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A new IPS earth retention system

Un nouveau système de la rètention de terre d'IPS

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ABSTRACT
A new innovative prestressed wale earth retention system (IPS) has been developed and introduced. The system uses a wale prestressed by steel wires. The IPS wale system consists of wales, steel wires, H-beam support legs, and hydraulic jacks. 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 the IPS earth retention system and presents advantages and limitations of this earth retention system. This paper also presents the results of field tests, which investigate applicability and safety of the IPS earth retention system. The field tests applied in a trench excavation and in an urban excavation performed successfully.

RÉSUMÉ
Ce mémoire a pour objet de présenter un nouveau système innovateur de support précontraint (IPS) pour la rétention de terre. Ce système emploie un support précontraint de căbles d'acier. Ce nouveau système de support se compose des supports, căbles d'acier, poutres longitudinales et vérins hydrauliques. Il a une haute rigidité flexionnelle pour résister à la flexion par la pression de terre. Ce système du rétention de terre offre un plus d'espacement de support, les avantages économiques, la facilité de construction, le bon fonctionnement et un contrôle stable. Ce mémoire explique les principes et le mécanisme du nouveau système innovateur de de rétention de terre et il présente les avantages et les défauts de ce système. Ce mémoire montre également les résultats de l'essai en exploitation concernant l'applicabilité et la sécurité de ce système. Cet essai en exploitation appliqué à la excavation pratiquée en longuer et la tranchée dans la zone urbaine s'est accompli avec un grand succès.

1 INTRODUCTION

Numerous excavation projects for buildings, water lines, power lines, and subway structures are being executed. Several types of temporary retention system have been used to support the retained ground due to excavation. Struts and ground anchors are in common use as supports.

Struts are horizontal compression members, which support earth pressure due to excavation. Struts are installed at regular spacings to wales, which transfer a load from wall to struts. Struts are easy to install, and easy to apply preload to each strut member by using hydraulic jack, to restrict wall deformation. In large excavation, strut supports are too long and may cause high cost and construction delay. The required amount of steel is huge and construction workspace is quite limited.

Ground anchors, which are often referred to as tiebacks or tiedowns, are steel tendons or strands secured in the ground by grouting. Ground anchors are capable of transmitting earth load to a loadbearing soil stratum. Various types of ground anchors have been used to provide lateral support for temporary and permanent earth retaining structures. Ground anchors can be good solution in large excavation. Anchored supports generally provide larger workspace than strut supports. In urban areas, however, it is very hard to get permission to put anchors in a private nearby area, and anchor hole drillings may damage to underground facilities.

The innovative prestressed wale earth retention system was developed and introduced as an alternative method (Kim et al, 2004). The innovative prestressed wale system (IPS) has high flexural stiffness than those of conventional wale system. The IPS earth retention system increases the spacing of struts drastically larger than those of conventional support system. Therefore, the IPS earth retention system can reduce quantity of steel beams than conventional strut support. The IPS earth retention system has a preloading effect on the wall and can restrict wall deformation by tensioning steel wires.

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 (Timoshenko & Gere, 1961; Chajes, 1974; Nilson, 1978; AISC, 1989; Troitsky, 1990; Gimsing, 1997; PCI, 1997; Salmon & Johnson, 1997).

This paper presents principles of the innovative prestressed wale earth retention system. The basic concept of this earth retention system is explained and is compared to those of conventional strut support in details. The components of the IPS earth retention system are explained. This paper presents advantages and limitations of the IPS earth retention system. Observed performance of the IPS earth retention system in a trench excavation and urban excavation is presented.

2 BASIC MECHANISM OF IPS EARTH RETENTION SYSTEM

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 its common use. In order to increase the spacing of supports, the flexural stiffness of wales should increase. The flexural stiffness of 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 system. As shown in Fig. 1, wale system is prestressed by tensioning steel wires attached to ends of the wale.

The schematic diagram of the conventional braced cut and the IPS earth retention system is shown in Fig. 2. As shown in Fig. 2, the spacing of struts increases drastically amount of steel was reduced and large workspace provides construction easiness.

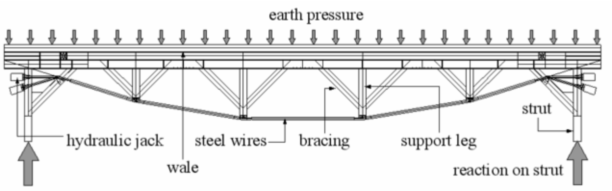

Figure 1. Components of the IPS wale system

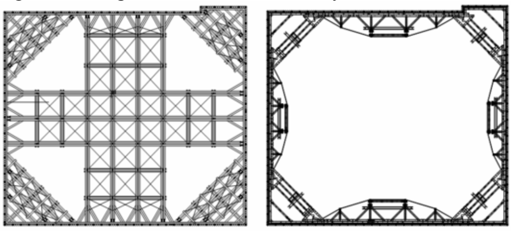
Figure 2. Braced cut and IPS earth retention system

2.1 *Mechanism*

A free body diagram of the IPS wale system is shown on Fig. 3. In order to determine sectional forces on the members of the IPS against earth pressure, the compressive force V on each support leg is assumed to be the same and then equation (1) applies as follows:

$$4V = \omega L \tag{1}$$

where, ω is the earth pressure on wale in kN/m, L is the length of wale in m, V is the compressive force on the support leg in kN. When summing the components of forces in the vertical and horizontal direction, at joint B and C, the following relationship applies:

Joint B: $$P\sin\alpha_1 - P\sin\alpha_2 - V = 0 \tag{2}$$

$$P\cos\alpha_1 - P\cos\alpha_2 + H_e = 0 \tag{3}$$

Joint C: $$P\sin\alpha_2 - V = 0 \tag{4}$$

$$P\cos\alpha_2 + H_i = P \tag{5}$$

where, P is the prestressing force on steel wires in kN, H_e and H_i is the compressive forces of horizontal bracing in kN, and α_1 and α_2 are the angles of steel wire. By combing equations (2) and (4), the relationship between α_1 and α_2 is as follows:

$$\sin\alpha_1 = 2\sin\alpha_2 \tag{6}$$

The prestressing force on steel wires, which is required to support earth pressure can be as follows:

$$P = \frac{\omega L}{2\sin\alpha_1} \tag{7}$$

The prestressing force obtained from Eq. (7) is the design tension load of steel wires. The length of support leg, h_t at the center of the wale can be obtained from the following:

$$h_t = h_i + d_i \tan(\sin^{-1}(\frac{\sin\alpha_1}{2})) \tag{8}$$

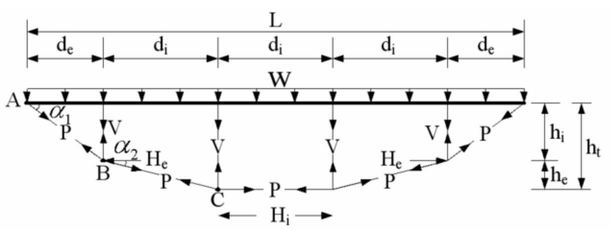

Figure 3. Free body diagram of the IPS

2.2 *Flexural stiffness*

The flexural stiffness of the IPS can be calculated by assuming the IPS deforms same as simple beam and can be derived from a deflected shape of the IPS caused by earth pressure, and the mathematical derivations are based on the following assumptions: 1) the distribution of earth pressure subjected to the IPS is uniform, 2) structural behavior of the IPS is equivalent to those of a simple beam, 3) deflected shape of the IPS by earth pressure is a parabola, 4) the largest deflection of the IPS is occurred to the center of the IPS, 5) the axial strain of the IPS is negligible. The stiffness factor of the IPS based on the foregoing assumptions is defined as the length of wale, the lengths of support leg, the lengths of steel wire, and the sectional area of steel wires (referred to Fig. 1).

$$K_{IPS} = \frac{\Delta\omega}{\Delta x_c} = \frac{4E_pA_ph_e}{L\,L_{p2}L_{po}}\left(\frac{7h_i}{16L_{p1}} + \frac{h_e}{2L_{p2}}\right) \tag{9}$$

where, K_{IPS} is the stiffness factor of the IPS in kN/m^2, x_c is the deflection of the center of the IPS in m, E_p is the modulus of elasticity of steel wire in kN/m^2, A_p is the section area of steel wires in m^2, h_e and h_i are the length of support legs in m, L_{p1} and L_{p2} are the length of steel wire in m. Here, L_{p1} is the length between Point A and B, and L_{p2} is the length between Point B and C as shown in Fig. 2, and $L_{po} = L_{p1} + L_{p2} + 0.125L$. The equivalent flexural stiffness of the IPS wale can be obtained as follows:

$$EI_{(IPS)} = \frac{5 \times K_{IPS} \times L^4}{384} \tag{10}$$

3 ADVANTAGES AND LIMITATIONS

The IPS earth retention system, as an alternative method, which is capable of solving limitations of conventional temporary support system, has excellent features. The advantages and limitations of the IPS earth retention system are summarized as follows:

3.1 *Advantages*

1) The IPS earth retention system provides wider strut spacing and large construction workspace. Since the IPS earth retention system has very flexural stiffness, the spacing of struts is larger than conventional strut support. Therefore, construction easiness due to larger workspace can be obtained.
2) The IPS earth retention system is easy to apply prestressing force of steel wires to have a 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 support system. It is equivalent to preloading several struts simultaneously.
3) The IPS reduces the quantity of steel beam or equivalents by approximately 30 percent of conventional braced cuts. The IPS earth retention system can save construction cost because wider spacing of struts reduces the number of struts required to support earth pressure.
4) The safety control of the IPS earth retention system is easier than conventional support system. If an excessive deflection occurs, the reload by applying the prestressing force of steel wires, by using hydraulic jacks, can be subjected on the wall. The required amount of instrumentation is smaller than conventional strut support system because the number of struts and wales is smaller than conventional braced cuts.
5) The IPS earth retention system can be applied in urban areas where it is difficult to get permission to put anchors and difficult due to buried water lines, power lines, etc.

3.2 *Limitations*

1) The IPS earth retention system is hard to apply the shape, which is not square or rectangular in an excavation. The sides of an excavation shape should be closed.
2) The IPS earth retention system requires trained workmanship since it is different from conventional support system.

4 MEASURED PERFORMANCE

In order to investigate applicability and safety of the IPS earth retention system, field tests were performed in a trench excavation and in an urban excavation, respectively. The IPS earth retention system applied in a trench excavation and in an urban excavation performed successfully.

4.1 *Trench excavation*

The IPS earth retention system (Photo 1) was applied in a trench excavation for water lines in Byungchun in Korea. In order to verify the IPS performance and to evaluate the each member's behavior, the IPS is instrumented and monitored during the excavation.

4.1.1 *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 7 meters wide. The subsurface condition at the location of the wall consists of loose fill from 0 to 3.4 meters, weathered soil from 5.5 meters to the end of boring. The ground water exists at 1.9 meter from the ground level.

4.1.2 *IPS earth retention system*
The sheet piles are used and driven up to the depth of 6.5 m from the ground surface. The sheet pile wall is supported with two lows of the IPS and two struts. The cross section of sheet pile is U type, and the width is 400 mm, and the depth is 150 mm, and the thickness is 13.1 mm. The strut is a wide flange shape of beam, and the section of the upper struts is that the width of flange is 300 mm, and that the depth of beam is 300 mm, and that the thickness of web is 10 mm, and that the thickness of flange is 15 mm. The section of the lower struts is H350×350×12×19 mm. The spacing of struts is 23 m. The IPS, which is located in the first level, consists of two wales, nine support legs, and twenty-four steel wires. And the second IPS consists of two wales, four support legs, and thirty-six steel wires. The cross section of beams used to the first and the second IPS is equal to those of struts located in the each floor. Each steel wire has a diameter of 15.2 mm.

4.1.3 *Instrumentation and construction details*
The instrumentation includes one inclinometer casing, two piezometers, twenty-three strain gauges on steel members, and twenty linear variable differential transducers. The inclinometer casing was installed 7 m deep into the weathered soil and 1 m behind the wall. Piezometers were installed 1 m and 7 m behind the wall to measure ground water level.

The trench excavation with the IPS earth retention system was performed with the following construction stages: 1) excavate to the depth of 2.0 m, 2) install the IPS at 0.5 m from the top of the wall and prestress up to 110% of the design tension load, 3) excavate to the depth of 3.5 m, 4) install the second level of the IPS at 3.0 m and prestress up to 190% of the design tension load, 5) excavate to the final depth of 5.2 m. In order to verify the safety of the IPS against over earth pressure, the prestressing forces of steel wires of the IPS installed in the first and second level were larger applied on the wall about 1.1 and 1.9 times, respectively, of the design load.

4.1.4 *Observed performance*
The maximum deflection of the wall was 2.9 mm at the top of the wall during the first construction stage. After the first IPS installed, the IPS was prestressed with 110% of the design tension load on steel wires. At this stage, the wall moved back into the original position. The preloading effect of the IPS was verified. After the third construction stage, the second IPS was installed and was prestressed up to 190% of the design tension load. The deflection of the wall was measured to be 0.4 mm towards the ground. Based on the measured performance, the IPS earth retention system has an excellent ability to restrict wall deformation.

Photo 1. IPS earth retention system in trench excavation

4.2 *Urban excavation*

The IPS earth retention system was selected for temporary earth support in apartment complex building in Anyang in Korea. Apartment complex building comprises 17 stories of superstructure and two levels of basement. 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.

4.2.1 *Site and subsurface condition description*
The excavation was 48 m wide, 44 m long, and 11.9 m deep. Each road 8 m, 10 m, and 30 m wide is adjacent to the site. The old houses were located in the vicinity of the construction site. The subsurface soil consists of fill from 0 to 4.0 m, silty clay with sand from 4.0 to 5.0 m, weathered soil from 5.0 to 8.0 m, and weathered rock from 8.0 m to the end of boring. The depth of the excavation ranges from 8.3 to 11.9 m.

4.2.2 *IPS earth retention system*
The cast-in-place (CIP) wall is braced internally with three levels of the IPS and corner system. The CIP wall is installed 0.4 m in diameter and in distance from center to center. Axial reinforcement with 19.1 mm in diameter and spiral reinforcement with 12.7 mm in diameter is used. The wall penetrated into weathered rock 2.5 m deep. The labiles wasserglass (LW) grouting is 0.6 m in diameter and 0.4 m in distance from center to center. The plan view of excavation is shown in Fig. 4, and the typical section of the IPS wall is shown in Fig. 5. Four IPS systems and four corner systems are closed and is braced on the wall. Details of the IPS are tabulated in Table 1.

Table 1: The IPS data

IPS		H-beam	Steel wires	Length of legs
1st level	IPS 1-3	H300x300x10x15mm	ϕ15.2mm,18EA	4.3 m
	IPS 2-4	H300x300x10x15mm	ϕ15.2mm,18EA	3.3 m
2nd level	IPS 1-3	H350x350x12x19mm	ϕ15.2mm,28EA	4.3 m
	IPS 2-4	H350x350x12x19mm	ϕ15.2mm,22EA	3.3 m
3rd level	IPS 1-3	H350x350x12x19mm	ϕ15.2mm,28EA	4.3 m
	IPS 2-4	H350x350x12x19mm	ϕ15.2mm,22EA	3.3 m

Each corner system consists of three struts (H-beams) and one channel. The length of strut and channel is 7.6 m and 4.0 m, respectively, and the section of strut is H300×300×10×15 mm at the first level and is H350×350×12×19 mm at the second and third level. The section of channel is that the depth of beam is 380 mm, and that the width of flange is 100 mm, and that the thickness of web and flange is 13 and 20 mm, respectively.

4.2.3 *Instrumentation and construction details*

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 m to 14.0 m below the ground surface.

The excavation for apartment complex building proceeds with the following sequences: 1) excavate to the depth of 3.5 m on 12th day, 2) install the IPS and corner struts at 1.5 m from the top of the wall and prestress the IPS up to 70% of the design tension load on 18th day, 3) excavate to the depth of 5.5 m on 26th day, 4) install the IPS and corner struts at 4.1 m from the top of the wall, and preload corner struts up to 50% of the design load, and prestress the IPS up to 70% of the design tension load on 32nd day, 5) excavate to the depth of 9.0 m on 40th day, 6) re-stress the IPS at 1.5 m from the top of the wall up to 100% of the design tension load on 43rd day, 7) install the IPS and corner struts at 6.8 m from the top of the wall, and preload corner struts up to 50% of the design load, and prestress the IPS up to 70% of the design tension load on 50th day, 8) excavate partially to each depth of 10.1 m and 11.9 m from the top of the wall on 54th day, 9) install the IPS wales and raker at 9.3 m from the top of the wall in the excavation area of 11.9 m deep on 64th day, 10) remove the IPS wales and rakers at 9.3 m from the top of the wall on 80th day, 11) remove the IPS wales and corner struts at 6.8 m from the top of the wall on 93rd day, 12) remove the IPS wales and corner struts at 4.1 m from the top of the wall on 115th day, 13) remove the IPS wales and corner struts at 1.5 m from the top of the wall on 128th day, 14) remove deck plates on 150th day.

Photo 2. IPS earth retention system in urban excavation

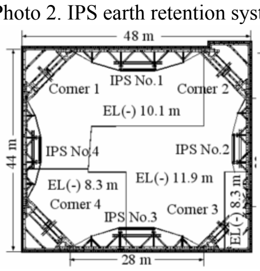

Figure 4. Plan view of excavation

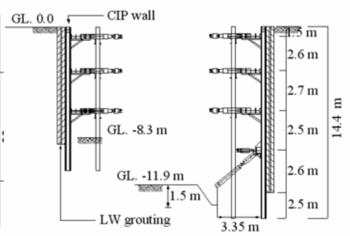

Figure 5. Typical section of the IPS wall

4.2.4 *Observed performance*

The IPS earth retention system in urban excavation performed successfully as shown in Photo 2. As can be seen on Photo 2, large workspace provided construction easiness similar to anchored excavation.

The lateral wall movements at various locations of inclinometers at the final construction stage were measured. The deflection profiles on the center of the IPS represent a bulged fashion, with maximum deflection right above the weathered rock stratum. The lateral deflection profiles on the edge of the IPS 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 average about 0.2% of the excavation depth proposed by Clough & O'Rourke (1990).

The measured loads on the corner struts at the first level vary from 15.4% to 42.3% of the Terzaghi & Peck's earth pressure loads at the first level.

5 CONCLUSIONS

This paper presented basic concept and theoretical background of the IPS earth retention system, and advantages and limitations of the IPS earth retention system. The IPS earth retention system applied in trench excavation and in urban excavation was instrumented and measured during construction. Based on the measurements, the following conclusions can be drawn:

1) The IPS earth retention system performed successfully.
2) The IPS earth retention system proved to provide large workspace and construction easiness.
3) The preloading effect of the IPS earth retention system was verified, and the prestressing of the IPS restricted the deflection of the wall. The maximum deflection of the wall did not exceed average about 0.2%, as recommended by Clough & O'Rourke (1990).
4) The measured load on the corner struts was approximately from 15.4% to 42.3% of the design load proposed by Terzaghi & Peck (1967).
5) The excessive stresses or buckling of structural members of the IPS earth retention system were not notified. The stresses on the IPS and corner struts were within the allowable stresses.

ACKNOWLEDGMENTS

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