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Performance of Innovative Prestressed Support Earth Retention System in Urban Excavation

도심지 굴착에 적용된 IPS 흙막이 구조물의 현장거동

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요 지

본 연구에서는 도심지 굴착 현장에 적용된 IPS(Innovative Prestressed Support) 흙막이 구조물의 거동을 파악하여 시스템의 안정성을 확인하였다. 새로운 흙막이 지보재인 IPS 띠장은 지반 굴착으로 인한 토압을 자체의 휨강성을 이용하여 버팀보에 전달하는 특징을 가지고 있다. IPS 띠장의 휨강성은 기존 굴착 공법에 적용된 띠장에 비해 월등하기 때문에 IPS 띠장을 활용하면 흙막이 벽체를 지지하는 버팀보의 설치 간격을 획기적으로 넓힐 수 있으며 굴착시에 넓은 작업 공간을 제공한다. 이로 인해 굴착 공사에 사용되는 강재의 물량을 줄일 수 있다. 또한 IPS 띠장에 강선의 인장력을 도입하여 선행 하중을 가함으로써 지반 굴착으로 인한 흙막이 벽체의 변형을 제한할 수 있다. 본 연구에서는 IPS 흙막이 공법을 적용한 도심지 굴착 현장에 시공 전기간 계측을 수행하여 그 적용성과 안정성을 확인하였다. 현장 계측 결과를 분석하여 혁신적인 흙막이 지보재인 IPS 띠장과 IPS 흙막이 벽체 그리고 코너 스트럿의 거동을 분석하였다.

Abstract

The performance of innovative prestressed support (IPS) earth retention system applied in urban excavation was presented and investigated. The IPS wales provide a high flexural stiffness to resist the bending by lateral earth pressure, and the IPS wales transfer lateral earth pressure to corner struts. The IPS wale provides a larger spacing of support, economical benefit, construction easiness, good performance, and safety control. In order to investigate applicability and stability of the IPS earth retention system, the IPS system was instrumented and was monitored during construction. The IPS system applied in urban excavation functioned successfully. The results of the field instrumentation were presented. The measured performances of the IPS earth retention system were investigated and discussed.

Keywords : Corner strut, IPS earth retention system, Lateral earth pressure, Urban excavation

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1. Introduction

The conventional temporary supports such as struts or anchors for excavation may cause high cost and construction delay during construction because the required amount of steel is huge and construction workspace is quite limited. An innovative prestressed support (IPS) earth retention system was developed as shown in Fig. 1 (b). The IPS earth retention system consists of IPS wales and corner struts. The IPS wales provide a high flexural stiffness to resist the bending by lateral earth pressure by using prestress on steel wires. The IPS earth retention system can provide a larger spacing of support. The conventional strut support and the IPS earth retention system are shown in Figs. 1 (a) and (b). As can be seen in Fig. 1, amount of steel was reduced drastically and large workspace provides construction easiness.

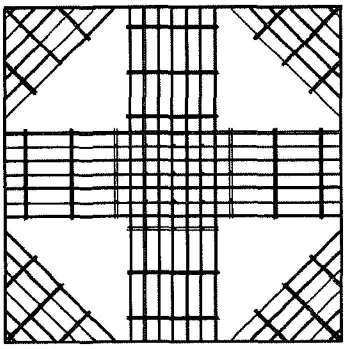
The concept of prestress is very useful to increase flexural stiffness in structural member. Many researchers have studied the basic mechanism and applications of prestress (Timoshenko and Gere, 1961; Chajes, 1974; Nilson, 1978; Lin and Burbs, 1981; AISC, 1989; Troitsky, 1990; Gimsing, 1997; PCI, 1997; Salmon and Johnson, 1997). The concept of prestress was adopted to develop a wale with high flexural stiffness to resist lateral earth pressure due to excavation.

There have been studies on the IPS earth retention system by Kim et al. (2003), Park et al. (2003), Han et al. (2003), Kim et al. (2004), and Park et al. (2004). The design of the IPS earth retention system was proposed and the stability of the IPS earth retention system was evaluated by numerical studies by Kim et al. (2003), Han et al. (2003). Park et al. (2003), Kim et al. (2004) and Park et al. (2004) investigated and discussed applicability and safety of new IPS system and performance of structural members of the IPS earth retention system. In order to evaluate the stability of the IPS system, it is important to check the performance of the IPS wales and corner struts.

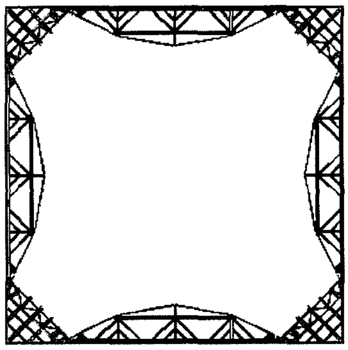
In this study, the stability of the IPS earth retention system applied in urban excavation was investigated. This paper describes the measured performances of the IPS wale, wall and corner strut. In order to investigate applicability and stability of the IPS earth retention system, the IPS system was instrumented and was monitored during construction. The IPS wale applied in urban excavation functioned successfully. The results of the field measurements of the IPS earth retention system were presented. Behavior and stability of the IPS wale, wall and corner strut were investigated and discussed.

2. Measured Performance of the IPS Earth Retention System Applied in Urban Excavation

The IPS earth retention system was selected for temporary earth support in apartment complex building in Anyang area. In order to verify performance of the IPS earth retention structure and to evaluate the each member's behavior, the IPS earth retention structure was instrumented and monitored during the construction process.



(a) Conventional braced cut



(b) IPS earth retention system

Fig. 1. Braced cut and IPS earth retention system

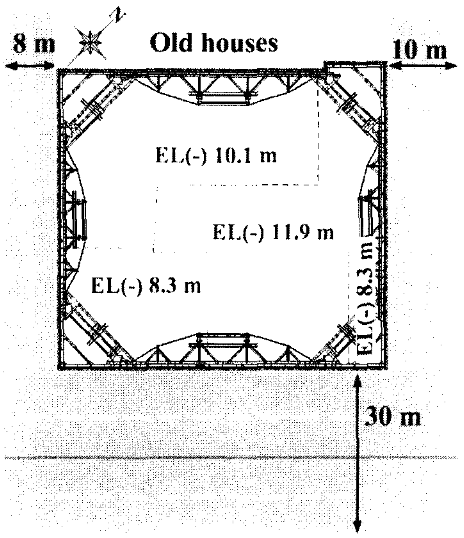
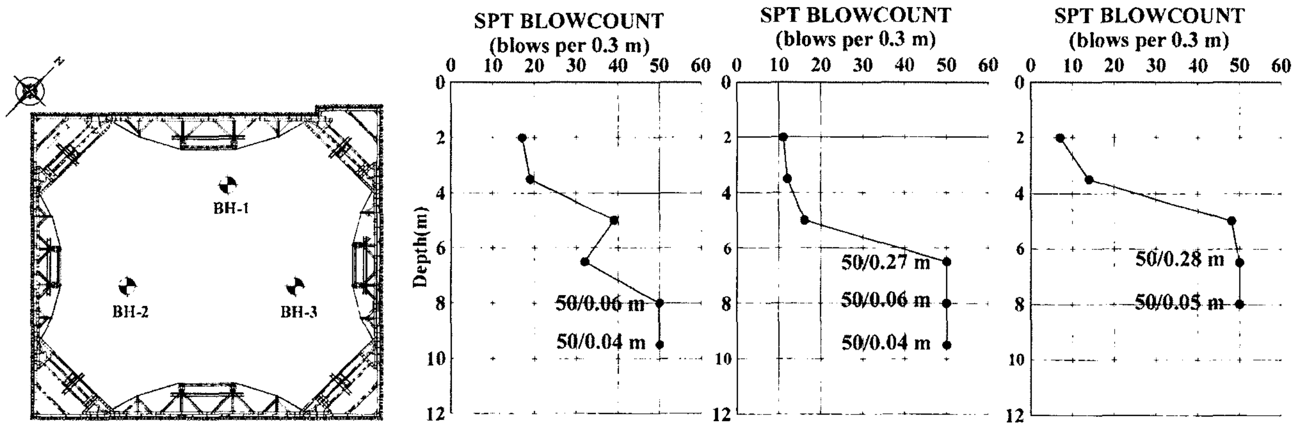


Fig. 2. Construction site

Apartment complex building comprises 17 stories of superstructure and two levels of basement. The excavation was 48 meters wide, 44 meters long and 11.9 meters deep. Each road of 8 meters, 10 meters, and 30 meters wide is adjacent to the site. The subway line No. 4 is located at a depth of 20 meters below the road surface of 30 meters wide. The old houses were located in the vicinity of the northwest side of the building site as shown in Fig. 2.

2.1 Site and Subsurface Condition Description

The standard penetration test profile and the soil profile distribution were shown in Fig. 3 and Fig. 4. The subsurface soil consists of fill, silty clay with sand, weathered soil and weathered rock. Fill is a composite of gravel, silty and clayey sand. Dark gray silty clay and gray brown silty sand underlie fill. Weathered soil is composed of brown and gray brown silty sand. Weathered rock has gray brown color and is highly weathered. Fill



(a) BH-1 (b) BH-2 (c) BH-3

Fig. 3. Standard penetration test profile

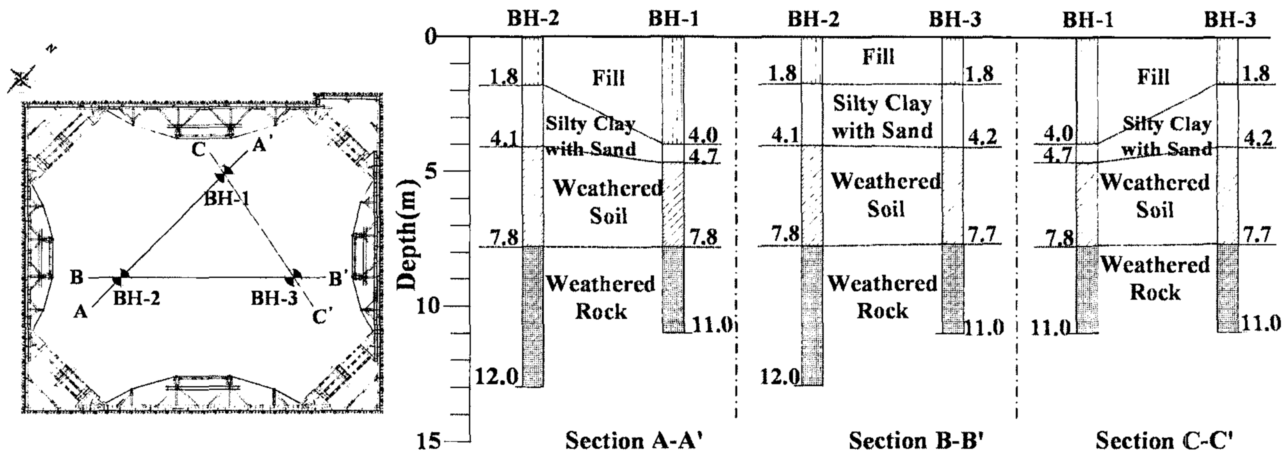


Fig. 4. Soil profile distribution

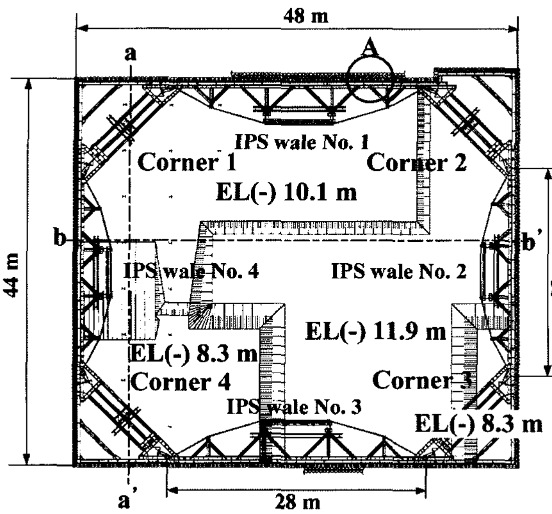


Fig. 5. Plan view of excavation

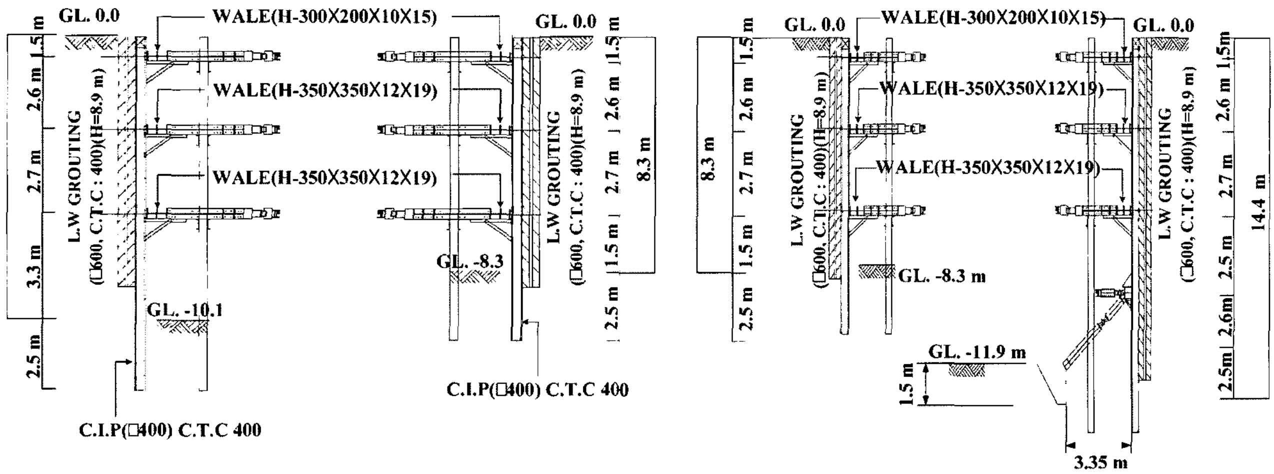
has SPT values ranging from 17 to 19. Silty clay with sand has N values ranging from 7 to 11. Weathered soil records N values ranging from 16 to 50. Weathered rock has N values of about 50 blows/100 mm. Weathered rock is located at a depth of 7.8 meters below the street surface. The groundwater existed at 3.1 meters from the ground level.

Site plan view and typical sections of the excavation are shown in Fig. 5 and 6 respectively. The depth of the excavation ranges from 8.3 to 11.9 meters. The wall penetrated into weathered rock of 2.5 meters deep. The CIP wall is braced internally with three levels of prestressed IPS wales and preloaded corner struts. LW grouting was used to prevent the inflow of the ground water.

2.2 Excavation Support System

The CIP wall is 0.4 meters in diameter and in distance from center to center. H-piles of H300×200×9×14(SS400) is 1.6 meters in distance from center to center. Axial reinforcement with 19.1 millimeters in diameter and spiral reinforcement with 12.7 millimeters in diameter is used as shown in Fig. 7. LW grouting is 0.6 meters in diameter and 0.4 meters in distance from center to center. Wall plan view is shown in Fig. 7.

The IPS earth retention system consists of IPS wales,



(a) section a-a' (b) section b-b'

Fig. 6. Typical sections of the IPS wall

Table 1. The IPS system data

IPS wales		H-beam	Steel wires	Length of wales	Length of legs
1st level	IPS 1-3	H300×300×10×15 (SS400)	ϕ15.2 mm, 18 EA	28 m	4.3 m
	IPS 2-4	H300×300×10×15 (SS400)	ϕ15.2 mm, 18 EA	22 m	3.3 m
2nd level	IPS 1-3	H350×350×12×19 (SM490)	ϕ15.2 mm, 28 EA	28 m	4.3 m
	IPS 2-4	H350×350×12×19 (SM490)	ϕ15.2 mm, 22 EA	22 m	3.3 m
3rd level	IPS 1-3	H350×350×12×19 (SM490)	ϕ15.2 mm, 28 EA	28 m	4.3 m
	IPS 2-4	H350×350×12×19 (SM490)	ϕ15.2 mm, 22 EA	22 m	3.3 m

Table 2. Prestress condition of the IPS wales and corner struts (kN)

		IPS 1	IPS 2	IPS 3	IPS 4	Preload of Corner struts
	Design Load	1,205	970	1,205	970	
1st level	Actual Load	1,323	980	1,323	980	N/A
	Percentage (%)	110	100	110	100	
	Design Load	3,538	2,764	3,538	2,764	
2nd level	Actual Load	2,646	1,882	3,528	1,882	1,300
	Percentage (%)	75	68	100	68	
	Design Load	3,538	2,764	3,538	2,764	
3rd level	Actual Load	2,508	1,980	2,509	1,980	1,300
	Percentage (%)	71	72	71	72	

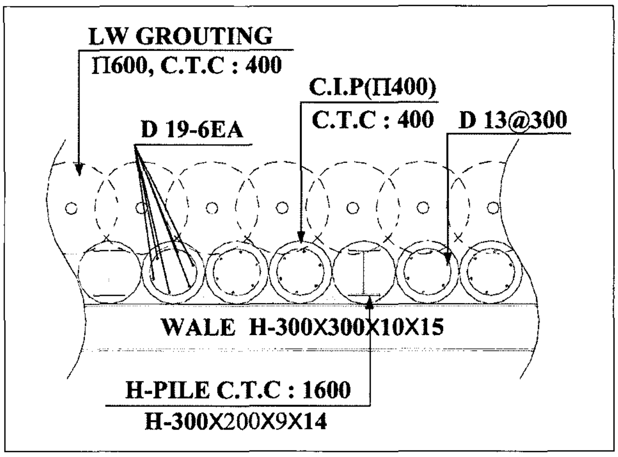


Fig. 7. Wall plan view

steel wires, legs to support wires and corner struts. Details of IPS wales are tabulated in Table 1.

Each corner consists of three H-beams and one channel. Each length of corner strut and channel is 7.6 meters and 4.0 meters. At the first level, H-beams of H300×300×10 ×15 (SS400) are used. At the second and the third level, H-beams of H350×350×12×19 (SM490) are used. Channels of 380×100×13×20 (SS400) are used.

Prestresses on steel wires of the IPS wales and corner struts are tabulated in Table 2.

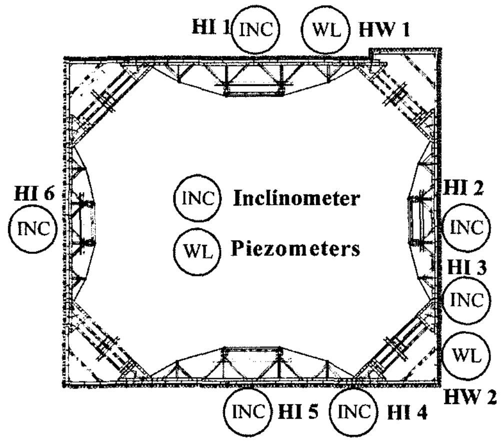
2.3 Instrumentation

The instrumentation includes six inclinometer casings, two piezometers and thirty-three strain gauges on steel members. The inclinometer casing and piezometer were installed to the depth of 12.0 meters to 14.0 meters below the ground surface. The location of inclinometers, piezometers and strain gauges is shown in Figure 8.

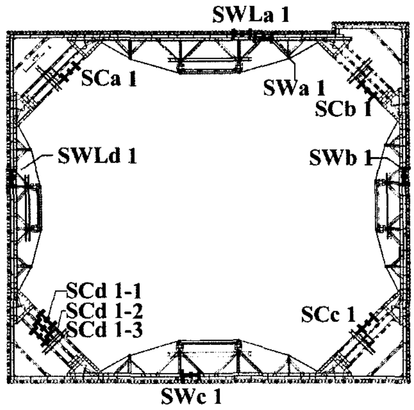
2.4 Construction Sequence

The excavation for apartment complex building proceeds with the following sequences.

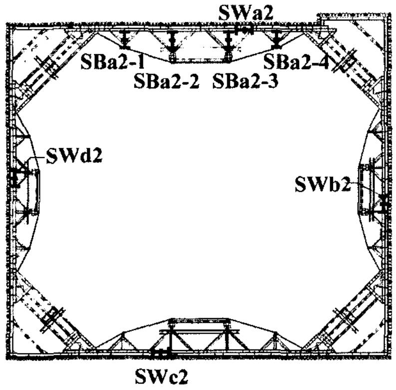
1) Excavate to the depth of 3.5 meters on 12th day.
2) Install the IPS wales and corner struts at 1.5 meters from the top of the wall and prestress the IPS wale up to 70% of the design tension load on 18th day.
3) Excavate to the depth of 5.5 meters on 26th day.
4) Install the IPS wales and corner struts at 4.1 meters from the top of the wall, and preload corner strut up to a load of 1300 kN, and prestress the IPS wale up to 70% of the design tension load on 32nd dayv.
5) Excavate to the depth of 9.0 meters on 40th day.
6) Re-stress the IPS wale at 1.5 meters from the top of the wall up to 100% of the design tension load on 43rd day.
7) Install the IPS wales and corner struts at 6.8 meters from the top of the wall, and preload corner strut up to a load of 1300 kN, and prestress the IPS wale up to 70% of the design tension load on 50th day.
8) Excavate partially to each depth of 10.1 meters and 11.9 meters from the top of the wall on 54th day.
9) Install the IPS wales and raker at 9.3 meters from the top of the wall in the excavation area of 11.9 meters deep on 64th day.
10) Remove the IPS wales and raker at 9.3 meters from the top of the wall on 80th day.



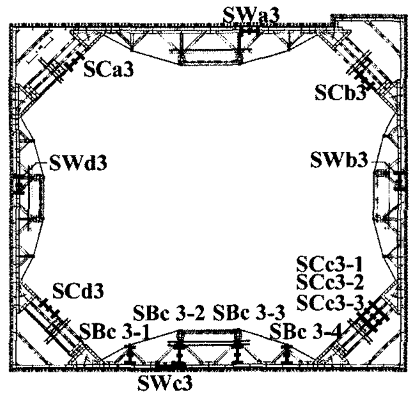
(a) Location of inclinometer and piezometer



(b) Location of strain gages on 1st IPS



(c) Location of strain gages on 2nd IPS



(d) Location of strain gages on 3rd IPS

Fig. 8. Instrumentation layout

11) Remove the IPS wales and corner struts at 6.8 meters from the top of the wall on 93rd day.

12) Remove the IPS wales and corner struts at 4.1 meters from the top of the wall on 115th day.

13) Remove the IPS wales and corner struts at 1.5 meters from the top of the wall on 128th day.

14) Remove deck plates on 150th day.

2.5 Measured Performance

The IPS earth retention system in urban excavation functioned successfully as shown in Photo 1. As can be

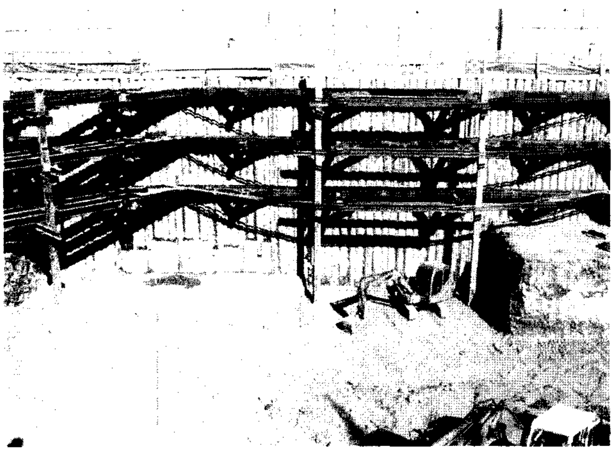


Photo 1. IPS earth retention system

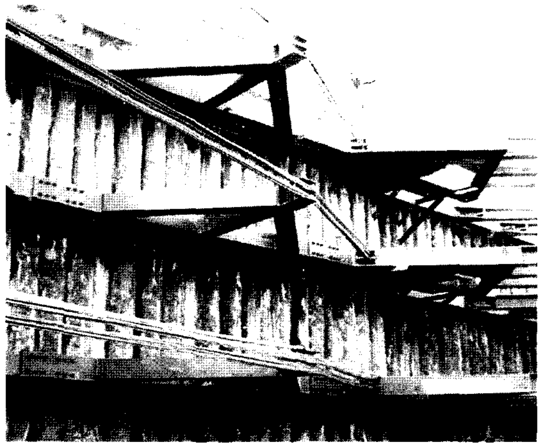


Photo 2. IPS wales in urban excavation

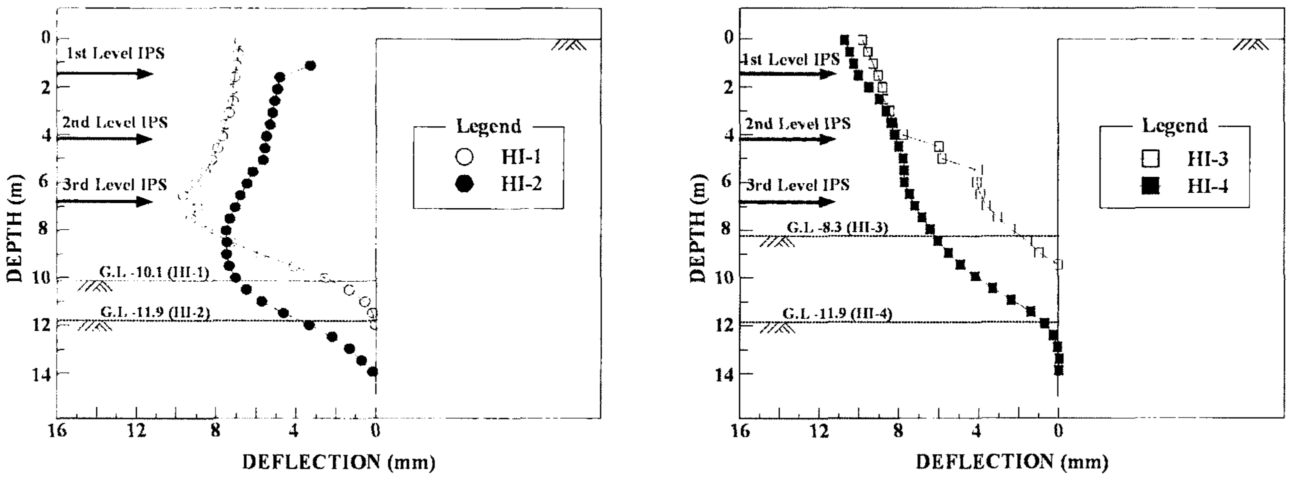
seen on Photos 1 and 2, large workspace provided construction easiness similar to that of anchored excavation.

2.5.1 Lateral Deflection of the IPS Wall

The lateral wall movements at various locations of inclinometers at the final construction stage are shown in Figure 9. The lateral deflections on the center of the IPS wales are shown in Figure 9 (a). The lateral deflections on the edge of the IPS wales are shown in Figure 9 (b). The deflection profiles on the center of the IPS wales represent a bulged fashion, with maximum deflection right above the weathered rock stratum. The lateral deflection profiles on the edge of the IPS wales show cantilevered fashion from the top of the wall. Based on the measured performance, the largest deflection of the IPS earth retention system did not exceed 0.5% of the excavation depth as a critical deflection proposed by Goldberg et al. (1976) and average about 0.2%, as recommended by Clough and O'Rourke (1990). Figure 10 shows the maximum deflections of the IPS wall at the construction stages.

2.5.2 The IPS Wale Performance

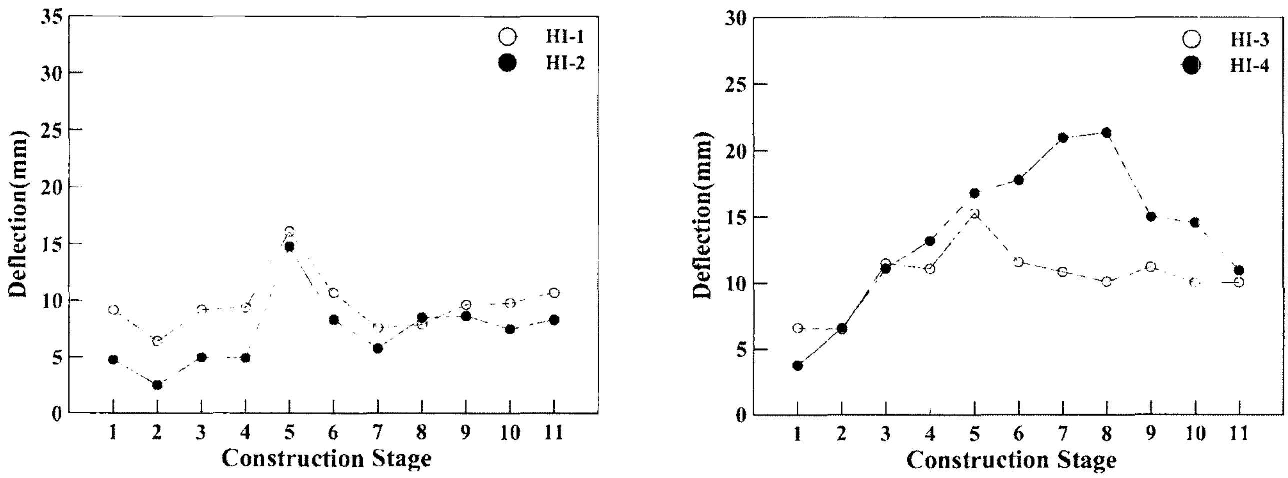
The performance of the IPS wale applied in urban



(a) on the center of the IPS wales

(b) on the edge of the IPS wales

Fig. 9. Deflections of the IPS wall at the final construction stage



1 - 1st excavation (Day12)
2 - 1st prestressing (Day18)
3 - 2nd excavation (Day26)
4 - 2nd prestressing (Day32)
5 - 3rd excavation (Day40)
6 - 1st re-prestressing (Day43)
7 - 3rd prestressing (Day50)
8 - Final excavation (Day54)
9 - After final excavation (Day64)
10 - After final excavation (Day81)
11 - After final excavation (Day96)

Fig. 10. The maximum deflections of the IPS wall at the construction stages

excavation was investigated and evaluated. While prestressing steel wires, the tension load on steel wires was measured. The loads on the H-beam support legs and wales were measured at several stages of the construction. The measured load on the steel wires while prestressing the steel wires of the IPS wale No. 2 at the second level is shown in Figure 11. The measured elongation of the prestressed steel wires was about 75% higher than the theoretical value. This result appeared since the wall deformed back into the ground while prestressing steel wires.

The axial load measured at the location of support legs (SBa2-2) of the IPS wale No. 1 at the second level is shown in Figure 12. The measured performance of the H-beam support leg was about 50% lower than the design load of H-beam support leg (Kim et al, 2004). As shown in Figure 12, the measured load on the H-beam support leg changed lettle during the construction stages.

The measured performance of the wale was observed during the construction stages. The measured axial load on the wale at the location of gage (SWb2) of the IPS wale No. 2 at the second level and at the location of gage (Swa3) of the IPS wale No. 1 at the third level is shown in Figure 13. The measured load on the wale was about 40% lower than the design load of wale (Kim et al, 2004). An axial fraction of the prestress load is reduced due to the friction between the wale and the wall.

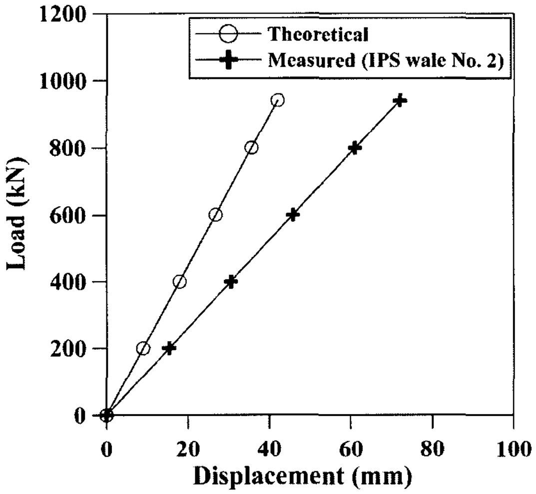


Fig. 11. Reaction of steel wires

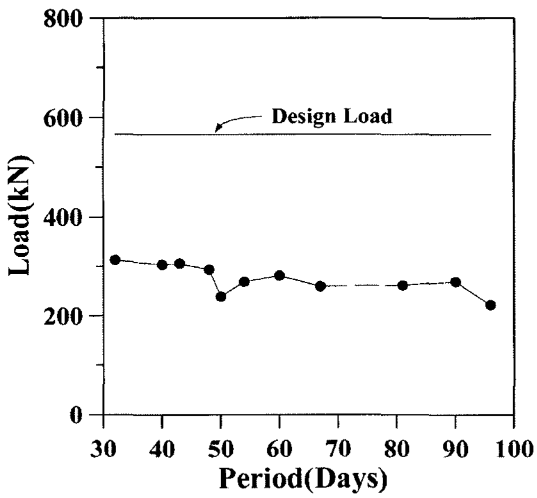
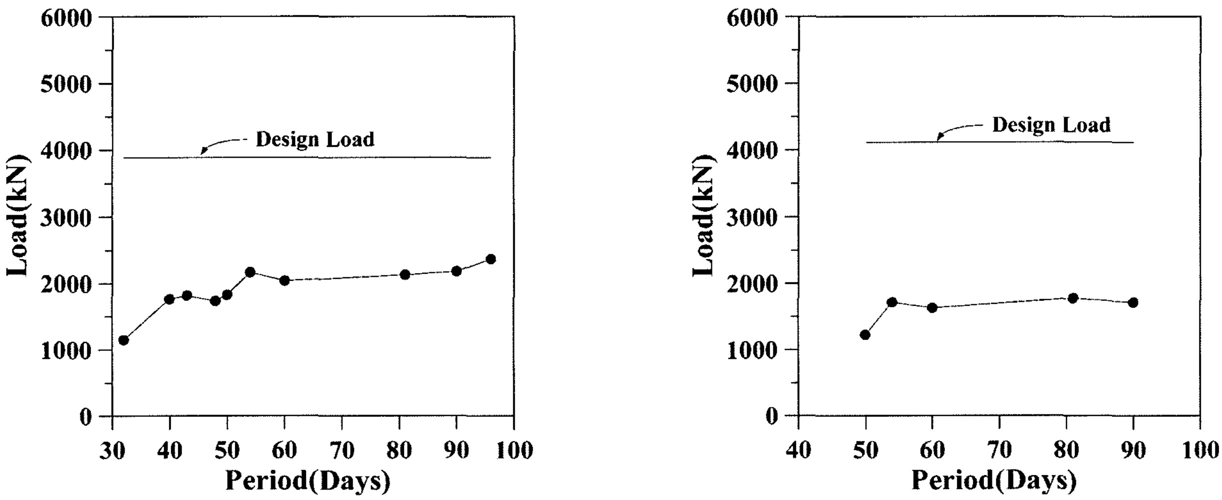


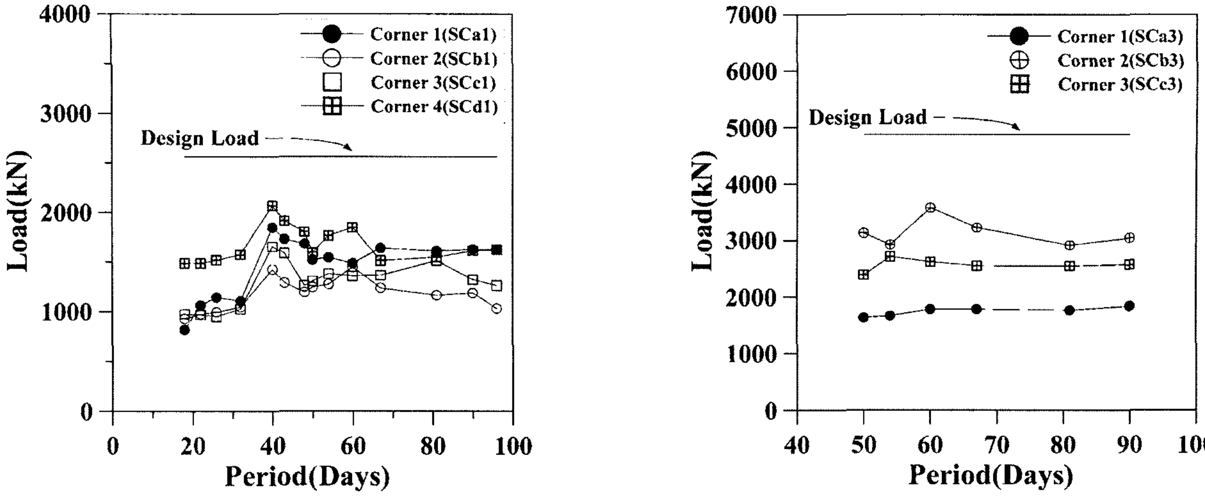
Fig. 12. Reaction of H-beam support leg



(a) IPS wale No. 2 at the second level

(b) IPS wale No. 1 at the third level

Fig. 13. Reaction of the wale



(a) Corner struts at the first level

(b) Corner struts at the third level

Fig. 14. Reaction of corner struts

2.5.3 Corner Strut Performance

Figure 14 shows the measured loads on the corner struts at the first level and at the third level. Lateral earth pressure loads as measured from the corner strut vary from 40% to 72% of the Terzaghi and Peck's earth pressure loads at the first level. The corner strut loads at the third level of the IPS wale vary from 34% to 73% of the Terzaghi and Peck's earth pressure loads at the final construction stage as shown in Figure 14.

3. Conclusions

This paper presents the measured performance of the IPS earth retention structure applied in urban excavation. The IPS earth retention structure applied in urban excavation was instrumented and observed during construction. Based on the measurements, the following conclusions can be drawn:

(1) The IPS earth retention system applied in urban excavation functioned successfully.
(2) The IPS earth retention system applied in urban excavation was proved to provide large workspace and construction easiness.
(3) The preloading effect of the IPS wale was verified and the deflection of the wall was restricted by prestressing the IPS wale. The IPS wall deformed back into the ground while prestressing the IPS wale. The maximum deflection of the wall did not exceed recommendations by Goldberg et al. (1976) and Clough and O'Rourke (1990).
(4) The measured load on the wale was about 40% lower than design load. An axial fraction of the prestress load reduced due to the friction between the wale and the wall.
(5) The measured load on the corner strut was approximately 40% lower than design load proposed by Terzaghi and Peck (1967).
(6) The excessive stresses or buckling of structural members of the IPS earth retention system were not notified. The axial compressive stress on the IPS wales and support legs were within the allowable stresses.
(7) The findings obtained from this study should be verified by further field tests.

Acknowledgments

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