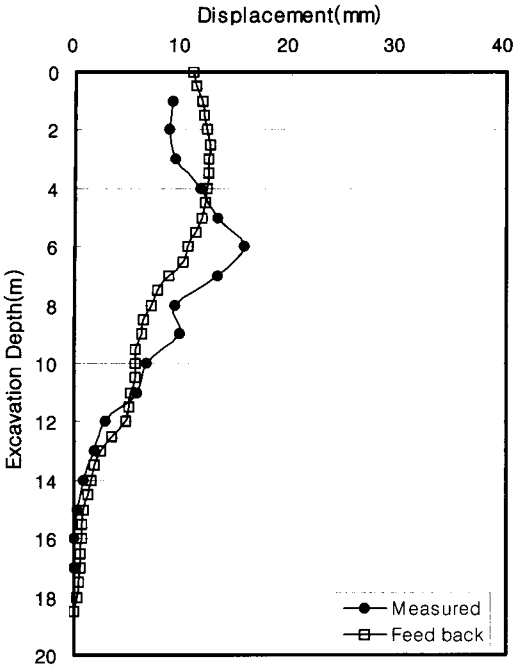
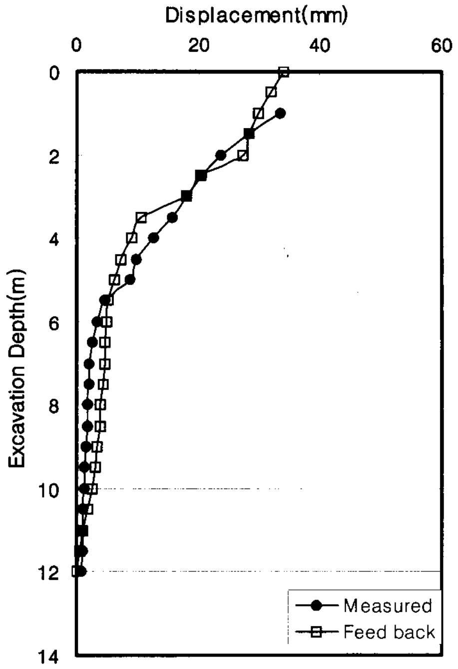


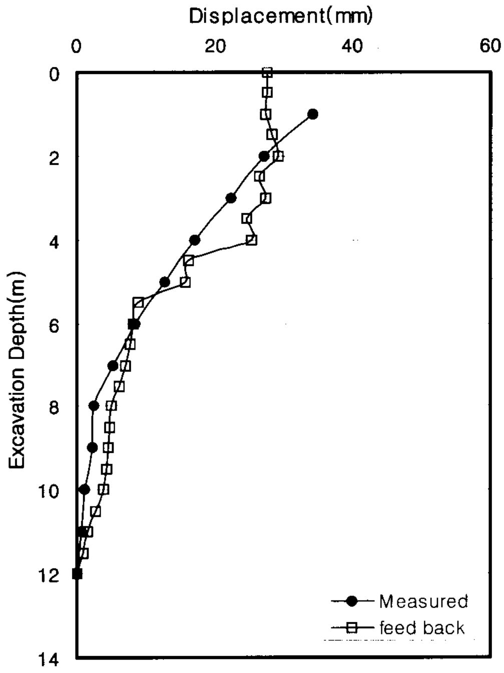
Fig. 2. Feed back analysis modelling



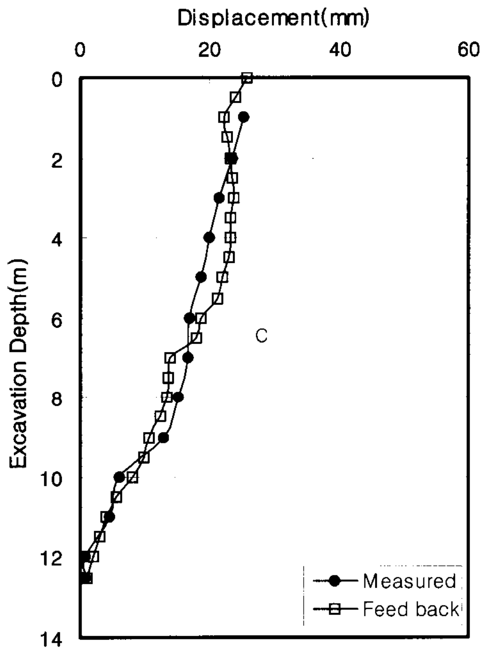
(a) Site 1



(b) Site 2



(c) Site 6



(d) Site 10

Fig. 3. The horizontal displacements of soil nailed wall at final excavation (feed back analysis and measurement)

3. The Tensile Force of Nail

The variation of tensile force of soil nail by feed back analysis and measurement based on field instrumentation at stepwise excavation is shown in Fig. 4.

In the case of sites 1 and 3, the maximum tensile force of nail at stepwise excavation showed that measurement value is larger about 1.0 ton than that of the feed-back analysis as shown in Fig. 4(a)(b). And the maximum tensile force of nail at stepwise excavation occurred at 3m of nail length from wall face in measurement case, and, in case of the feed back analysis, it occurred at 2.75 ~ 3.75m.

On site 6, the maximum tensile force of nail occurred

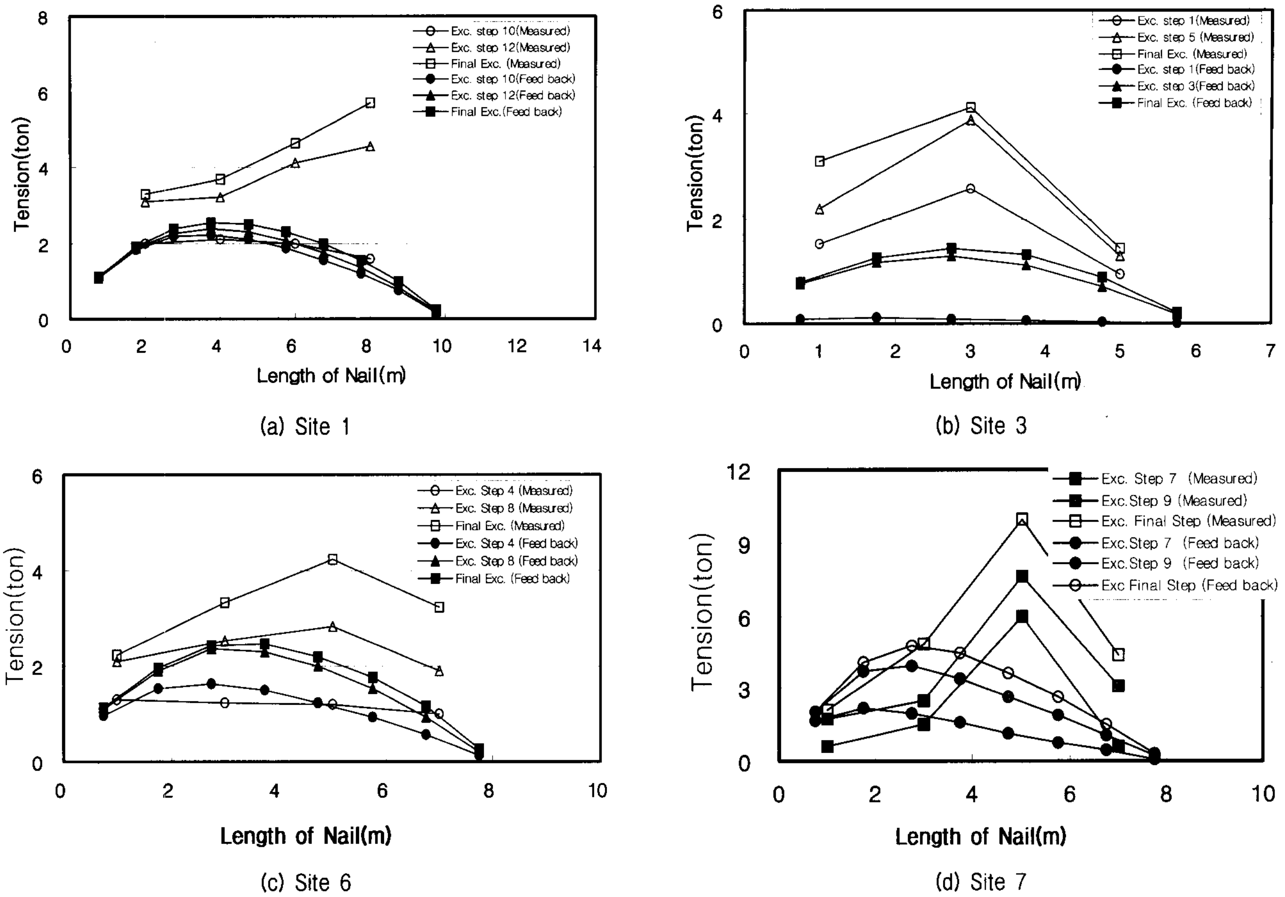


Fig. 4. Variation of tensile force at stepwise excavation for typical sites (feed back analysis and measurement)

at 5m, 3.75m of nail length from wall face, and was about 4.3ton, 2.5ton in the measurement and feed back analysis cases respectively in Fig. 4(c).

And, on site 7, the maximum tensile force of nail at final excavation occurred at 5m, and 2～4m of nail length from wall face. The maximum tensile force (10ton) by measurement was 2 times larger than 4.8ton of the feed back analysis in Fig. 4(d).

3.1 Maximum Tensile Force

The ratio ($=T_{max}/T_{\sigma y}$) of maximum tensile force of nail (T_{max}) to the yield tension of nail ($T_{\sigma y}$) at the final excavation depth is shown in Fig. 5 to compare feed back analysis and measurements.

The maximum tensile force of the nail reached up to respectively 20% and 40% of the yield tensile force at the final excavation step both in feed back analysis and measurements.

The results of the feed back analysis are less than about 50% of the measured ones.

It could be presumed that these results are caused by ground water, the thickness of soil layer, workmanship, and etc.

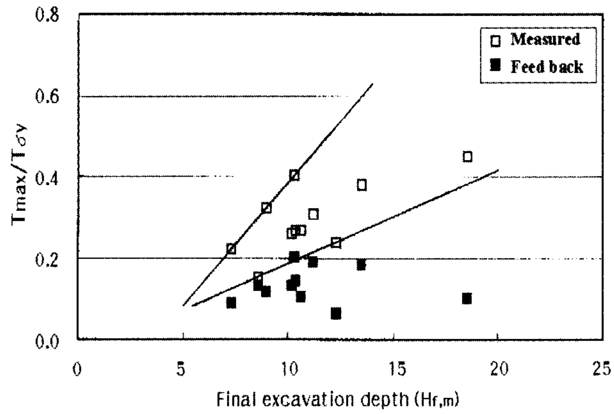


Fig. 5. The ratio of T_{max} to $T_{\sigma y}$ at the final excavation depth

3.2 Distribution of Maximum Tensile Force in Profile

The maximum tensile force (T_{max}) in nails is expressed as non-dimensional parameter K of equation (1) which is proposed by project CLOUTERRE and Cartier & Gigan, and K with relative depth of z/H_f is plotted in Fig. 6.

$$K = \frac{T_{max} \cdot COS\theta}{\gamma \cdot Z \cdot S_v \cdot S_h} \tag{1}$$

where, T_{max} ; maximum tensile force

θ ; inclination of nails with respect to the horizontal

$\gamma \cdot Z$; overburden pressure above the point of maximum tensile force

Sv, Sh ; vertical and horizontal spacings between nails

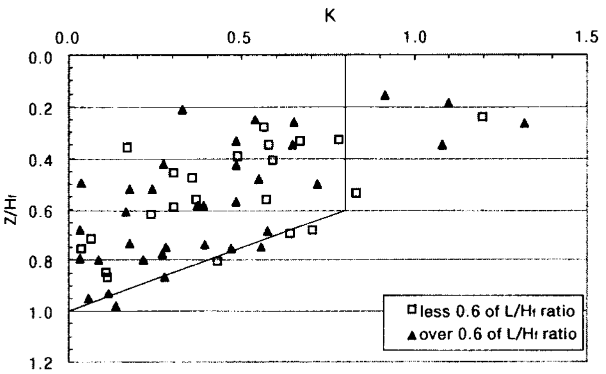
The measurements are plotted in Fig. 6(a), the value of K from ground surface to $0.6H_f$ was less than 0.8, and decreased linearly similar to the result of numerical analysis, but it was shown not to be effected by the L/H_f ratio.

On the other hand, from the result of feed back analysis as shown in Fig. 6(b), if the L/H_f ratio was above 0.6, the value of K from ground surface to $0.4H_f$ was less than 0.6 and decreased linearly from $0.4H_f$ to the final excavation depth.

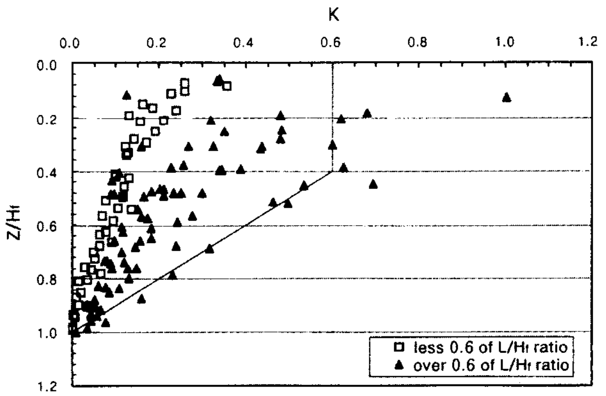
If the L/H_f ratio was below 0.6, the value of K from ground surface to the final excavation depth (H_f) decreased linearly and was considerably smaller than the case of above 0.6. It can be predicted that these results are caused by displacements.

These results coincide with the research by Schlosser (1982), Cartier-Gigan (1983) and Plumelle (1990) who showed that K value decreased linearly in relation to depth.

The difference of K value, however, was caused by the condition of ground with the multi-layered strata including rocks and homogeneous layers.



(a) Measurement



(b) Feed back analysis

Fig. 6. The value of K in relation to depth

4. Potential Failure Surface

When the potential failure surface is assumed as a line made up at the point of the maximum tensile force of each nails, the potential failure surface could be proposed by a parabolic shape in Fig. 7 as shown in project CLOUTERRE. The mass is divided into an active and

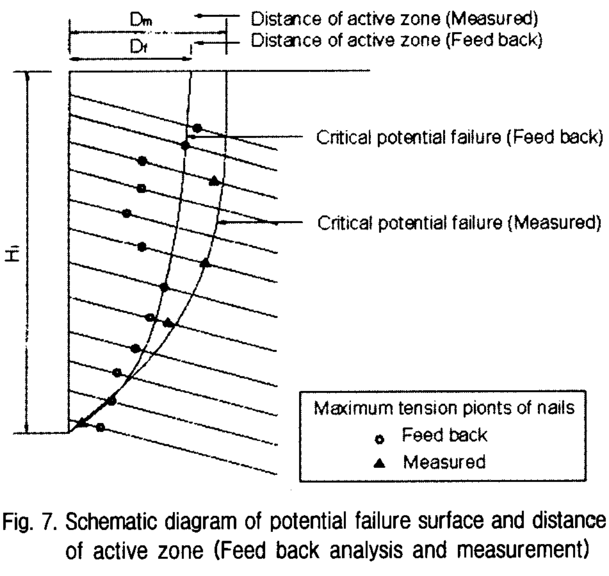


Fig. 7. Schematic diagram of potential failure surface and distance of active zone (Feed back analysis and measurement)

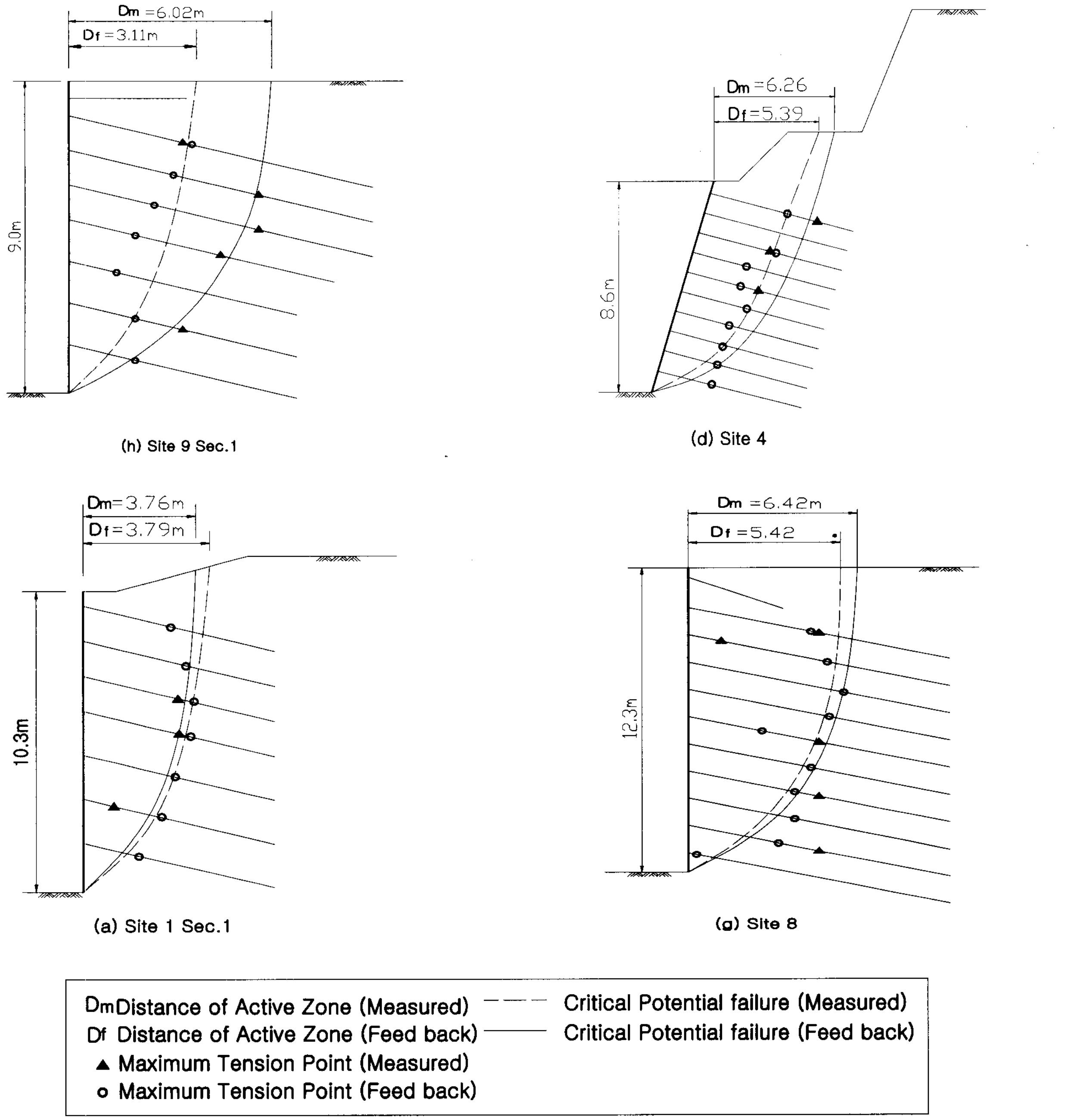


Fig. 8. Potential failure surface and distance of active zone for typical sites (feed back analysis and measurement)

passive zone, and the distance of active zone is estimated from the surface of wall to the potential failure surface.

Fig. 8 shows the potential failure surface and distance of active zone which are obtained from the maximum tensile force by feed back analysis and measurement.

From the results of Fig. 8, the correlation of the distance of active zone by feed back analysis (D_f) versus measurements (D_m) is shown in Fig. 9.

As shown in Figs. 8 and 9, the distance of active

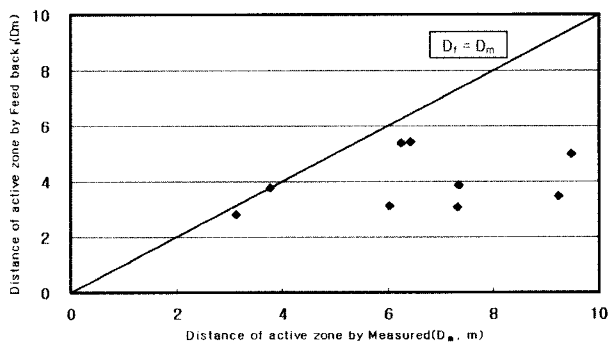


Fig. 9. Distance of active zone by feed back analysis (D_f) and measurement (D_m)

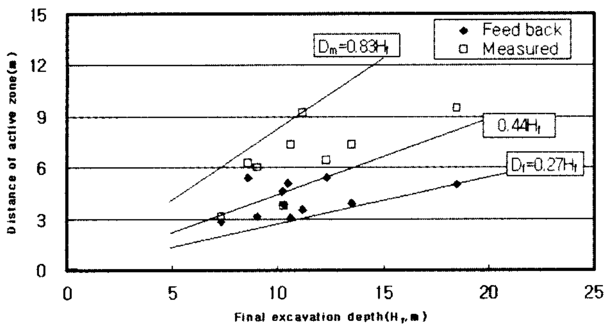


Fig. 10. Distance of active zone at the final excavation depth

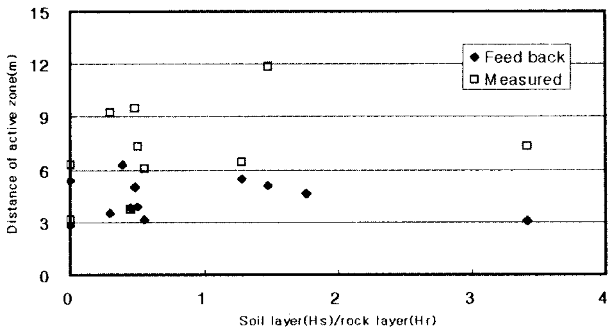


Fig. 11. Distance of active zone vs soil layer (Hs)/rock layer (Hr)

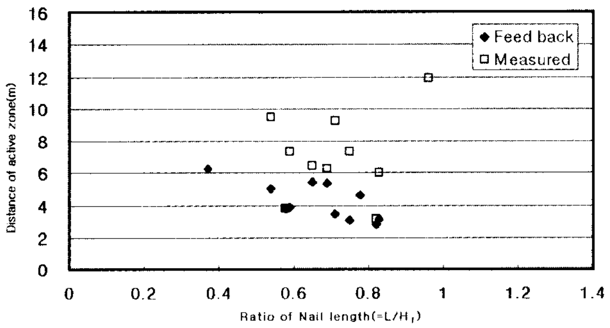


Fig. 12. Distance of active zone vs ratio nail length

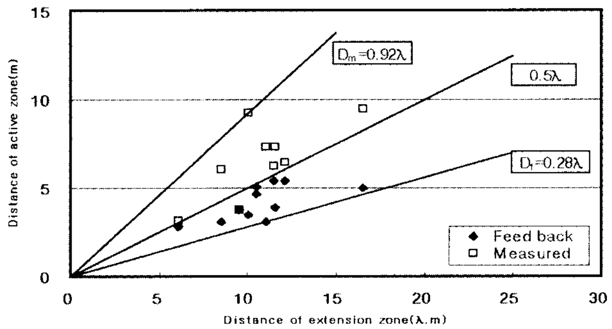


Fig. 13. Distance of active zone vs distance of extension zone

zone by measurements is larger than that of feed back analysis.

The distances of active zone determined based on feed back analysis and measurements, increased as the final excavation depth (H_f) increased, and are D_f=0.27H_f~0.44H_f and D_m=0.44H_f~0.83H_f respectively as shown in Fig. 10.

The results of feed back analysis are within the range proposed by the project CLOUTERRE and Cartier & Gigan (1983) which were 0.3H_f and 0.5H_f respectively, but the values of the measurement were larger than those of feed back analysis.

It could be presumed that the results were caused from neglecting the effect of workmanship, ground water, etc. during the construction period of nails.

Fig. 11 shows the correlation of distance of active zone and ratio of soil layer to rock layer. And it is shown that the change of the ratio of the soil layer thickness (Hs) to the rock layer thickness (Hr) does not affect the distance of active zone, and the distances of active zone by feed back analysis and measurement have constant range about 3~6m, about 6~9m respectively, and the value of measurement was 2 times larger than that of feed back analysis.

The relastionship of the ratio of nail length to distance of active zone is shown in Fig. 12, the distance of active zone by feed back analysis and measurement tends to decrease when the ratio of nail length increases. It could be shown that the ratio of nail length affects to the stability of soil nailed system.

Fig. 13 presents the correlation of the distance of active zone which is obtained by feed back analysis and measurement, and the distance of extension zone by feed back analysis.[reference to companion paper about the distance of extension zone (λ)]

From the correlation, the distances (D_f, D_m) of active zone by feed back analysis and measurement are $D_f \fallingdotseq 0.28 \sim 0.5\lambda$ and $D_m \fallingdotseq 0.5 \sim 0.92\lambda$ respectively.

It is expected that there are useful data for checking the stability of back ground and soil nailed system due to excavation at design and construction.

5. Conclusions

In this paper, the feed back analyses are carried out at 11 excavation sites to investigate the behavior of tensile force of nails at stepwise excavation in the multi-layered strata including various rock layers.

As a result, the maximum tensile forces of the nail reached up to respectively 20% and 40% of the yield tensile force at the final excavation step both in feed back analysis and measurements, and the results of the feed back analysis are less than about 50% of the measurement ones. It could be presumed that these results are caused by ground water, the thickness of soil layer, workmanship, and etc.

The results of feed back analysis are within the range proposed by the project CLOUTERRE and Cartier & Gigan (1983) which were $0.3H_f$ and $0.5H_f$ of the final excavation depth (H_f) respectively, but the values of the measurement were larger than those of feed back analysis. It could be presumed that the results were caused from neglecting the effect of workmanship, ground water, etc. during the construction period of nails.

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