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Development of Innovative Prestressed Support Earth Retention System

IPS 흙막이 공법의 개발

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요 지

본 논문에서는 강선의 선행하중을 이용한 새로운 흙막이 공법의 원리와 적용 사례를 다루고자 한다. IPS (Innovative Prestressed Earth Retention System) 흙막이 공법은 띠장에 강선의 인장력을 적용한 선행하중 공법이다. IPS 흙막이 공법은 강선, H-Beam 받침대, 띠장으로 구성된 띠장에 강선의 긴장력을 도입하여 굴착 지반에 선행하중을 가하고 지반의 추가 굴착으로 인한 토압의 증가를 IPS 띠장과 트러스 버팀보 또는 코너 스트럿으로 지지하는 개념을 가지고 있다. IPS 흙막이 공법은 경제성, 시공성, 안정성을 제공하며 휨 강성이 큰 IPS 띠장을 이용하여 지지 간격을 획기적으로 증대시킨 특징을 가지고 있다. 본 논문에서는 IPS 흙막이 공법의 기본 원리 및 메커니즘을 설명하고 IPS 흙막이 공법의 특징, 적용 범위와 설계 방법을 언급하였다. IPS 흙막이 공법의 현장 시험을 수행하여 현장 적용성과 안정성을 확인하고 현장 계측결과를 분석하여 IPS 흙막이의 거동을 파악하였다.

Abstract

A new innovative prestressed support (IPS) earth retention system has been developed and introduced. The IPS is a wale system prestressed by steel wires. The IPS consists of wale, wires, and H-beam support. The IPS provides a high flexural stiffness to resist the bending by earth pressures. The IPS earth retention system provides a larger spacing of support, economical benefit, construction easiness, good performance, and safety control. This paper explains basic principles and mechanism of new IPS system and presents a design method of IPS earth retention system. In order to investigate applicability and safety of new IPS system, field tests were performed in a trench excavation. The new IPS system applied in a trench excavation was performed successfully. The measured performances of IPS system were presented and discussed.

Keywords : Earth pressure, Earth retention system, Excavation, Large excavation, Prestress

1. Introduction

Recently, excavations should accommodate requirements of high-rise buildings, subway structures and huge underground structures in urban areas. Especially in large excavation, conventional temporary strut support

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causes high cost and construction delay because the required amount of steel is huge and construction workspace is quite limited. Anchored support can be a good solution, but usually, it is very hard to get permission to put anchors in a private nearby area.

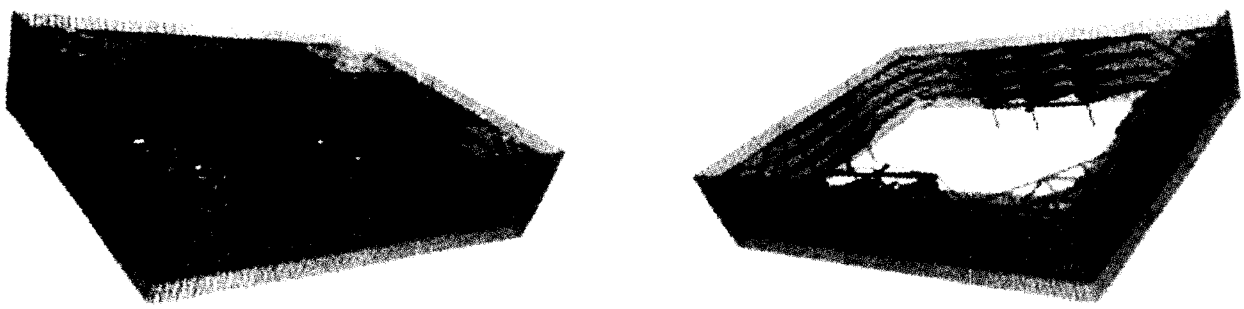
An innovative prestressed support (IPS) earth retention system can be an excellent solution to the case. The conventional strut support and the IPS earth retention system are shown in Figs. 1(a) and (b). As can be seen in Fig. 1, amount of steel was reduced drastically and large workspace provides construction easiness. The IPS earth retention system consists of wale, steel wires, legs to support steel wires and hydraulic jacks to apply prestress on steel wires as shown in Fig. 2. The IPS is a prestressed wale with flexural stiffness high enough to expand the support span.

This paper describes the basic mechanism of the IPS earth retention system and presents where to apply and where not to apply. The advantages and disadvantages of the IPS earth retention system were also presented. The construction procedure of the IPS system was explained. Field tests on the IPS system in trench excavation were performed to evaluate the applicability and safety of the IPS system. The IPS earth retention system was performed successfully.

2. Basic Mechanism of IPS Earth Retention System

The idea of prestress has been known to be very efficient way to increase flexural stiffness in structural member. Many references are available on the basic mechanism and applications of prestress (AISC, 1989 ; Chajes, 1974 ; Nilson, 1978 ; Gimsing, 1997 ; PCI, 1997 ; Salmon & Johnson, 1997 ; Timoshenko & Gere, 1961 ; Troitsky, 1990). This idea of prestress was adopted to develop a wale with high flexural stiffness to support earth pressure due to excavation.

In temporary excavation, the conventional earth retention system uses struts or anchors to support earth pressure. The spacing of struts or anchors is approximately several feet. In order to increase the spacing of supports, the flexural stiffness of wales and design load of supports should increase. The flexural stiffness of



(a) Conventional braced cut (b) IPS earth retention system

Fig. 1. Braced cut and IPS earth retention system

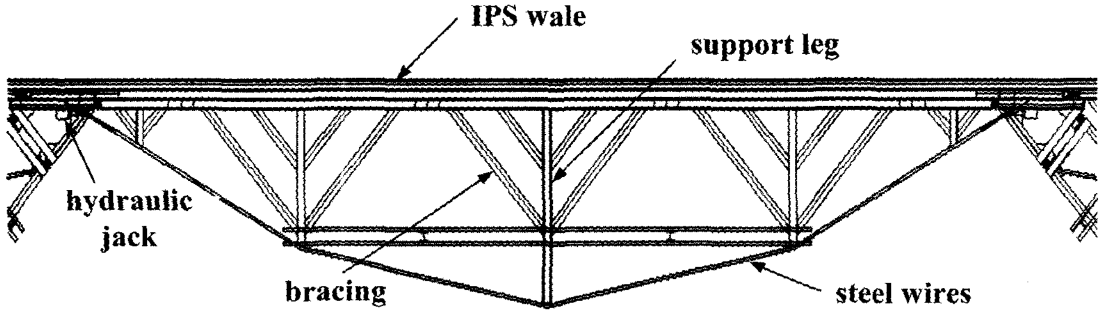


Fig. 2. Prestressed wale of IPS earth retention system

wales can be increased either by using larger section or by applying prestress. The IPS earth retention system is a temporary earth supports by using prestressed wale. As shown in Fig. 2, wale is prestressed by steel wires which are attached to each end of wale. The prestress is applied by using hydraulic jack attached at the ends of wale.

The comparison between the conventional braced cuts and the IPS earth retention system is shown in Fig. 3. As shown in Fig. 3, the spacing of struts in IPS system increased, the stiffness of wales increased and the section of the struts increased. The basic model and free body diagram of the IPS system are shown in Fig. 4. In order to determine the required prestress, the compressive force V on the support legs is assumed to be the same and then equation (1) applies as follows:

$$3V = wL \tag{1}$$

where, w is the earth pressure on wales in kN/m, V is the compressive force on support legs, L is the length of wale. At joint D and C, the following relationships apply:

$$\text{Point D: } 2P\sin a_2 - V = 0 \tag{2}$$

$$\text{Point C: } P\sin a_2 - P\sin a_1 + V = 0 \tag{3}$$

$$P\cos a_2 - P\cos a_1 - H = 0 \tag{4}$$

where P is the prestressing force on steel wires in kN, H is the compressive force of inner bracing in kN and a_1, a_2 are the angles of steel wire set up. By combining equations (2) and (3), the angle of steel wires a_1, a_2 is as follows:

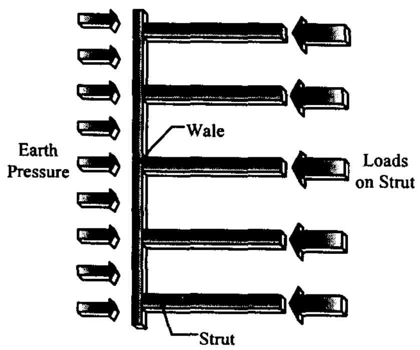
$$\sin a_1 = 3\sin a_2 \tag{5}$$

Therefore, the prestress required in order to be equivalent to the conventional brace cuts shown in Fig. 3 (a) can be calculated as follows:

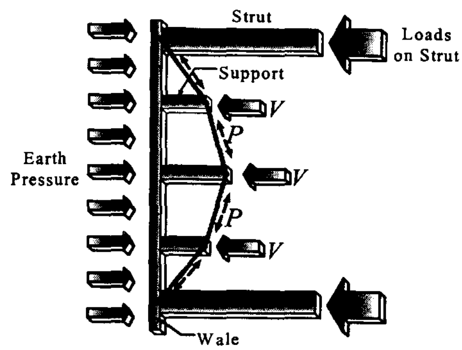
$$P = \frac{wL}{2\sin a_1} \tag{6}$$

The length of support leg, h_c at the center of wale can be related to the length of supports next to that as follows:

$$h_c = h_e + d_i \tan\left(\sin^{-1}\left(\frac{\sin a_1}{3}\right)\right) \tag{7}$$



(a) Conventional braced cuts



(b) IPS earth retention system

Fig. 3. Comparison between conventional braced cuts and IPS system

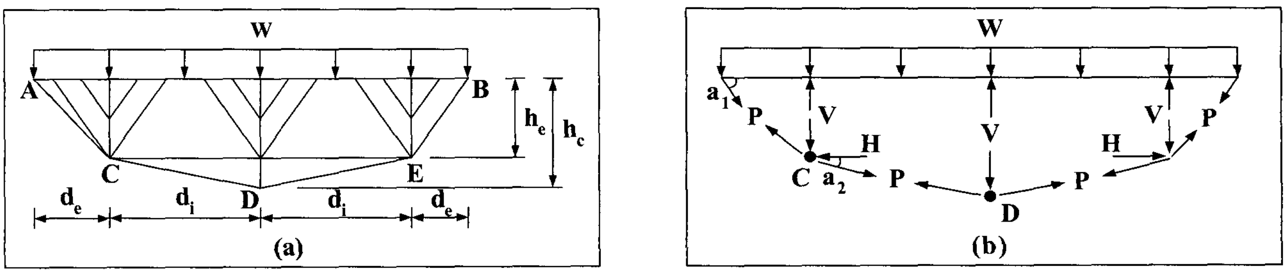


Fig. 4. Basic model and free diagram of IPS

where h_e is the height of the outside H-beam and d_i is the distance between legs.

3. Advantages and Disadvantages of IPS Earth Retention System

The IPS earth retention system is a temporary support to an excavation by applying prestress force on steel wires. The IPS earth retention system is equivalent to any preloading supports, such as anchored excavation and braced cuts with preload. The advantages and disadvantages of the IPS earth retention system are summarized as follows:

(1) The IPS system provides wider support spacing and large construction workspace. Since the wale has very high flexural stiffness, the spacing between struts is larger than conventional braced cuts. Therefore, construction easiness due to larger workspace can be obtained.

(2) The IPS system is easy to apply prestress to have preloading effect on the wall. In order to restrict the wall deformation, the preload can be applied by using hydraulic jacks on wider area than conventional earth supports. It is equivalent to preloading several struts simultaneously.

(3) The IPS system reduces the quantity of H-beam or equivalents by approximately 30 percent of the conventional braced cuts. It saves construction cost, because wider spacing of struts reduces number of struts required to support earth pressure.

(4) The safety control is easier than conventional system. If an excessive deformation occurs, the prestress on the IPS wale can be reloaded by using hydraulic jacks. The required amount of instrumentation is smaller than the conventional system, since the number of struts and wales is smaller than that of the conventional braced cuts.

(5) The IPS system can be applied in urban congested area where it is difficult to get permission to put anchors and difficult due to buried pipelines, power lines, etc.

(6) The IPS system is hard to apply in an excavation, the shape of which is not square or rectangular. The sides of an excavation shape should be closed.

(7) The IPS system requires trained workmanship since it is quite different from the conventional system.

4. Measured Performance of IPS System

The IPS system was applied to the trench excavation for water lines in Byungchun area. In order to verify the IPS system performance and to evaluate the each member's behavior, the system is instrumented and monitored during the excavation.

4.1 Site and Subsurface Condition Description

The trench excavation for water lines goes along the bank of the small river, 1.2 kilometers long, 5.2 meters deep and 7meters wide. The sheet piles are used and driven up to the depth of 6.5 meters from the ground surface. The sheet pile wall is supported with two lows of the IPS wales and struts. The sheet pile is U400×150×13.1, the first and the second struts are H300×300×10×15 and H350×350×12×19. The spacing of struts is 23 meters. The upper IPS wale consists of two H-beams (H 300×300×10×15) and the second IPS wale consists of two H-beams (H350×350×12×19). The IPS wale has four legs to support 24 steel wires at the upper location and 36 wires at the lower location.

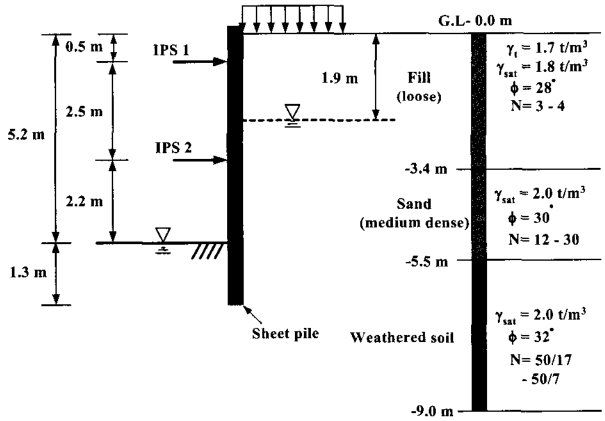


Fig. 5. Subsurface condition

Each steel wire has a diameter of 15 millimeters.

The subsurface condition at the location of the wall consists of fill from 0 to 3.4 meters, medium dense sand from 3.4 to 5.5 meters, weathered soil from 5.5 to the end of boring. The ground water exists at 1.9 meter from the ground level. The subsurface condition is shown in Fig. 5.

4.2 Instrumentation

The instrumentation includes one inclinometer casing, two piezometers, twenty-three strain gauges on steel members and twenty L.V.D.T.'s The inclinometer casing was installed 7 m deep into the weathered soil and 1 meter behind the wall. Piezometers were installed 1 m and 7 m behind the wall to meaure ground water level as shown in Fig. 6. The location of strain gages and L.V.D.T.'s is shown in Figs. 7-8.

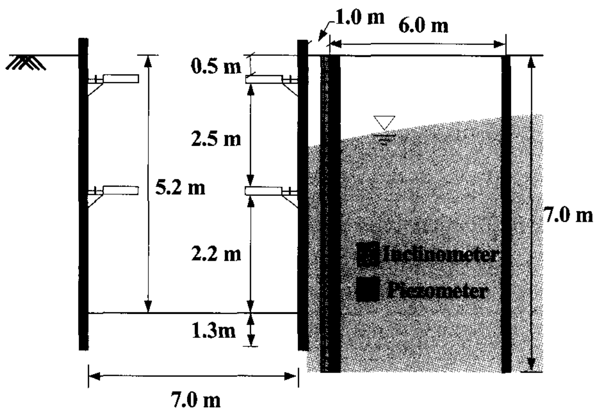


Fig. 6. Section of test wall

4.3 Construction Sequence

The trench excavation with the IPS system was performed with the following construction stages.

(1) Excavate to the depth of 2.0 meters.
(2) Install the IPS wale at 0.5 m from the top of the wall and prestress up to a load of 3920 kN.
(3) Excavate to the depth of 3.5 meters.
(4) Install the second level of the IPS wale at 3.0 m and prestress up to a load of 5292 kN.
(5) Excavate to the final depth of 5.2 meters.

4.4 Observed Performance

The IPS earth retention system was applied in a trench

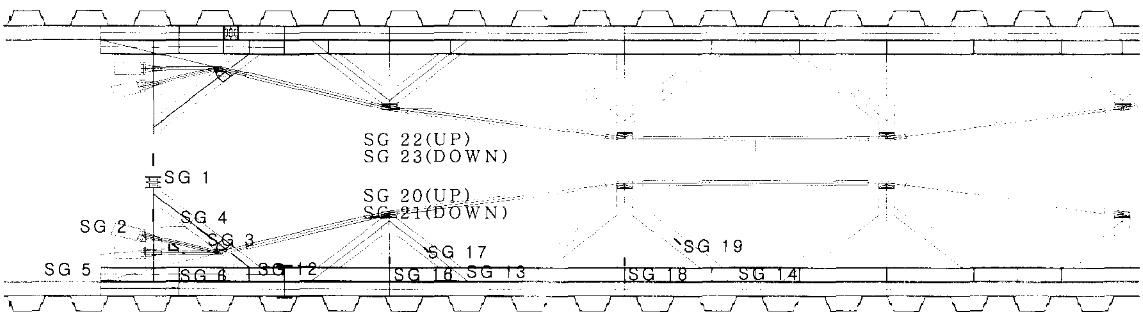


Fig. 7. Full-scale test wall-plan view(at location of strain gauge)

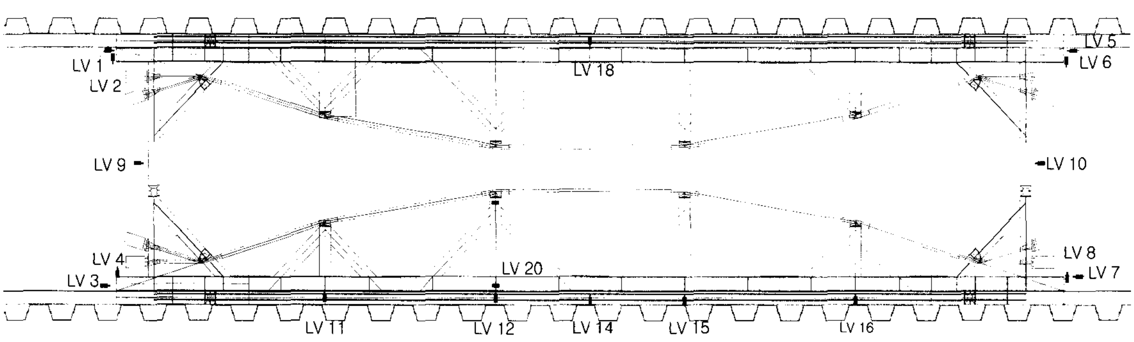


Fig. 8. Full-scale test wall-plan view(at location of L.V.D.T)

excavation and performed successfully as shown in Photo 1. The observed performance of the IPS earth retention system was discussed and the system stability was investigated.

The maximum deflection of the wall was 2.9mm at the top of the wall during the first construction stage. After the IPS wale was installed, the wale was prestressed with a force of 3920 kN on steel wire. At this stage, the wall moved back into the original position. The preloading effect of the IPS system was verified. At the third construction stage, the horizontal deflection of the wall was measured to be 0.3 mm towards the ground. At the fourth construction stage, the lower level of the IPS wale was installed and was prestressed up to 5292 kN. The deflection of the wall was measured to be 0.4 mm towards the ground. The deflection of the wall at the final construction stage was measured to be 0.7 mm towards the ground. The measured deflection of the wall during the construction was shown in Fig. 9. Based on the measured performance, the IPS earth retention system has an excellent ability to restrict the wall deformation.

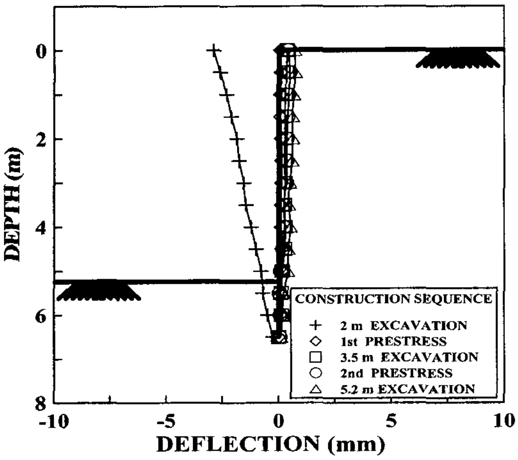


Fig. 9. Deflection of IPS wall

The performance of struts and the IPS wale in the IPS earth retention system was investigated at the fourth construction stage. While prestressing the steel wire, the load on struts and the IPS wale was measured and

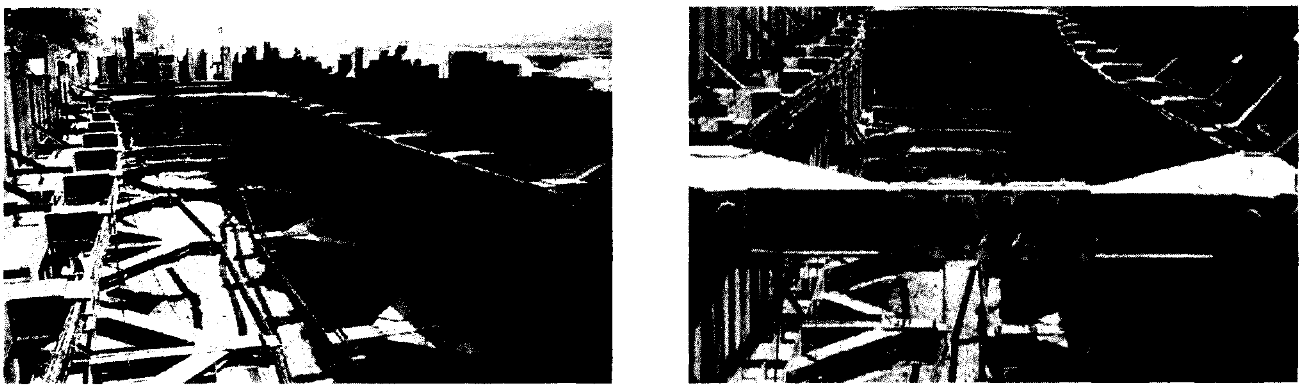


Photo 1. IPS earth retention system

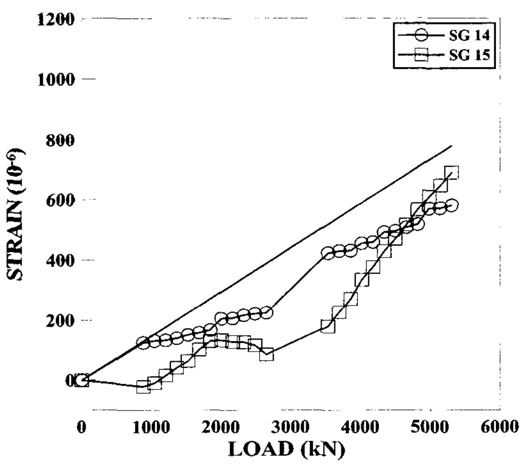


Fig. 10. Reaction on wale

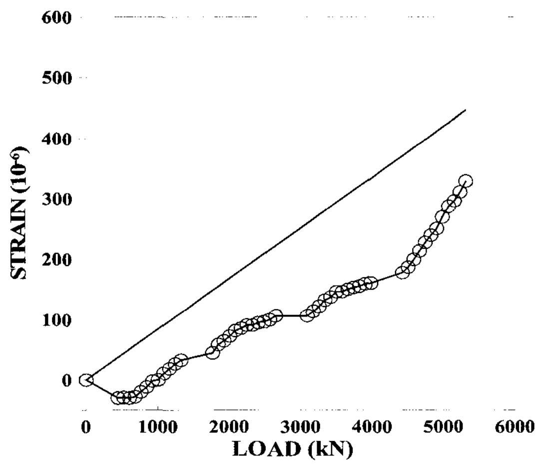


Fig. 11. Reaction of strut

evaluated. With a prestress of 5292 kN, the measured loads on the IPS wale were 4236 kN and 5032 kN at the location of SG14 and SG15 in Fig. 7. As shown in Fig. 10, the compressive loads measured on wale shows 5.3 percent smaller at the location of SG15 and 25 percent smaller than theoretical values. A fraction of the prestress load is transferred to the wall by the friction between the wale and the wall. As shown in Fig. 11, the measured load on the strut was 1201 kN and 23 percent smaller than the theoretical value since the IPS wale and the wall deforms back into the ground at the location of struts while prestressing.

5. Conclusions

This paper presents basic principles and measured performance of the IPS earth retention system applied in trench excavation. The advantages and disadvantages of the IPS earth retention system were explained. The IPS earth retention system applied in trench excavation was instrumented and measured during construction. Based on the measurements, the following conclusions can be drawn:

(1) The IPS earth retention system was performed successfully.
(2) The preloading effect of the IPS earth retention system was verified and the deflection of the wall was restricted to be approximately zero.
(3) The spacing of the struts was 23 meters and the IPS wales were performed within the allowable stresses. The IPS system reduced the quantity of steel for the construction.
(4) The excessive stresses or buckling of structural members of the IPS earth retention system were not notified due to the prestress load.

Acknowledgments

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