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Development and Structural Assessment of Joints of Permanent Uni-Wall System and Floor Systems in Substructure

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Abstract

Recently the Permanent Uni-wall System (PUS) has been developed which improved the disadvantage of the Cast-In-Place Concrete Pile (CIP) and could be used as permanent retaining wall. In this study, joints between PUS and floor systems were developed. From analyses of the characteristics of design and construction of PUS, shear friction reinforcements with couplers were adopted for shear design of the joints. Twelve types of joints were developed which were classified according to the types of floor structures, wale, and piles of PUS. Two typical joints were tested and the joints showed satisfactory behaviors on the points of shear strength, stiffness, and serviceability. Especially the shear strengths were much higher than the design strengths due to the shear keys which were by-products in splicing shear reinforcements. However, the shear strength of the joint is recommended to be designed by only shear friction reinforcement because shear key is not reliable and too brittle.

Keywords : CIP, uni-wall method, retaining wall, shear friction, wall-floor joint

1. Introduction

Cast-In-Place Concrete Pile (CIP) is a soil retaining wall that uses a series of circular piles as retaining walls. CIP is being used widely because of easy construction and relatively low noise and vibration. However, because CIP requires a large construction tolerance for vertical bars and each pile is set in place independently, it is difficult to secure continuity between the piles. Due to the disadvantage of the discontinuity between piles, CIP retaining walls have not been used as permanent structures in spite of its high stiffness for lateral pressure. Consequently, the numerous CIPs that have been buried and abandoned have led to waste of materials and environmental degradation.

For the efficient usage of resources and economic improvement of underground construction, studies are needed to employ CIP retaining walls as permanent structures rather than just as temporary installments. The majority of such studies so far have focused on integrating reinforced concrete into temporary retaining walls such as CIP [1, 2]. Diaphragm walls have also been widely employed as retaining walls as well as permanent walls. However, such methods require heavy equipments and facilities, lengthening of

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construction period, or pose the problem of low constructability. In this study, as part of the development of the PUS (Permanent Uni-Wall System) method [2, 3] which improves on the CIP so that it could be used as a permanent structure, joints between PUS and floor systems were developed. To utilize the PUS which has already been constructed as a permanent retaining wall, the floor systems of the basement floor has to be connected with the PUS. The joints that connect the PUS with the floor systems have to have details that are appropriate to the shape and function of the PUS and the type of the floor system. In addition, the joints must conduct satisfactorily the structural functions that are required of them.

In this study, the functions and features required for the PUS and floor systems were investigated and then the available types of joints were classified. Furthermore, the classified joint types were developed and the design methods for the joint types were suggested. Finally, structural tests on representative joint types were conducted and the joint design methods were verified.

2. PUS (Permanent Uni-wall System)

The Uni-wall method [1] is a modification of the CIP method. It improves upon the CIP by solving the major problems of vertical tolerance and discontinuity between piles seen in the CIP due to independent construction of each pile.

In the Uni-wall method, normal casings and special casings are used to drill four to five piles continuously. Then, the drilled piles are placed at the same time and a continuous monolithic panel is formed. Thus, unity is achieved among the piles.

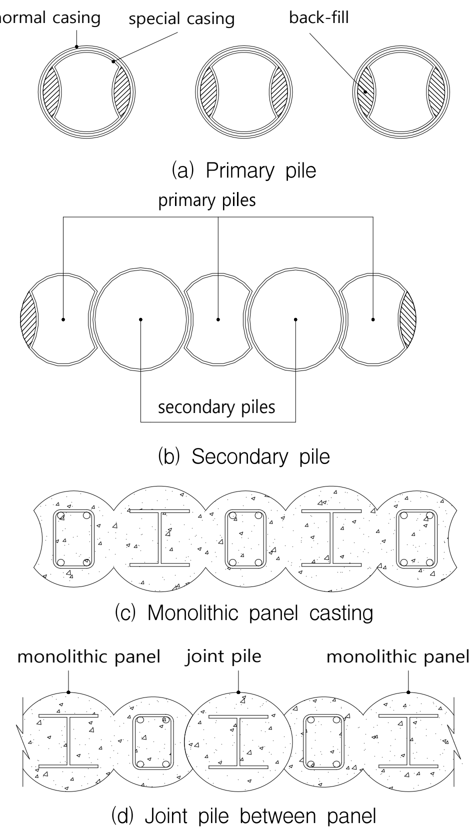


Figure 1. Construction Sequence of Uni-wall system

Figure 1 shows the sequence of constructing a monolithic panel using the Uni-wall method. It shows the process of how five piles are constructed in continuity. The construction of each phase is described below.

a) Primary pile: After normal casing is installed, special casing is inserted. During insertion, to fix the location of the special casing and to secure vertical angle, soil is filled up between the special casing and normal casing and then normal casing is removed.
b) Secondary pile: Holes along the two special casings that have been filled up with soil should be drilled. Then the normal casing is inserted.
c) Monolithic panel casting: Reinforcement such as I-shape steel or re-bar caging is inserted inside the normal casing and special casing.

Then concrete is simultaneously poured into each pile. Casings are pulled out to cast a monolithic panel.

d) Joint pile between panel: The joint between panels are connected using circular piles reinforced with I-shaped steel or re-bar. At that moment, a cold joint is formed between the joint pile and the existing panels.

Since Uni-wall method induces after-drilling along the concave side of the special casing already in place, maintenance of verticality and continuity of piles becomes easy. In addition, because of the huge benefit of water barrier due to the overlapping of the concrete piles, the Uni-wall method is widely being used as underground barrier walls without additional reinforcements. PUS is a method of adding performances required for permanent substructures to a Uni-wall formerly used only as a retaining wall.

3. Development of Joints of PUS and floor system

When PUS is used as the permanent wall, the floor system is directly connected to the PUS. Since PUS is first constructed before the floor systems are formed, special details for joining the PUS to the floor systems is necessary.

The joint between the retaining wall and the floor system must transfer the horizontal load (weight and pressure of soil) applied to the retaining wall to the floor; the joint must also transfer the vertical load of the floor to PUS. Generally, for joints between high-stiffness walls and low-stiffness floor systems, shear connection is selected in consideration of the stiffness difference and construction performance.

In this study, the characteristics of the shear connection between PUS and floor system was analyzed. The joint details that can be adapted to various floor systems in accordance with required performances were proposed.

3.1 Characteristics of joints of PUS and Floor System

1) Unit construction

PUS is constructed with five piles as a basic unit. Consequently, it is rarely possible that the center of the individual piles of PUS coincide with the center of beam.

2) Maximum pile diameter: 658 mm

In case concrete is placed against hardened concrete as shown in Figure 2, bent re-bars are put into a Halfen box [4]. Since PUS is formed by a series of circular piles, the bent re-bars which have been set into the floor system cannot be embedded within PUS. Consequently, short-length embedments such as couplers have to be used.

3) Construction tolerance

Retaining walls are constructed underground. Therefore, the possibility for vertical error is high in comparison to general reinforced concrete construction. Also, horizontal error arises during pile drilling. Therefore, a joint detail with high tolerance is required.

4) Space for tremie pipe

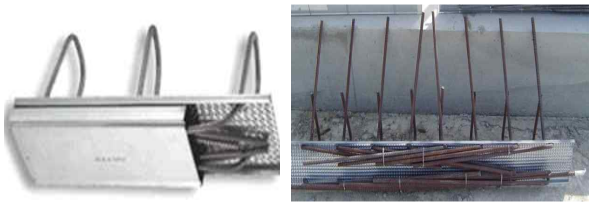
Since a tremie pipe is required to pour concrete, a detail that cuts through the inside of PUS is impossible.

5) Diversity of substructures

Various systems are employed for floor systems in substructure in accordance with the following: type of retaining wall construction method, superstructural system, ground conditions, construction period, and presence of nearby structures. Consequently, diverse details are required which can be adapted to various structural systems such as reinforced concrete structure, steel structure, steel reinforced concrete structure, precast structure, and flat-plate structure. Additionally, details have to account for the presence of wale.

6) Cost

To secure cost effectiveness in comparison with other construction methods, the use of special material should be ruled out. Rather, by utilizing re-bars and other existing materials, cost of materials should be minimized. To allow construction by general workers, as opposed to technicians, welding in place should be avoided. Instead, simple tasks should be able to complete the construction. There is the need to minimize both construction costs and period.



(a) Halfen rebend Connection (b) Application of rebend connection

Figure 2. Rebend connection for re-bar connection

3.2 Analysis of existing methods

For joints to connect the retaining wall which is first constructed with the floor system that is installed later, there are two types of construction methods according to the type of retaining wall.

In case the floor system and the retaining wall are reinforced concrete structures, bent re-bars for splicing are wrapped in either thin steel plates or Expanded PolyStyrene (EPS) and then embedded in the retaining wall. After excavation, the thin steel plates or EPS are removed. Then the bent re-bars are straightened out and then used as connection with the floor re-bar or used as shear friction re-bar. However, since circular piles are used as the basic units for PUS, there is too little room for embedding the bent re-bars and installment is impossible.

In case the retaining wall is steel frame or steel frame reinforced concrete, headed studs are used to integrate the wall with the floor system. When the headed stud is installed at the factory, the risk for damage during delivery and construction is high. If welded on site, then adequate electric power and work by a technician are required. Additionally, the standardized products have low yield strength and there is risk of increasing number of installments.

3.3 Design of joint using shear friction re-bar

In consideration of PUS characteristics and required performance of joints, a shear friction using coupler is employed to support the shear force. When the tension member that is placed perpendicularly to the joint side generates tension, then the compressive force corresponding to the tension is applied as the couple of force. When that compressive force is multiplied by the friction coefficient of joint surface, the shear friction strength of the joint surface can be obtained.

In the reinforced concrete pile of PUS, the re-bar anchorage which has the coupler can be embedded. In steel or steel reinforced concrete piles, couplers are welded onto the flange. After PUS construction, the coupler can be found at the location where the floor system is installed. Then the coupler is spliced with a shear friction re-bar.

When the coupler is welded onto the flange, the coupler should be covered in elastic material in order to prevent damage to the coupler during construction and for easy locating of the coupler. In case of reinforced concrete piles that have the shear friction re-bar anchorage embedded in them, the risk of damage or repositioning during construction process is high if individual couplers are embedded. If damage or repositioning occurs, it is difficult to locate the coupler during floor system construction. Furthermore, since the coupler direction is twisted, installment of shear friction re-bars becomes difficult. Therefore, as shown in Figure 3, a steel plate [5,6] which has all the couplers to be used for a single pile fastened onto it is developed. Then installment and locating of couplers become easy and coupler damage during construction can be minimized.

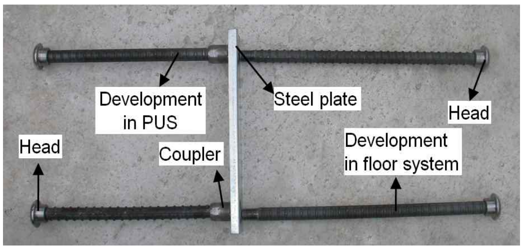


Figure 3. Assembly of Steel Plate for Re-bar connection

In consideration of the sectional characteristic of PUS which has limited diameter and space for tremie pipes, headed bars were used for the anchorage of shear friction re-bars in place of standard hooks. By using headed bars, interference between shear friction re-bars during coupler fastening was eliminated. Since up to SD400 can be utilized as shear friction re-bars, high shear force can be support by less quantity than in comparison to headed studs. Additionally, since normal re-bars and couplers are used, general workers can conduct the construction. There is also the benefit of easy supply of materials.

Using Eq. (1) of KBC2009 for shear friction design, the shear strength is calculated [7, 8, 9]. The anchorage length design of the headed bars is determined according to Eq. (2) given in Section 126(2) of ACI 318-08 [10].

$$\phi V_{nsf} = 0.75\mu A_{st} f_y \quad \text{----- (1)}$$

$$l_{dt} = \frac{0.19 f_y}{\sqrt{f_{ck}}} d_b \quad \text{------- (2)}$$

where, V_{nsf} is nominal shear friction strength, ϕ is strength reduction factor 0.75, μ is friction coefficient 1.0, A_{st} is cross sectional area of shear friction re-bar, f_y is specified design yield strength of shear friction re-bar, l_{dt} is development length of headed bar, and f_{ck} is concrete strength.

To connect the coupler installed on PUS with the shear friction re-bar, a concrete block-out is required as shown in Figure 4. The concrete block-out acts as the shear key between PUS and the floor system and contributes to transfer the shear force. As shown in Figure 4, the concrete block-out forms a 60° angle between the coupler side and the external side of PUS. Concrete is blocked out with high density high elasticity material. To secure safety and constructability for PUS during construction phase, it is advisable to minimize the depth of the concrete block-out. The shear strength due to the shear key is evaluated by following Eq. (3) in accordance with the structural standard for precast concrete prefabricated buildings [11].

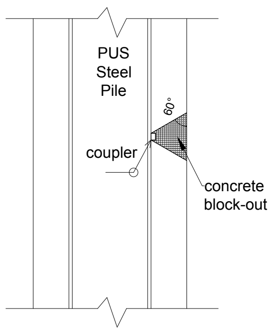


Figure 4. Coupler for Re-bar Connection in PUS Steel Pile

$$\phi V_{nk} = 0.85 \times 0.2 f_{ck} A_j \quad \text{-------- (3)}$$

where, V_{nk} is nominal shear key shear strength, ϕ is strength reduction factor of 0.75, A_j is shear key area.

3.4. Proposed joints of PUS and floor system

3.4.1 Classification of joint types

Table 1 shows the classification of joints in accordance with types of floor systems, wale, and

PUS pile. Since PUS consists of several circular piles, there is high possibility that the center of the piles do not line up with the center of the shear friction re-bars. Such cases were differentiated from cases when the center of PUS pile coincides with center of shear friction re-bars and classified as separate types of joints. The explanations for the joint names are given in Table 1.

3.4.2 Design conditions

The load conditions of the structures required for the joints are identical to those of the previous study [2]. The maximum factored shear load that is applied to one joint of PUS and floor system is 270 kN.

Considering the peculiarities of underground construction, allowed vertical tolerance was set at ±150mm and horizontal tolerance at ±50mm. The minimum width for the wale was determined at 300 mm for the placement of the main re-bar and the shear re-bar. To ensure the easy construction of the wale, shear friction re-bar with diameter of 16 mm of SD400 grade was used.

3.4.3 Joint of PUS with reinforced concrete floor

Table 1. Classification of joints of PUS and floor system

Type of floor system \ Type of wale	RC	Steel	None
RC	RR-S, RR-S-E RR-R, RR-R-E	-	RO-S, RO-S-E RO-R, RO-R-E
Steel (MHS)	SR-S, SR-S-E SR-R, SR-R-E	SS	SO
Half PC	PR-S, PR-S-E PR-R, PR-R-E		
Flat plate			OO
Mat slab			MO-R

* ①②-③-E: ①-type of floor system (R-reinforced concrete, S-steel, O-flat plate, M-mat slab), ②-type of wale (R-reinforced concrete, S-steel, O-none), ③-type of PUS pile where shear friction reinforcing bars are connected, (S-steel or steel reinforced concrete pile, R-reinforced concrete pile), E represents that center of PUS pile does not coincide with center of shear friction reinforcing bars.

A floor which has reinforced concrete (RC) beam is connected to PUS using a RC wale. Figure 5 (a) and (b) show the joint of PUS with steel pile and RC pile connecting with RC floor. For connecting the shear friction re-bar, the coupler is welded onto the flange of steel pile. Steel plate for re-bar connection is installed on the RC pile.

3.4.4 Joint of PUS and steel integrated floor or PC floor

Floors consisting of steel beam or PC beam can be connected to PUS using RC wale as shown in Figure 5 (d), (e), and (g). The joining of PUS and RC wale is identical to that of RC beam in 3). The steel beam and wale are joined by shear connection and headed studs are used.

When using steel wale for fast construction, a bracket can be installed on PUS steel pile as shown in Figure 5 (f) and then the steel frame wale can be placed on the bracket. To transfer later load from PUS to slab, a back-filler is installed between PUS and the steel frame wale. For the steel beam and wale, on-site weld is done only on the web for securing shear connection.

3.4.5 Joint of PUS and flat plate

For flat plates, RC wale can be used to connect the floor to PUS in the same way as Figure 5 (a), (b). In case there is no wale, it is difficult to secure precise vertical levels. Consequently, post-installed anchors are used for shear connectors as shown in Figure 5(h). The diameter and spacing of the post-installed anchors are determined by the magnitude of the shear force that has to be transferred from the floor system to PUS. Since shear force is not big in general floor systems, post-installed anchors are set in minimum spacing of 600 mm.

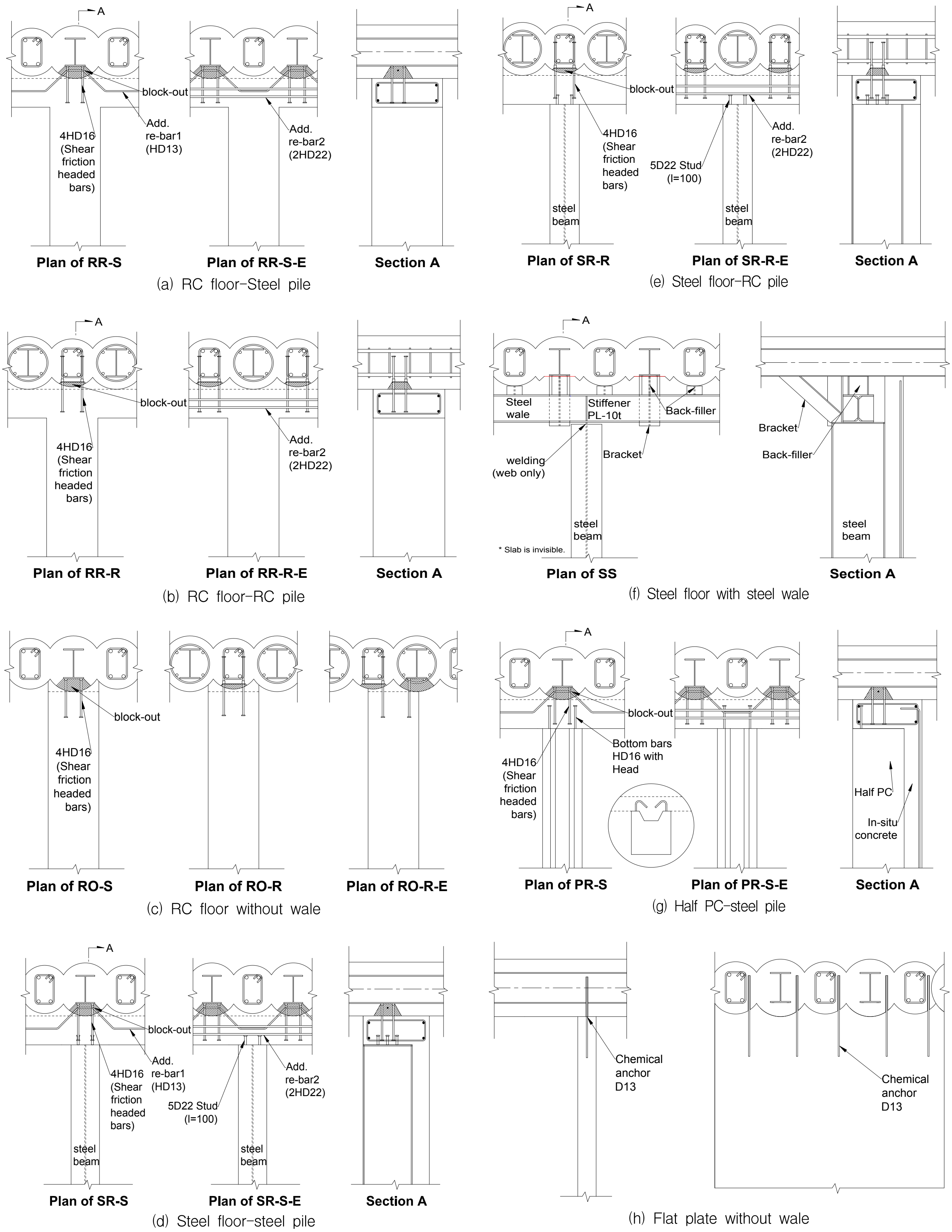


Figure 5. Proposed joints of PUS and floor system

4. Experimental Evaluation of Joint between PUS and RC floor system

4.1 Objectives of test

In regards to the joints of PUS and floor systems developed in chapter 3, tests on the joints were conducted to achieve two objectives: 1) confirm whether the shear performance meets up to expectation and 2) establish a rational design method by which the shear strength of the joints could be predicted.

For evaluation items, the shear strength of the joint between PUS and floor system was selected as the main item of evaluation. In addition, serviceability such as cracks and deflection at service load were also investigated. Furthermore, it was also observed whether there were any damages done to the wale and PUS to see if there could be any unexpected additional damages before the collapse of the joints.

4.2 Joint types

Of the joints developed in chapter 3, performance evaluation is unnecessary for the steel frame bracket because the path of load transfer and design concept are both clear. Therefore, two joints among the shear friction design types were selected that are anticipated to be most frequently used in actual structures.

4.2.1 RR-S-E

This joint is forecasted to be employed widely. Re-bar for shear friction is connected with a coupler to the reinforced concrete pile of PUS and the joined to the floor system. In the standard design shown in Figure 5, additional re-bars were placed for reinforcing the concrete block-out. However, because shear capacity may be enhanced with the additional re-bars, they were eliminated in the testing. Since the possibility that the center of the beam and the center of the steel pile will not align is high, an eccentric joint was selected for the specimen.

4.2.2 RR-R-E

In case the PUS pile is designed as a SRC pile, it is not easy to install a concrete block-out to connect the shear friction re-bar to the steel frame flange. Consequently, steel plate for re-bar connection is installed on the RC pile. As with the RR-S-E type, the case in which the center of the beam does not align with the center of the RC pile was selected as the specimen.

4.3 Experiment program

4.3.1 Test method

A test setup shown in Figure 6 was designed to apply the designed shear force to the joint and to minimize the bending moment. A hinge was placed at the end opposite to the joint side to prevent deflection and minimize bending moment that may be generated due to rotation.

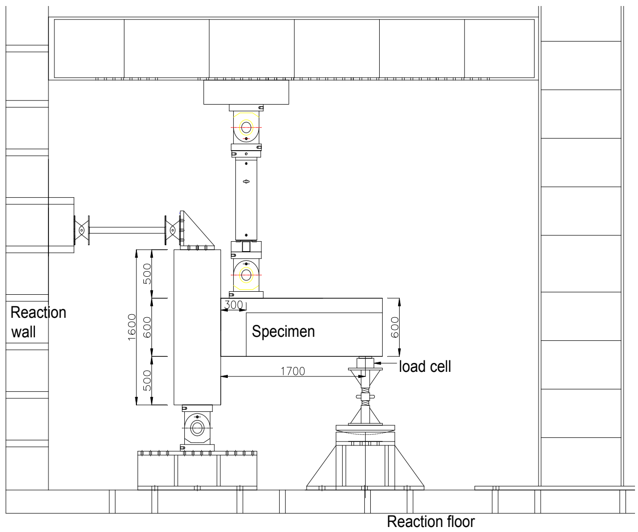


Figure 6. Test setup

4.3.2 Design of specimen

The shear failure of the joint surface was configured as the final failure and the floor system and PUS were designed to stay at elastic states until the final failure.

Shear force (V_u) of 270 kN and bending moment (M_u) of 0 kN · m, both figures computed from the standard plane in chapter 3, were selected as the design load of the joint. D 16 re-bar of SD 400 grade was chosen as the shear friction re-bar. The design strength in accordance with the structural concrete design code is 239 kN and is lower than the design load by 11.5%. However, if the strength reduction factor is eliminated and over-strength of the material is considered, then the strength is expected to be 398 kN as seen in Eq. (4). Concrete was designed at 24 MPa, which is used widely in actual retaining walls and floor systems.

$$V_c = \mu A_{st} \alpha f_y = 1.0 \times 796 \times \frac{1.25 \times 400}{1000} = 398\text{kN} \quad ---(4)$$

where, V_a is actual strength in consideration of the over-strength of the material and α is over-strength coefficient of the re-bar which is 1.25.

For the anchoring of the shear friction re-bar, headed bars were used in place of the standard hooks in order to prevent interference with nearby

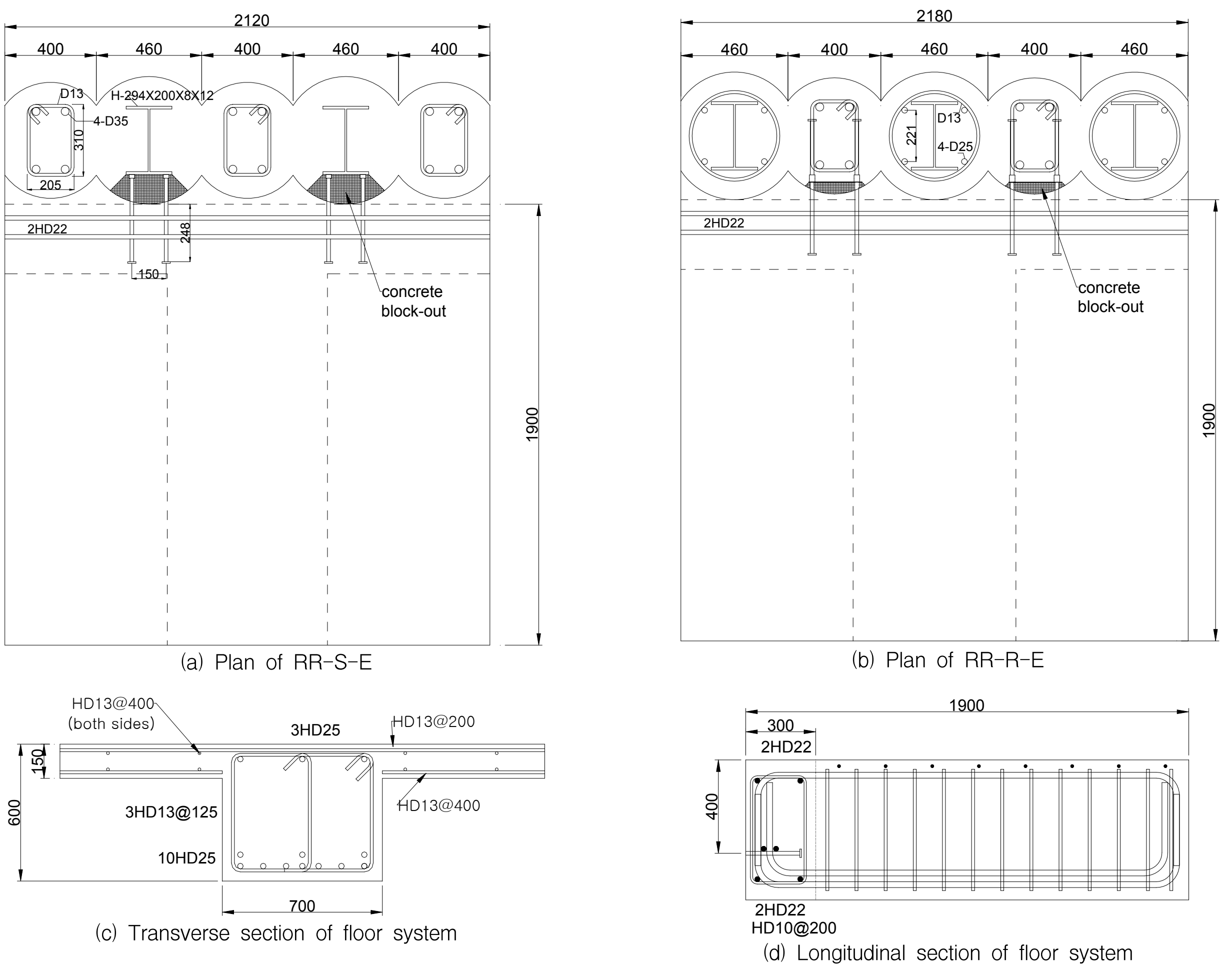


Figure 7. Details of specimens

re–bars during fastening of the couplers. In accordance with the design equation for mechanical anchoring lengths given in ACI 318–08 12.6, anchoring length of 248 mm was secured from the joint surface.

PUS was made according to actual constructible sizes. Normal casing was made to be 550 mm and special casing was at 500 mm. As can be seen in Figure 7, PUS for the specimen is formed by five piles. Wale was arranged with minimal re–bars. 2 HD 22 were used for both top and bottom main re–bars. For shear reinforcement, HD10@200 was used.

Actual construction sequence and direction for concrete pouring were followed in constructing the specimen. PUS was first made and then the floor concrete was poured. Other specifications regarding the specimen are given in detail in Figure 7.

4.3.3 Plan for measurement

The load applied to the joint surface was set as the reference. Cracking was checked at every 50 kN. After exceeding the service load, cracks were checked at every 100 kN units. Displacement transducers were installed in two places left and right of wale – to measure the relative vertical displacement of PUS and floor system at the joint. Of the four shear friction re–bars, strain gages were attached to check upon the yield of the shear friction re–bars. The points of attachment of the gage were the joint surface, 50 mm from joint surface to PUS, and 80 mm from joint surface to wale. At each point, the gages were attached to both sides

4.4 Test results

4.4.1 Material test results

The design and measured properties of the re–bars and concrete are summarized in Table 2. The measured concrete strength of the floor system was 40.5MPa and higher than the design strength. Yield and tensile strength of shear friction re–bar D16 were 522 MPa and 646.7 MPa respectively.

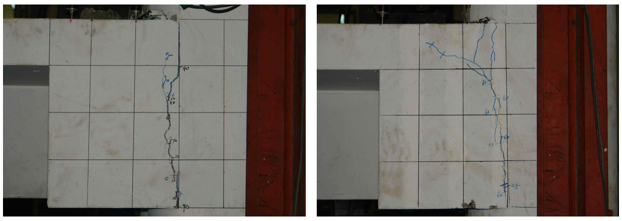
Table 2. Design and measured material properties (MPa)

Concrete	Design strength	Measured strength	
PUS	24	28.7	
Floor system	24	40.5	
Reinforcing bars	**Design yield strength**	**Measured yield strength**	**Measured tensile strength**
D13	400	546.3	653.0
D16	400	522.0	646.7
D22	400	518.0	749.3
D25	400	437.3	631.7

4.4.2 Observed behavior

Only fine cracks were observed for both specimens at the joint surface up to peak loads. At peak loads, relative vertical displacements were significantly generated at the joint between the floor and PUS and strength was drastically reduced. Figure 8 shows photos of the joints at service load (V_s=162kN) and peak loads. No cracks were observed at service load. The relative vertical displacements at the joints at service load were very small at 0.25 mm for RR–S–E and 0.24 mm for RR–R–E as can be seen in Figure 9. For RR–R–E, vertical crack was observed at the joint surface at 441 kN; however, the crack width was very small. The crack propagated upwards but there was almost no change in the crack width. For both specimens, all failures occurred along the circular surface of PUS.

(a) RR-S-E at service load (160kN) (b) RR-R-E at service load (160kN)



(c) RR-S-E at peak load (1,016kN) (d) RR-R-E at peak load (632Kn)

Figure 8. Crack propagation and failures of specimens

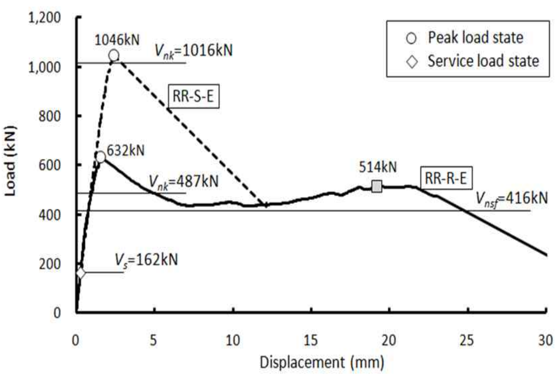


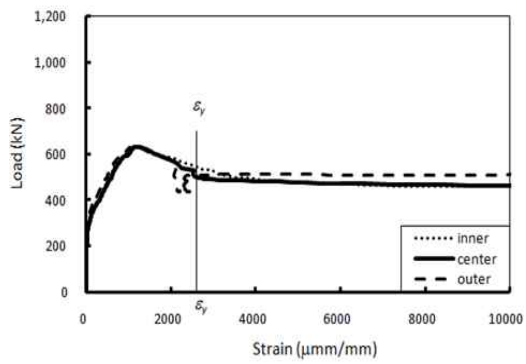
Figure 9. Load displacement relationships

4.4.3 Shear performance of joint

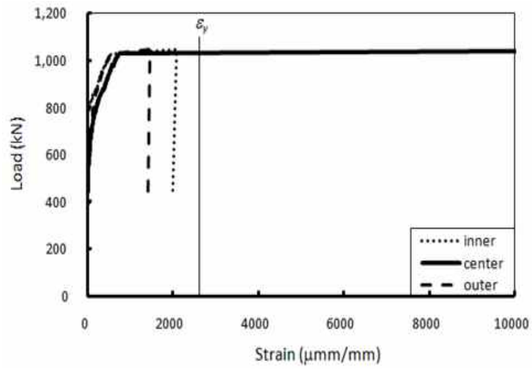
Figure 9 shows the load displacement relationship at the joint. For RR-S-E, strength was suddenly reduced at peak load of 1,046 kN; thus the test was terminated. For RR-R-E, strength was reduced at peak load of 632 kN. But afterwards, the joint stably possessed strength of over 400 kN. Additionally, at relative displacement of 19.2 mm, the joint failed after generating secondary maximum strength of 514 kN.

The nominal shear friction strength (V_{nsf}) which reflects the measured material strength of Table 2 is 416 kN. Both specimens satisfactorily exceeded the nominal strength. The shear friction strength computed based on the tensile strength of the shear friction re-bar is 515 kN. This value coincides with the secondary peak load of the RR-R-E specimen.

Figure 10 shows the strains of the shear friction re-bars where center represents the strain measured at the joint; inner at 50 mm from joint surface towards PUS and outer at 80 mm from joint surface towards wale. RR-S-E showed low stress levels of 600Omm/mm until peak load; at peak load, however, the specimen yielded instantly. For RR-R-E, strain was 1,100OOmm/mm at peak load; afterwards, the specimen did not yield right away. Only after additional relative displacement, the specimen reached yield strain ($\mathscr{M}_y$).



(a) RR-S-E



(b) RR-R-E

Figure 10. Strains of shear friction reinforcing bars

This means that peak load is not generated by shear friction re-bars. To install shear friction re–bars, a concrete block–out is formed on PUS as shown in Figure 7 (a), (b). The block–out acts as a shear key. Since failure occurred along the curved surface of the PUS, the shear key area (A_s) could be computed by multiplying the height of the shear key by the length of the curved surface. The size of one shear key is as follows: for RR–S–E, height 172 mm, length 365 mm, and area 62,708mm^2; for RR–R–E, height 117 mm, length 257 mm, and area 30,062 mm^2. Since for the RR–S–E the concrete block–out is formed from the steel frame flange, the shear key area is approximately double that of RR–R–E.

When nominal shear strength is evaluated according to the structural design standard and commentary for precast concrete building [11], the strength is 487 kN and 1,016 kN for RR–S–E and RR–R–E, respectively.

The nominal shear strength of the shear key is shown in Figure 9. For the RR–S–E specimen, peak load and shear key strength was almost the same. For RR–R–E, peak strength 30 % higher than shear key strength was developed.

Since shear key area is large for RR–S–E, the strength and stiffness were significantly high. It was also found that peak load was mostly generated by the shear strength of the shear key. On the other hand, because RR–R–E has relatively smaller shear key area than RR–S–E, the stiffness of vertical relative displacement was low. Consequently, deformation of the shear friction re–bar is possible. Therefore, for the RR–R–E specimen, the shear friction re–bar seems to have partially contributed to shear capacity.

Through analyzing strains of shear friction re–bars and nominal shear strengths, the followings are found: 1) shear strengths of specimens are developed by the shear key of the concrete block–out and 2) residual strengths are obtained by shear friction strength.

4.5 Proposed joint design method

Test results showed that the shear key strength of the concrete block–out is very high and does not maintain strength after reaching peak strength. On the other hand, since shear friction strength is developed due to tensile deformation of the re–bar, its stiffness is relatively low in comparison to shear key strength and it is very ductile. Due to difference in stiffness, two strengths cannot be developed at the same time. Therefore, using only one strength as the design strength is suggested.

Because of construction characteristics of PUS being installed underground, it is difficult to maintain accurate size of shear key. Therefore, it is recommended that joint shear be designed as shear friction strength.

5. Conclusion

To develop the PUS(Permanent Uni–Wall System) method, which improves upon the CIP method that uses temporary retaining walls and allows for permanent retaining walls, joints of PUS and floor systems were developed. Additionally, through structural tests on representative joints, design and construction methods were verified. The following conclusions were reached through this study.

1) PUS and floor system were designed as shear connection in consideration of the difference of stiffness between PUS and floor system. Due to circular shape of piles, the shear friction re–bars were connected by couplers.
2) Twelve joints were classified according to types of floor systems and wale and the types of piles that consists PUS. Details for each joint type were provided.

3) Shear performance was evaluated for joints with RC floor system and RC wale. The joints showed satisfactory behavior the points of shear strength, stiffness, and cracks and deflection at service load.
4) The concrete block-out for the installment of shear friction re-bars acts as shear key of the joint. Consequently, shear strength exceeding design strength was secured. Although shear keys have high strength and stiffness, they are brittle. Additionally, because of the characteristics of underground construction, it is difficult to precisely construct the concrete block-out. Consequently, shear key strength should be considered as reserve strength. It is suggested that shear friction strength is used solely for the shear strength of joints.

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