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Design, Construction and Performance of A Removable Soil Nailing System

제거식 쏘일 네일링 공법의 설계 및 시공

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요 지

쏘일네일 벽체는 국내에서 과거 10년간 가시설 및 영구구조물에 상당수 시공되어 왔다. 그러나 쏘일네일링 공법은 많은 장점이 있음에도 불구하고 인접한 건물의 하부에 쏘일네일이 삽입되는 것을 허용하지 않아 제한적으로 사용되고 있는 실정이다. 따라서 본 논문에서는 쏘일네일이 인접한 건물의 하부에 삽입되는 문제를 해결하고 철근을 재활용할 수 있는 방안으로 제거식 쏘일네일링 공법을 소개하였다. 제거식 쏘일네일링 공법은 연직굴착시 가시설 흙막이벽체로 주로 사용할 수 있다. 제거식 쏘일네일의 인발특성을 규명하기 위해 총 23회의 현장인발실험을 실시하였으며, 이를 통해 고정자 소켓의 설치간격과 시멘트 그라우트의 W/C 비가 중요한 설계인자라는 것을 알 수 있었다. 또한 본 논문에서는 국내에서 처음으로 시공되는 제거식 쏘일네일 벽체의 설계 및 시공과 시공상태 등을 소개하였으며, 제거식 쏘일네일의 철근을 제거하기 전과 후에 벽체의 변형을 계측자료로 부터 분석하였다.

Abstract

In Korea, a large number of soil nailed walls have been constructed during the past 10 years, both for temporary and permanent structures. Although the soil nailing systems have many advantages, the systems have been constructed within limit because soil nails generally are not allowed to be installed under the neighbouring buildings. In this paper, a removable soil nailing system is introduced in the way for solving to be installed under the neighbouring buildings and recycling the steel bar of nails. A removable soil nailing system is mainly applied to construct temporary support systems of vertical excavations. To investigate pull-out characteristics of removable soil nails, field pull-out tests are carried out 23 times. From the analyzed pull-out characteristics, it is found that the spacing of fixed socket and W/C ratio of cement grout are important design parameters. Also, this paper describes the design, construction and performance of the first removable soil nailed walls in Korea. Instrumentation data, including wall deflections before and after the steel bars are removed, are further discussed in details.

Keywords : Removable soil nailing system, Fixed socket, Field pull-out tests

1. Introduction

Recently, a removable soil nailing system is demanded due to problems beyond of economical and engineering purpose. In this paper, the first removable soil nailing system in Korea is introduced, and design methodology,

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construction scheme and performance of the removable soil nailed walls are described. The removable soil nailing system has been used to construct temporary support of vertical excavations of Samsung Cyber apartment and Tower Palace building located in Dogok-dong, Seoul, Korea. A typical section of this system is shown in Fig. 1.

2. Basic Concept

2.1 Components of Removable Soil Nail

The removable soil nails consist of fixed socket, P.V.C pipe and steel bar as shown in Fig. 2. The fixed sockets act as spacer and transmit friction resistance on the cement grout to the steel bar of the nails. The P.V.C pipes function as separating cement grout and steel bar of the nails.

2.2 Distribution of Nail Forces in the Pull-Out Tests

In the pull-out tests, typical distributions of nail forces of general soil nails and removable soil nails are shown in Fig. 3. In the general soil nails, the maximum nail force usually occurs at the nail head. Also, the maximum nail force in the removable soil nails occurs at the fixed socket.

2.3 Construction Sequence

A removable soil nail wall construction typically involves the following six steps, as shown in Fig. 4:

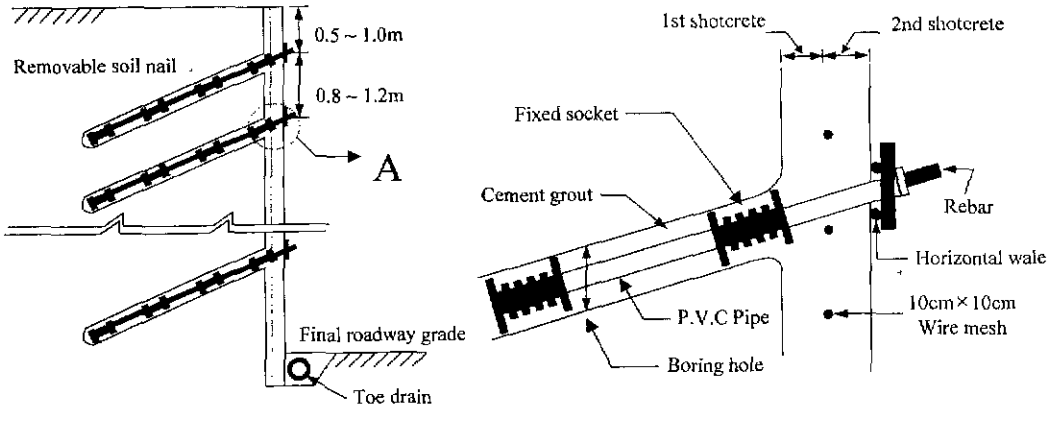
Step ① : Excavate cut and install nails
Step ② : Repeat process to final grade
Step ③ : Remove steel bars (3~4m from final grade)
Step ④ : Place walls
Step ⑤ : Repeat process ③~④
Step ⑥ : Place final walls

3. Pull-Out Characteristics of Removable Soil Nails

3.1 Field Pull-out Tests

Field pull-out tests of removable soil nails are carried out at Tower Palace building site located in Dogok-dong, Seoul, Korea. Plan view of Tower Palace building site is shown in Fig. 5. At this site, the controlled displacement pull-out tests(constant speed) including the controlled force tests(creep steps) are carried out 23 times (11 times in A-site, 5 times in B-site, 2 times in C-site, and 5 times in D-site). In the pull-out tests, the spacing and the installed position of fixed socket, the length of the soil nail, and W/C ratio of cement grout in the removable soil nail changed variously. Also, the short-term and long-term pull-out characteristics of the removable soil nailing systems evaluated from them.

The controlled displacement pull-out tests of 21 times



(a) Typical section (b) Details "A"

Fig. 1 Construction details of removable soil nailing system

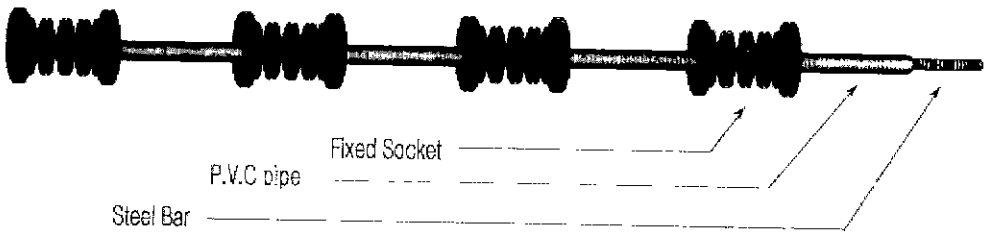
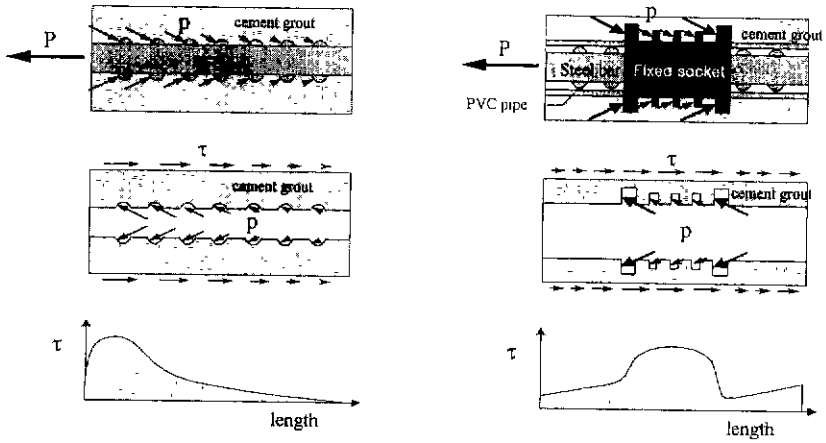


Fig. 2 Components of removable soil nail



(a) General soil nails (b) Removable soil nails

Fig 3 Distribution of nail forces in the pull-out tests

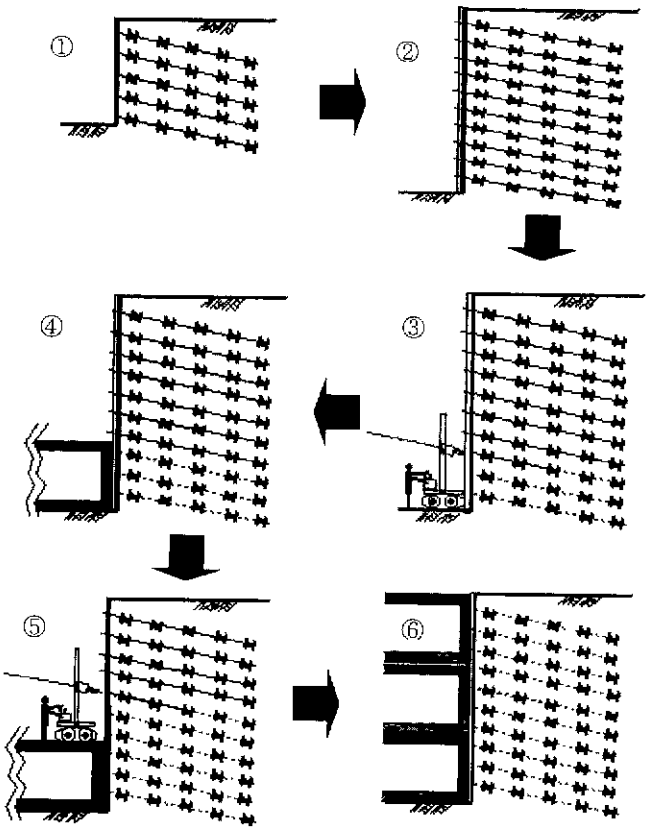


Fig. 4 Construction sequence of removable soil nail wall

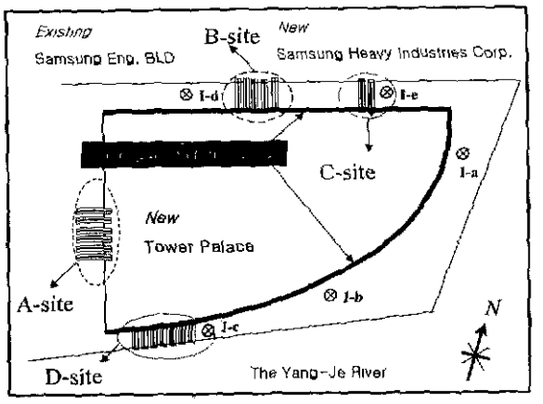


Fig. 5 Plan view of Tower Palace building site

stopped once the tension force has either passed a maximum or has stabilized. The tests continued until the tensile force at the head of the nail varies less than 1 percent for a 1 mm displacement. Also, the nail is put into tension at a speed of 1mm/min, and the margin of error on the speed keeps on ± 10 percent. The controlled force tests are carried out 2 times at D-site. Before carrying out a controlled force test, it is necessary to estimate the limit pull-out force T_{LE}, which is assessed from the controlled displacement pull-out tests. Loading steps maintained during 1 hour, except the 0.7 T_{LE} step, which is maintained during 3 hours. The first loading step is applied at 0.2 T_{LE}.

3.2 Effect of Spacing of Fixed Socket

In the removable soil nailing system, steel bars not completely bonded to cement grout. So, pull-out characteristics is affected by spacing of fixed socket. In the field pull-out tests, spacing of fixed socket is changed to 0.5, 1.0m and the length of nails are fixed to 4m as shown in Fig. 6.

Pull-out characteristics of the removable soil nails appeared a tendency to be similar to pull-out characteristics of the general soil nails, as the spacing of the fixed socket is closer. Especially, when the spacing of fixed socket is 0.5m, the pull-out characteristics is almost the same as the general soil nails.

3.3 Effect of Depth of The Fixed Socket

In these tests, fixed sockets are installed at 1.0m, 2.0m,

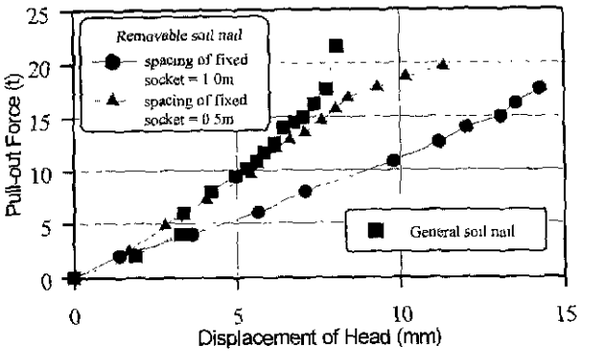


Fig. 6 Effect of spacing fixed socket

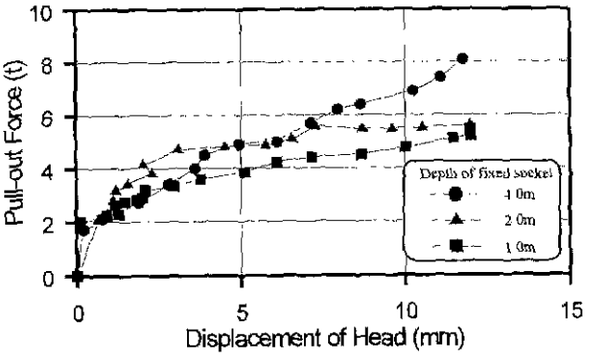


Fig. 7 Effect of depth of fixed socket

3.0m, and 4.0m from the head of the nail and the length of nails are fixed to 4m. The results of these pull-out tests are shown in Fig. 7. As depth of the fixed socket increases, the bond strength of the fixed sockets increased to 5~8 ton. Also, the bond strength of the fixed socket is about 4 ton in atmosphere, which is a state having no confined stress. As the depth of the fixed socket is deeper, that is, as confining stress is increased, pull-out forces are gradually increased due to deformation of the fixed socket restrained.

3.4 Effect of W/C Ratio of Cement Grout

The effect of W/C ratio of cement grout is shown in Fig. 8. In these test, the length of nails are fixed to 4m. The W/C ratio of cement grout is one of significant factors, on which the compressive strength of the cement grout is dependent. In these tests, W/C ratios of use cement grout of 48% and 55%. The compressive strengths of the cement grout in the W/C ratio 48% and 55% are measured to 241.9kg/cm^2 and 148.5kg/cm^2(the compressive strength aged 7 days). As

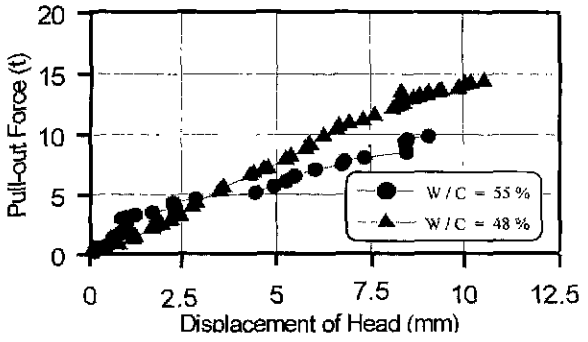


Fig. 8 Effect of W/C ratio of cement grout

W/C ratio of cement grout is lower, that is, as the compressive strength of cement grout increases, pull-out force increases.

3.5 Effect of Length of the Removable Soil Nail

The length of the removable soil nails are installed to 4.0m and 8.0m, and the spacing of fixed socket is installed to 1.0m. Effects of length of removable soil nails and general soil nails are shown in Fig. 9. The length of the removable soil nails did little affects on pull-out force.

3.6 Pull-Out Characteristics of the Removable Soil Nail in Long Term

To evaluate the pull-out characteristics of the removable soil nail in long-term, a controlled force test is carried out. The results of the controlled force test is shown in Fig. 10. In these test, the length of nails are fixed to 4m and T_{LE} is used to 20 ton from Fig. 6. Also, the ground condition around the test nail was weathered soil. Fig. 10(a) is shown that the deformation in head of the nail was measured with each load step ($0.2T_{LE}$ to T_{LE}) for 1, 2, 3, 4, 5, 8, 10, 15, 20, 25, 30, 45, 60 minutes individually. In Fig. 10(b) gradient of creep curve, α, relative curve plotted log t deformation at head of nail, is plotted by step of pull-out.

Especially at step of $0.7T_{LE}$ deformation at head of nail is measured with 1, 2, 3, 4, 5, 8, 10, 15, 20, 25, 30, 45, 60, 90, 120, 150, 180 minutes individually. From Fig. 10(b), the ultimate creep pull-out force Tc is about 14.2t to 16.3t and ratio of ultimate pull-out force and ultimate creep pull-out force k is about 1.34 to 1.55. This value is greater than general value of k(see Table 1.).

Therefore, in the removable soil nailing system, pull-out characteristics in long-term are not conservative than the general soil nailing system. Also, in the general soil nailing system, classification to the period of use is shown in Table 2.

4. Design Method

4.1 Concepts

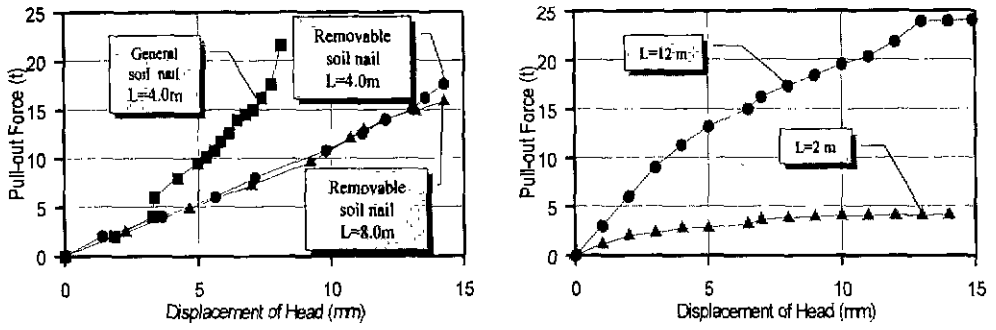
The design approach used for removable soil nailing systems is based on classical stability analysis similarly to the general soil nailing system. However, the internal stability analysis of the nails is somewhat different to the general soil nailing system. In the general soil nailing system, minimum value between the friction mobilized along the length of nails and yield strength of steel bars is evaluated as the resistance force of the nails. However, inthe removable soil nailing system, minimum value between the friction mobilized along the length of nails and bond strength of fixed sockets is determined to the resistance force of the nails. Also, in the external stability

Table 1. k values in general soil nails(Schlosser, 1993)

Type of soils	Sands	Clays	Marls and Chalks
$k=T_{LE}/T_C$	1 2	1.3	1.4

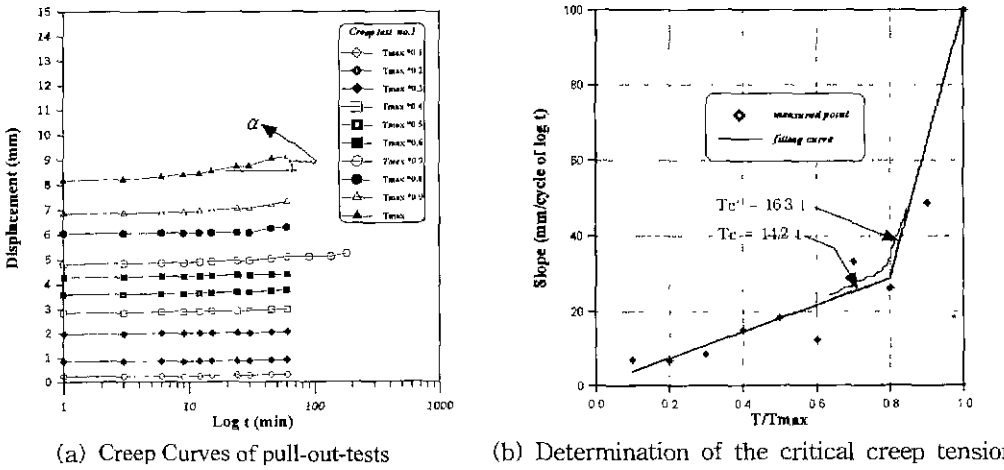
Table 2. Classification to the period of use(Schlosser, 1993)

Classification	Short-term	Medium-term	Long-term
period of use	≤ 18 months	1.5 ~ 30 years	30 ~ 100 years



(a) Removable soil nails (b) General soil nails

Fig. 9 Effect of length of soil nails



(a) Creep Curves of pull-out-tests (b) Determination of the critical creep tension

Fig. 10 Results of the controlled force test

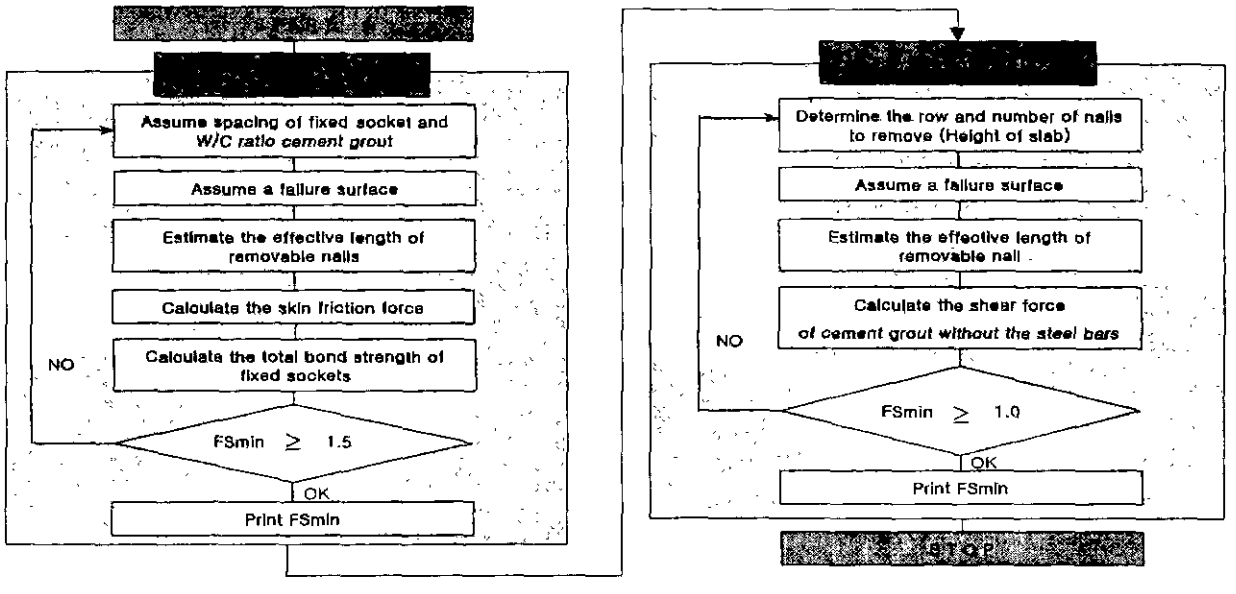


Fig. 11 Design process flow chart

analysis after the steel bars are removed, shear resistance of the nails without the steel bars must be considered. A design process flow chart is shown in Fig. 11.

4.2 Resistance Forces of Removable Soil Nails

Resistance forces of removable soil nails are classified

into two cases, which is resistance force of the nails before and after the steel bars are removed. In each case, resistance forces of removable soil nails are shown in Fig. 12. Before the steel bars are removed, resistance forces of removable soil nails can be calculated in Eq. (1).

$$T_i = \min(\text{friction resistance of ground, total bond strength of fixed sockets}) = \min(\pi D \tau_f l_e, \sum_{i=1}^{n} P_{F_i}) \quad (1)$$

where, D : diameter of bore hole

τ_f : friction resistance

l_e : effective length of soil nail

P_{F_i} : bond strength of a fixed socket

Also, after the steel bars are removed, resistance forces of removable soil nails can be calculated in Eq. (2). In Eq. (2), the shear forces and the bending moments mobilized in the nails without the steel bars are calculated considering the equation of the elastic bending of the nails and assuming that the soil can be represented by a series of elasto-plastic springs.

$$P_s = \frac{M_y}{0.32\left(\frac{2l_e}{\pi}\right)} \quad (2)$$

where, $M_y = \frac{\pi D_{hole}^3}{32}\sigma_{cb}$

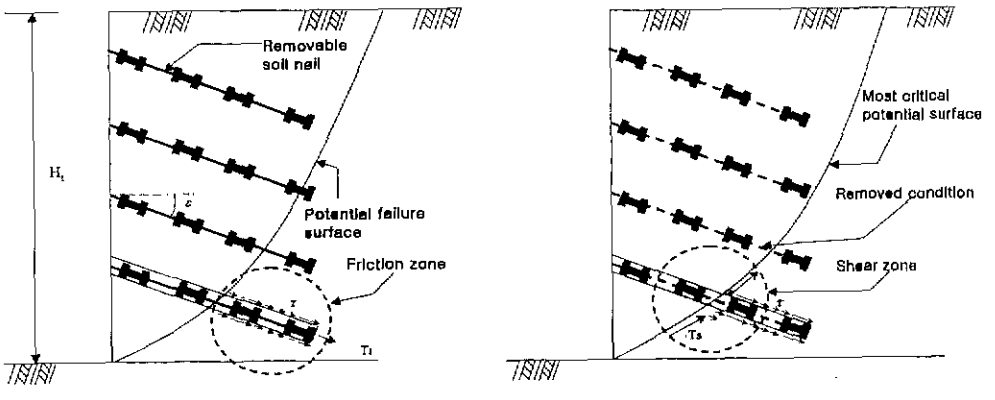
σ_{cb} : bending strength of cement grout after the steel bars are removed

$l_e = \frac{\pi d_{hole}}{4}\sqrt[4]{\frac{\pi E}{k_s d_{hole}}}$

d_{hole} : diameter of drilling hole

k_s : lateral soil reaction modulus around the nails

E : elastic modulus of the nail



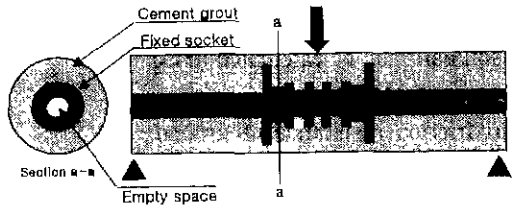
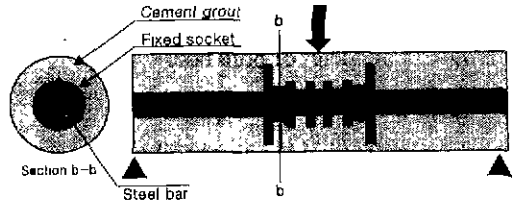
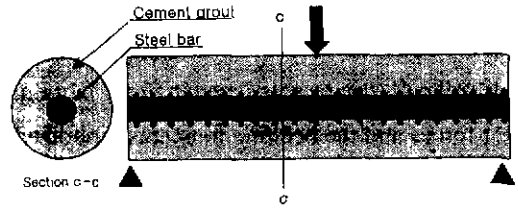
(a) before the steel bar is removed (b) after the steel bar is removed

Fig. 12 Resistance forces of removable soil nails

Table 3. Bond strength of fixed sockets

Specifications	Bond strength (t)	Test sample
Fixed socket	1.45	Steel bar, Fixed socket
Fixed socket + cement grout	1 80	Cement grout

Table 4. Results of bending tests

Type	Steel bars	Bending strength (kg/cm^2)	Test sample
Removable soil nail	no	0.91	
	installed	14.18	
General soil nail	no	24 12	

4.3 Bond Strength of Fixed Sockets

To estimate the bond strength between fixed sockets and steel bars, pull-out tests were carried out 4 times. Also, the steel bar is put into tension at a speed of 2mm/min in controlled displacement. The average bond strength of fixed sockets was summarized in Table 3. From Table 3, the bond strength of composite of fixed socket and cement grout is calculated to 1.80 ton. In the field pull-out tests, the bond strength of the fixed sockets is measured to 5 ~ 8 ton. Therefore, bond strength in the front and end disks of a fixed socket shares about 70% of total bond strength. The bond strength in the middle disks of a fixed socket has about 30% of them.

4.4 Bending Stiffness of Removed Soil Nails

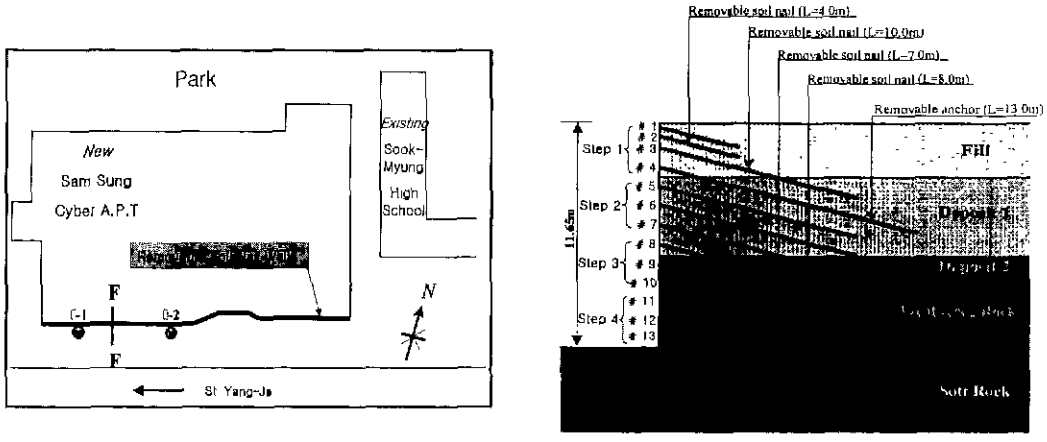
For estimating the degree of bending stiffness of the nails after removal of the steel bars, bending tests of nails were carried out 3 times. The method of bending tests was chosen to the third point bending test of simple beam. Also, the simple beam is put into vertical load at a speed of 2mm/min in controlled displacement. The test results were summarized in Table 4.

From Table 4, the bending strength of removable soil nails has about 60% of that of general soil nails, and the bending strength of removable soil nails after the steel bars are removed has about 6% of before removal.

5. Performance of Removable Soil Nailing System

5.1 Introduction

The removable soil nail walls at Cyber Appartement site located in Dogok-dong, Seoul, Korea are designed with height of 11.65m and nail length of 4.0m to 10.0m. Plan view of Cyber Appartement site is shown in Fig. 13. In this site, two inclinometers were installed behind the face of the wall. Inclinometers were read two to three times a week.



(a) Plan view (b) Typical section F-F

Fig. 13 Plan view and typical section of Cyber Appartement site

Table 5. Soil properties used in stability analysis

Classification	Unit weight (t/m³)	Friction angle (°)	Coehesion (t/m²)	Elastic modulus (t/m²)
Fill	1.80	30 00	0.00	5000 0
Deposit 1	1.70	28 00	0.00	4000.0
Deposit 2	1.80	30.00	0.50	6000.0
Weathered rock	1 90	33.00	1 00	7000.0
Soft rock	2.00	40 00	2 00	10000.0

Table 6 Variations of safety factor after steel bars are removed

Analysis steps	G L (m)	Removed steel bars	Depth of removed steel bars	Safety factor	
				Neglect bending stiffness	Consider bending stiffness
Step 1	−11.65	No.11~13	3 00m	1 18	1 33
Step 2	−8 65	No.8~10	3.00m	1 22	1.41
Step 3	−5.65	No.5~7	3.00m	1.20	1.40
Step 4	−2.65	No.1~4	2.65m	1 14	1 16

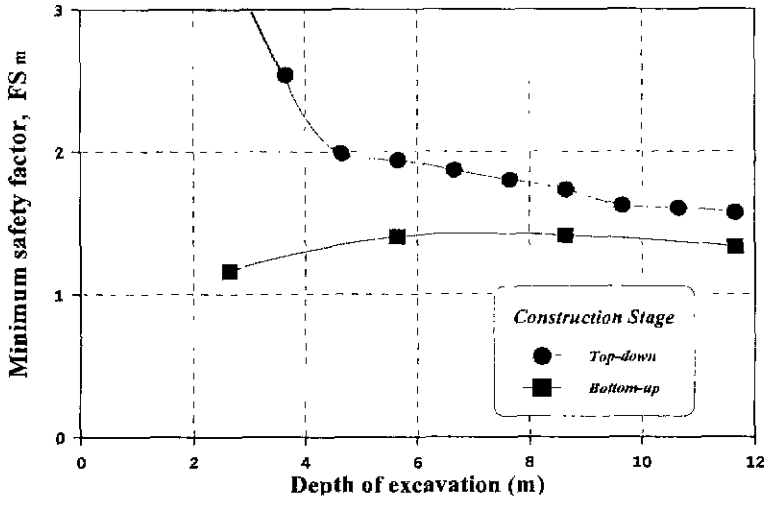
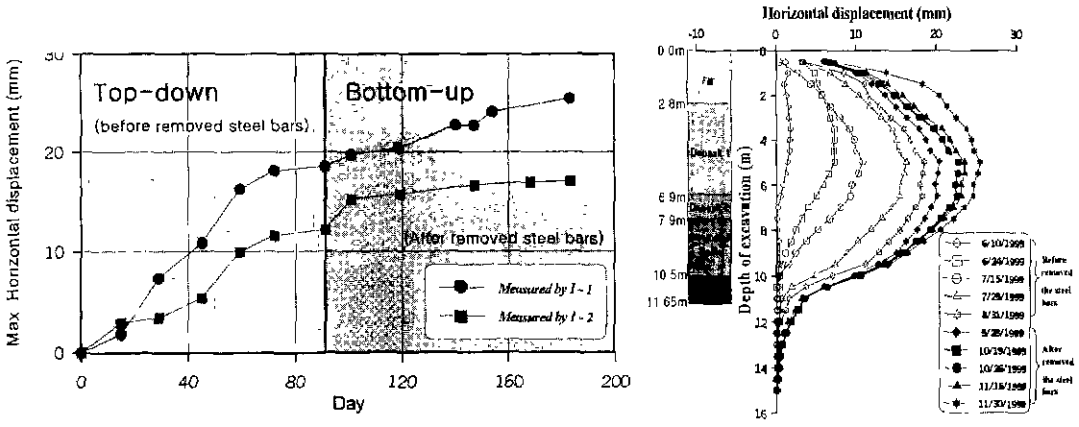


Fig. 14 Variations of safety factors at each construction stage



(a) Maximum horizontal displacement by I-1 and I-2 (b) Wall deflections by I-1

Fig. 15 Horizontal wall deflections of removable soil nail walls

5.2 Stability Analysis of the Removable Soil Nail Walls

Soil condition consists of fill, deposit soil, weathered rock, and soft rock, and the soil properties used in stability analysis of removable soil nail walls are shown in Table 5.

The stability analysis of the removable soil nail wall was carried out by "Visual Nail" computer program. In "Visual Nail" program, the stability analysis is used for the modification of the procedures used in the simplified Bishop method. The potential failure surface is assumed to be a logarithmic spiral curve, and the slices are divided into the direction of reinforcement.

Variations of safety factor after steel bars are removed are shown in Table 6. In Table 6, the bending strength of cement grout after steel bars are removed affects on about 2~16% to overall stability. Variations of safety factor before and after steel bars are removed are shown in Fig. 14. The stability of the removable soil nail walls in Cyber Appartement site is satisfied within allowable safety factor, which is equal or greater than 1.5 before the steel bars are removed, and 1.0 after removed.

5.3 Horizontal Wall Deflections

Deflections measured on the high wall are shown in Fig. 15. Fig. 15(a) are ploted to maximum lateral displacements each construction steps by inclinometers I-1 and I-2. Inclinometer data of I-1 are shown in details as Fig. 15(b). Incremental deflections are gradually decreased at excavating above 60% of the final excavation level. The maximum deflection occurred at the middle of the wall. The total deflection before and after the steel bars are removed were 12.1~18.5mm to 17.0~25.4mm, which is increased about 40% by removing the steel bars. However, maximum deflections after the steel bars are removed were measured within 0.3%H in maximum lateral movements of the general soil nail walls.

6. Conclusions

This paper describes the design, construction and performance of the first removable soil nailed walls in Korea. Instrumentation data, including wall deflections before and after the steel bars are removed, are also discussed in detail.

The following conclusions could be drawn from this study.

1) From the pull-out characteristics, we found that the spacing of fixed socket and W/C ratio of cement grout are important design parameters. In the removable soil nailing system, pull-out characteristics in long-term are not conservative than that the general soil nailing system from the controlled force tests.
2) The design approach used for removable soil nailing systems is based on classical stability analysis similarly to the general soil nailing system. In the removable soil nailing system, minimum value between the friction mobilized along the length of nails and bond strength of

fixed sockets is determined as the resistance force of the nails. Also, in the external stability analysis after the steel bars are removed, shear resistance of the nails without the steel bars must be considered.

3) The bond strength in the front and end disks of a fixed socket shares about 70% of total bond strength. The bond strength in the middle disks of a fixed socket has about 30%. of total bond strength. Also, the bending stiffness of removable soil nails has about 60% of that of general soil nails. And the bending stiffness of removable soil nails after the steel bars are removed has about 6% of before removed.

4) Deflections measured on the removable soil nail wall at Cyber Appartement site, Seoul, Korea decreased gradually at the level of above 60% of the final excavation. The maximum deflection occurred at the middle of the wall. The total deflection after removal of the steel bars increased about 40% compared to the deflections before removal of the steel bars. However, maximum deflections after the steel bars are removed were measured within 0.3% H in maximum lateral movements of the general soil nail walls.

Acknowledgements

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