IPA News Letter Volume 9, Issue 3 September 2024

Interview Report

Permanent steel-concrete composite retaining wall utilizing the press-in piling method

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1. Forward

In the Japanese architectural field, retaining structure materials are specified as "RC, masonry or similar corrosion resistance materials" in the Building Standard Acts. Therefore, these materials are routinely and exclusively used for permanent retaining structures in the Japanese architectural field. On the other hand, steel walls, such as sheet pile walls and tubular pile walls, are normally used as temporary retaining structures in order to construct permanent RC substructures.

However, this traditional system often requires a relatively large amount of space for substructures. This is because the overall thickness of a substructure comprises a temporary retaining wall and a permanent structure. On the other hand, it is seen that applications of sheet pile walls and tubular pile walls for permanent retaining structures are gradually increasing mainly for the following reasons.

1) The recent development of more rigid and robust sheet piles.
2) The development of piling techniques for high modulus piles.
3) The expansion of composite design practices between steel and concrete in retaining wall design.

This report focuses on the future prospect of steel retaining walls for permanent use, based on recent case histories. These maximized land use by utilizing high modulus steel piles, state-of-the-art press-in piling technologies and composite retaining wall design practices.

<u>Overview of the project</u>

Project: Kyoto Higashiyama Project (Kyoyamato & Park Hyatt Kyoto)
Location: Masuyacho, Higashiyama-ku, Kyoto-shi, Kyoto, Japan
Interviewee：Takenaka Corporation (Owner & Developer, Project Planner, Designer and Building Contractor)

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2. Scope of work

The project was the construction of new hotel buildings in Kyoto, the tourism capital of Japan. The buildings comprise 2-4 storey buildings and 1-2 level basements. The construction site was located on a steep slope with the height difference being approximately 30m and was adjacent to an existing building. Fig. 1 and Fig. 2 show the layout of the hotel complex. Due to the Kyoto City Landscape Policy, which was implemented in 2007 to retain Kyoto's magnificent landscapes for future generations, all building heights are restricted. Therefore, in order to provide enough hotel space, a relatively deep basement was required.

The requirement necessitated the construction of a retaining wall alongside the east boundary with a retained height of up to 13m. The working conditions were unfavorable for traditional retaining walls. As such, a solution using a high modulus permanent steel-concrete composite retaining wall and the press-in piling method were selected and approved.

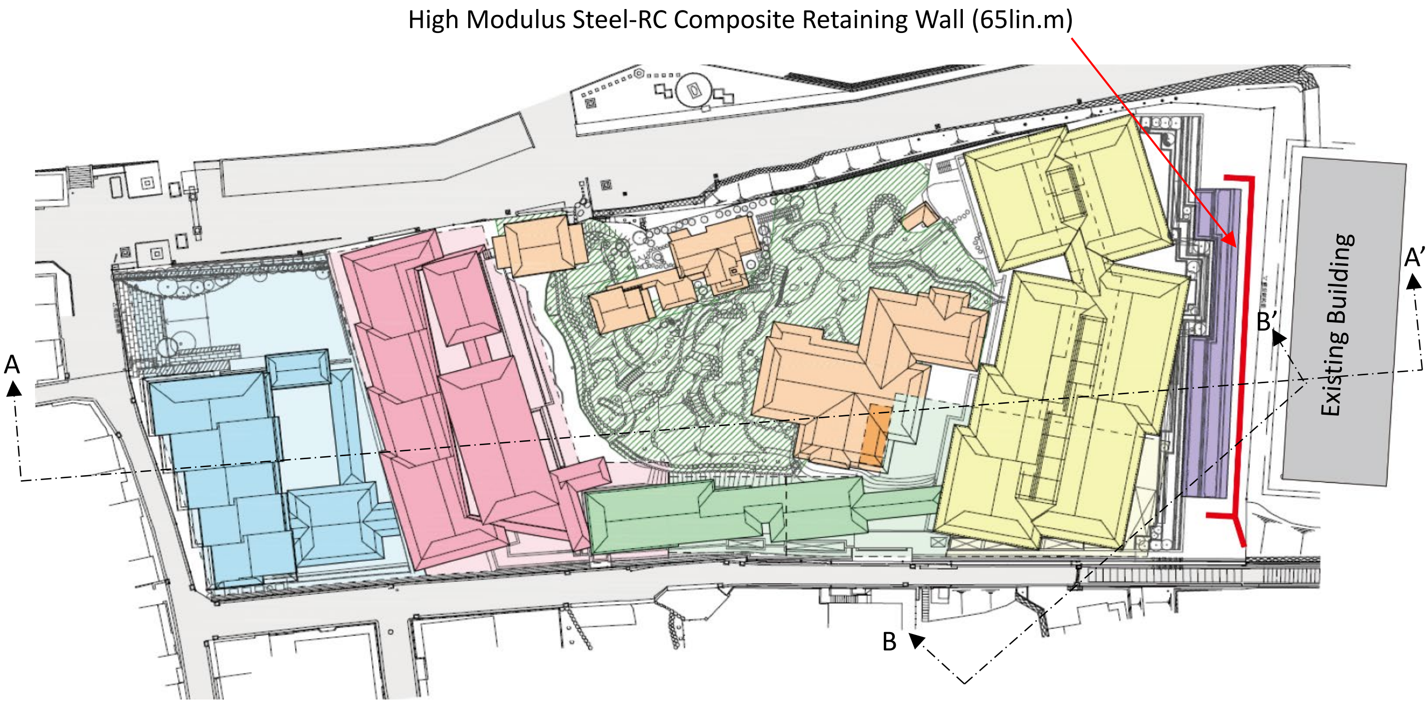

Fig. 1. Building Complex Layout Plan

<u>Overview of high modulus steel-concrete composite retaining wall</u>

- Temporary condition: 37no. steel tubular piles 1,500mm O.D. x 25mm w.t. L=27.6m (2 splices) + temporary ground anchors
- Permanent condition: Composite retaining wall (steel tubular pile wall + L-shaped RC retaining wall)

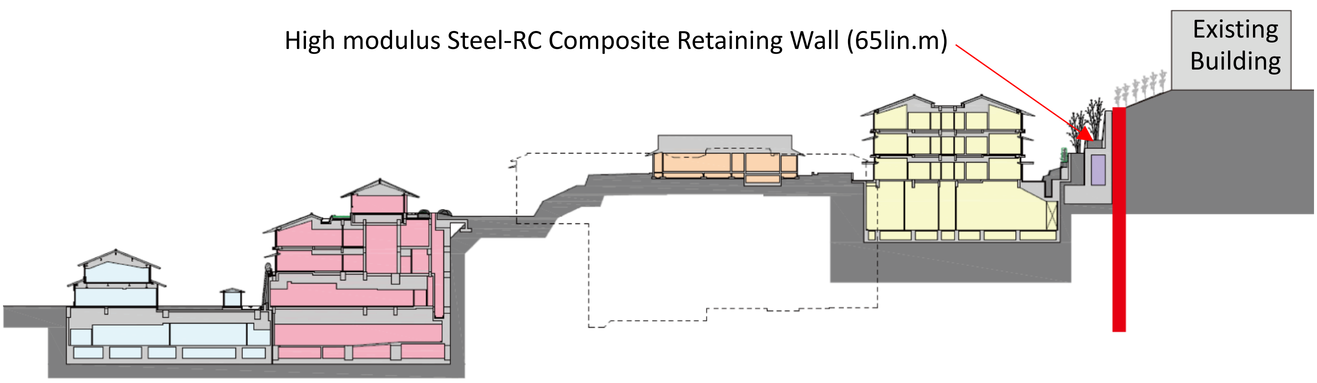

Fig. 2. Longitudinal Section of Building Complex (Section A-A')

3. Ground conditions

The project site is located on a diluvium formation. Underneath the surface soil layer of Fill (F), the following soil layers are underlying from the top.

1) Gravel mixed sandy clay (dt, SPT N=6-15)
2) Silt mixed sandy gravel (Dg2-c, SPT N=10-43)
3) Sandy clay (Dc-2, SPT N=15-24)
4) Clay mixed sandy gravel (Dg3-c, SPT N>60, maximum extrapolated SPT N=250)

At the design stage, as the proposed formation level was +34mAOD, it was expected that the retaining wall would need to be installed into the very dense sandy gravel layer (Dg3-c). Also, a relatively large earth pressure was anticipated since the Cu (undrained shear strength) of the approximately 10m thick sandy clay layer (dt) is rather low (32-82kN/m^2).

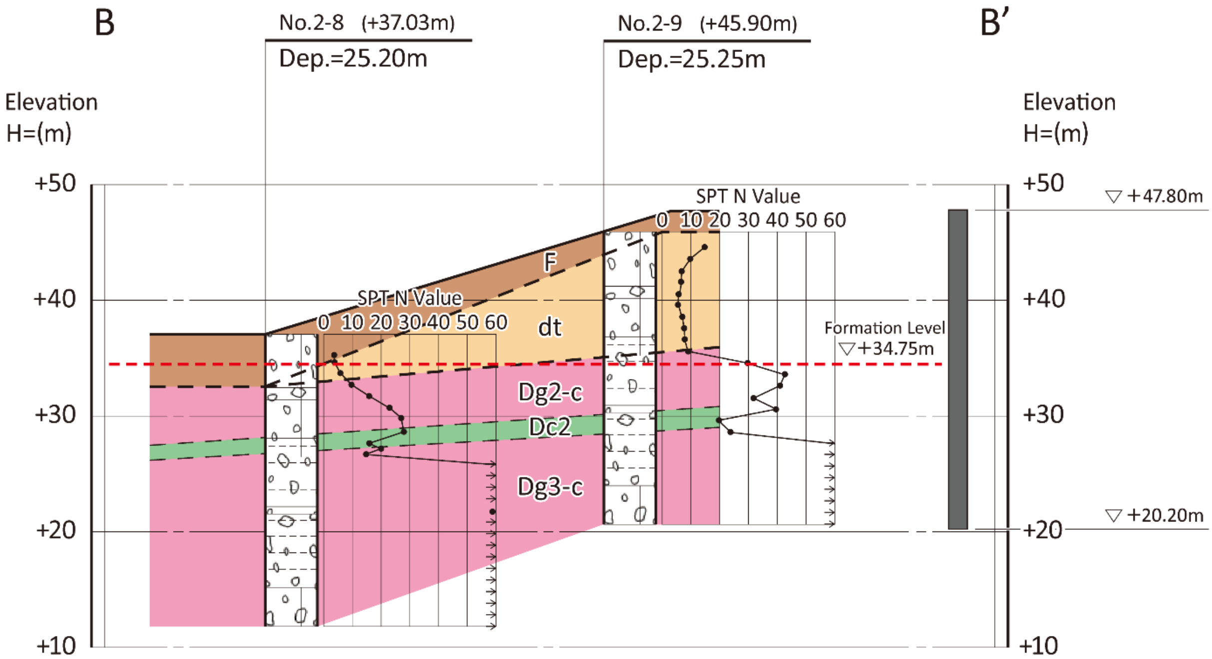

Fig. 3. Longitudinal Geographic Section (Section B-B')

4. Selection of retaining wall type and construction method

The construction of the new buildings required a retaining wall with a retained height of 13m along the east boundary. Due to difficult working conditions along the east boundary, it was not feasible to install a conventional king post pile wall as a temporary retaining wall. In order to satisfy the design criteria, a high modulus temporary/permanent dual use retaining wall composed of a steel tubular pile wall and an L-shaped RC wall was adopted (Fig. 4 and Fig. 5). Regarding the construction method, the Gyropress Method^{TM} (Rotary Press-in Method) was selected to overcome the difficult conditions. On the project, the primary factors in selecting the retaining wall type and construction method were as follows.

1) A deeper basement than the depth of foundation piles of the adjacent building was required.
2) The use of permanent ground anchors was not permitted due to the presence of adjacent properties. Thus, the 13m free-standing retained height was required permanently since the ground anchors were removed after temporary use.
3) As the adjacent building was supported by a group-pile foundation, it was necessary to install ground anchors below the pile foundation. Due to this, it was not feasible to fix the most ideal position of the retaining wall i.e. the top of the retaining wall, with the ground anchors. Therefore, the ground anchors were attached to the retaining wall at the middle height of the retained height.
4) The construction site was designated as a “sediment disaster special alert area”. It was necessary to circumvent the alert by constructing a high modulus retaining wall.
5) Due to 1) – 4) above, it was not possible to construct the basement using typical traditional retaining wall system i.e. a combination of a temporary soldier pile retaining wall with ground anchors and an L-shaped RC wall.
6) The construction site was located on a steep slope with the height difference being approximately 30m from top to bottom. Therefore, a construction technique which can be carried out on a slope commencing surface needed to be selected.

7) Due to the narrow access to the construction site and working space, firstly a construction technique to overcome these constraints needed to be considered.
8) The Gyropress Method was adopted in order to satisfy the requirements stated in 6) and 7) above.

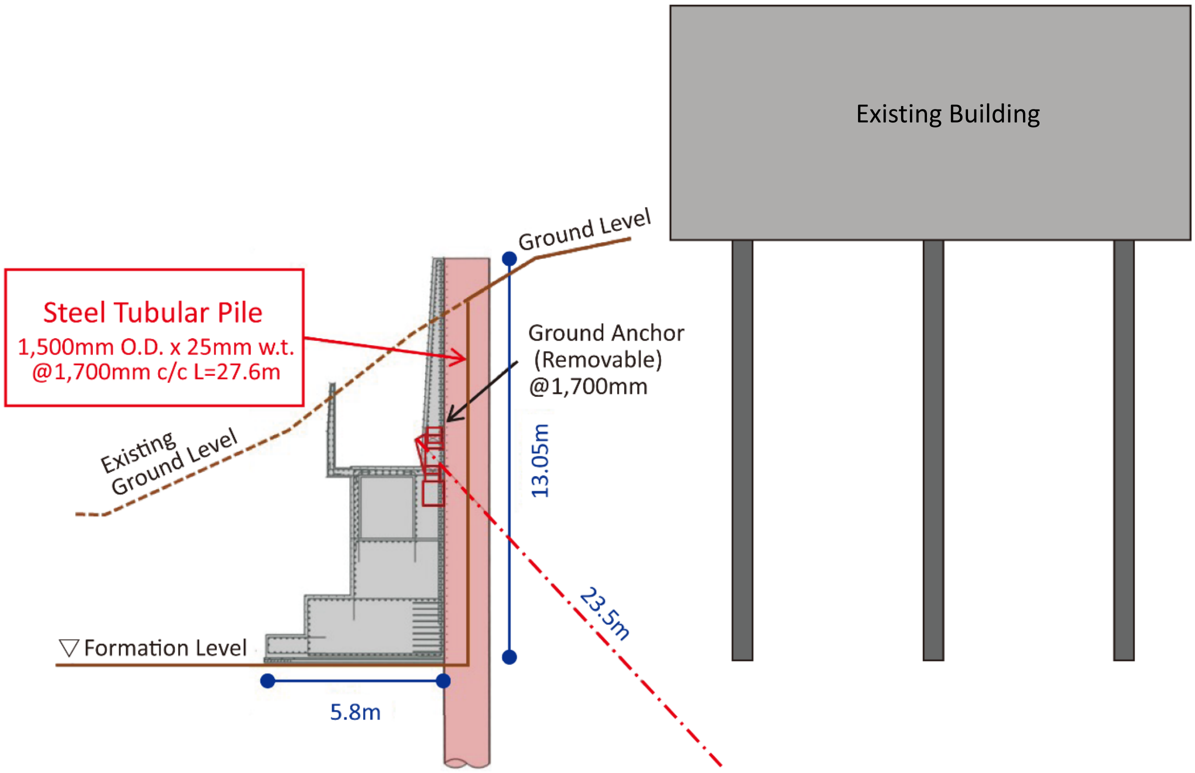

Fig. 4. Cross Section of High Modulus Steel-RC Composite Retaining Wall

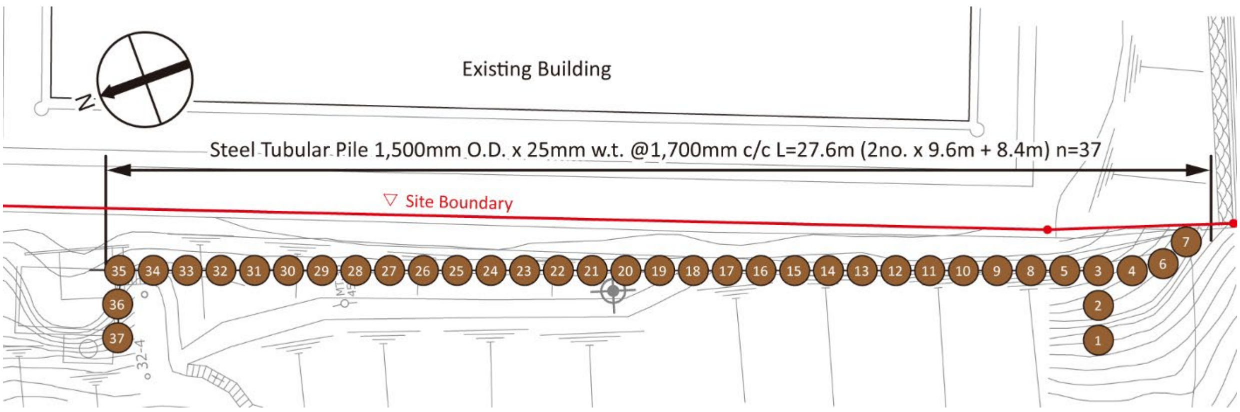

Fig. 5. Plan Layout of Steel Tubular Pile Wall

5. Design of high modulus steel-RC composite retaining wall

At the design stage, due to the required retained height of 13m, the proposed retaining wall was not considered to be a cantilevered wall, but one supported with temporary struts or ground anchors. Temporary struts were an unrealistic solution on the project taking into account location and orientation of the proposed retaining wall. Therefore, ground anchoring was the preferred option. However, due to the presence of the existing building supported by the group piles behind the proposed retaining wall, ground anchors were designed to be below the tips of the group piles. This resulted in the anchor head elevation not been set at the top of the retaining wall, but in the middle of the retained height. In order to avoid leaving ground anchors in place, removable ground anchors were used. (Fig. 5)

The retaining wall construction needed to satisfy the following criteria.

1) The retaining wall shall be rigid enough to maintain its lateral deflection to within 30mm using single level ground anchors.
2) Construction materials and equipment must be able to be delivered to the job site through the narrow access road.
3) The construction method shall be capable of installing the retaining wall into hard ground, with an extrapolated SPT N value of up to 250.
4) Construction works shall be carried out within the specified noise and vibration limits.
5) Construction works must be able to be carried out on a steep commencing surface.

To fully satisfy these criteria, a steel tubular pile retaining wall installed utilizing the Gyropress Method (Rotary Press-in Piling Method) was selected. Regarding the tubular pile profile, 1,500mm O.D. x 25mm w.t. was specified as the maximum applicable profile for the GYRO PILER™ (the press-in piling machine of the Gyropress Method), which can be delivered to the job site. However, the bending stiffness of the tubular pile wall was not sufficient against the maximum earth pressure after the ground anchors were removed. Therefore, a retaining wall design in a permanent condition with a steel-RC composite retaining wall (Fig. 6) was used. Therefore, a retaining wall in a permanent condition composed of steel tubular piles along with an RC composite retaining wall (Fig. 6) was designed. In addition, the RC structure was also designed as the base of the garden landscape as well as the structural component of the retaining wall. The bending moment acting on the steel tubular pile wall was effectively transferred to the RC structure by transferring shear force and tensile force using shear studs and reinforcing bars. As for the RC structure, an L-shaped RC wall was designed to spread the ground surcharge caused by the bending moment. It was assessed that the moment capacity of the composite wall would have an approximately 30% cushion as the actual stress ratio to the allowable stress of the reinforcing bars would be 76%.

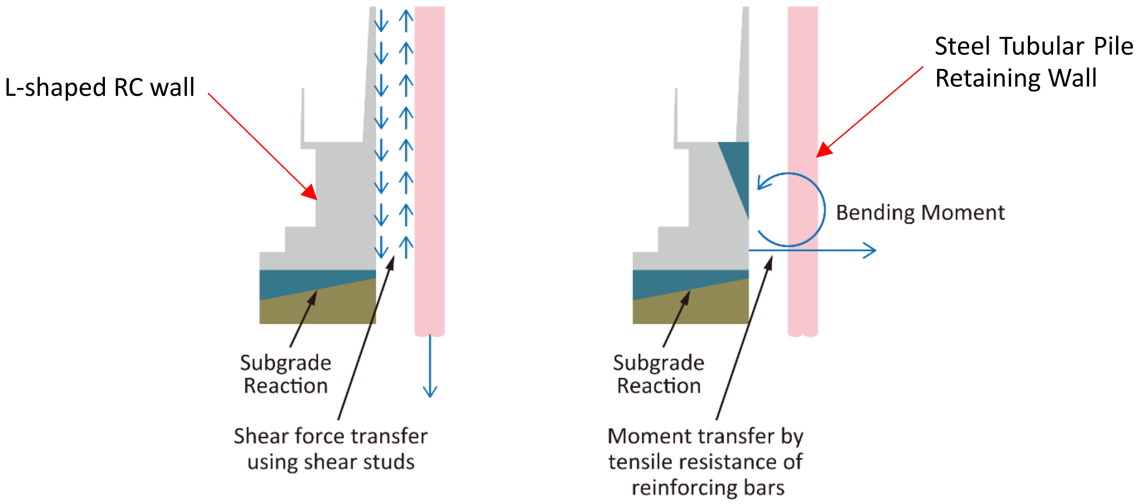

Fig. 6. Design Concept of the High Modulus Steel-RC Composite Retaining Wall

The maximum allowable lateral deflection of the proposed tubular pile retaining wall was specified at 30mm. (The general deflection limit used in Japanese building construction sites). The retaining wall was designed based on behavior analysis of the surrounding ground and the existing adjacent building. The design was approved after agreement with the owner of the existing adjacent building.

6. Construction of high modulus steel-RC composite retaining wall

1) Installation of tubular piles using the Gyropress Method

Due to the proximity of the proposed retaining wall to the site boundary line (2-4m apart), the press-in piling method was selected to minimize noise and vibration during pile installation. In addition, other defining points of the method selection were a) the press-in piling method is capable of installing piles on a steep commencing surface (Fig. 7) and b) the high exposed height of piles.

Among several press-in piling modes, the Gyropress Method (Rotary Press-in Piling Method) was selected as it is capable of installing tubular piles into hard ground.

Fig. 7. Before Tubular Pile Installation

The Gyropress Method (rotary press-in piling method) is used to install steel tubular piles. The Gyropress Method consists of axial press-in and rotation, that increases the efficiency of press-in piling. Depending on soil conditions, a suitable ring bit is attached onto the pile toe. This enables tubular piles to be installed into very hard ground and/or through underground obstacles. The GYRO PILER grasps a tubular pile with its hydraulic chuck and installs the pile using axial hydraulic press-in force and rotational torque. In order to reduce the rotational penetration resistance and prevent the forming of pile plugs, rotary press-in piling employs driving assistance using a water lubrication system. Fig. 8 and Fig. 9 below show the overview of the Gyropress Method and pile installation respectively.

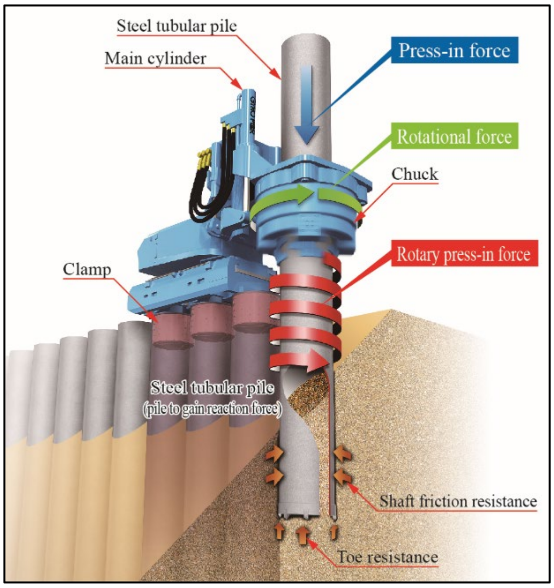

Fig. 8. Overview of Gyropress Method

Fig. 9. Pile Installation in Progress

As with other press-in piling modes, the GYRO PILER installs piles deriving its reaction force by gripping previously installed piles which are called reaction piles. The GYRO PILER can self-move above the reaction piles during pile installation. The process is shown below in Fig. 10.

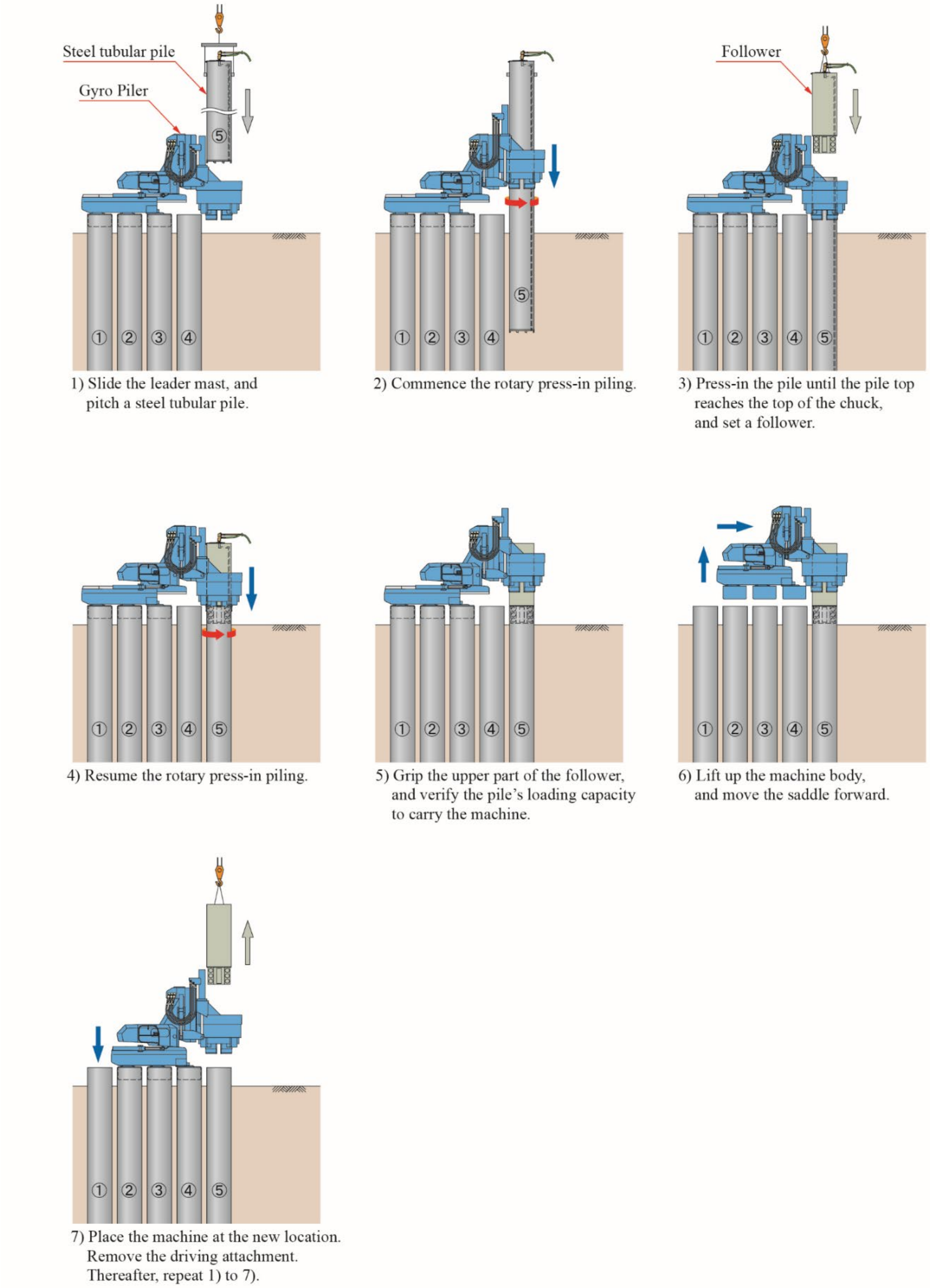

Fig. 10. Sequence of Gyropress Method

On this particular project, the required length of tubular pile was 27.6m. This exceeded the deliverable pile length, due to restricted site access. Therefore, piles were spliced on site as shown below in Fig. 11. Due to the restriction of the lay-down area, horizontal pile splicing was not feasible. Therefore, piles were spliced vertically during pile installation (bottom pile, middle pile and then upper pile). Circumference welding was used to splice piles, which were inspected using liquid penetrant testing on all splices, and ultrasonic testing on 1 in 20.

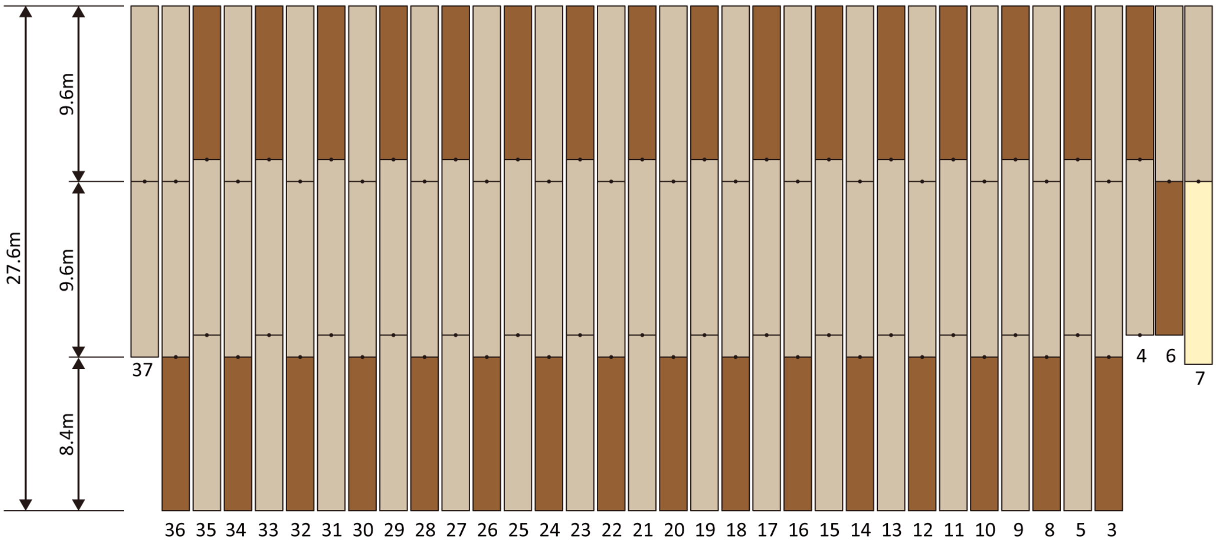

Fig. 11. Longitudinal Section of Tubular Pile Wall

In general, tubular piles are installed with a gap between adjacent piles to avoid the interference of adjacent piles and to enable the adjustment of installation tolerances. On this project, 1,500mm O.D. tubular piles were installed at 1,700mm intervals, which left a 200mm gap between piles. In order to prevent particle loss in the retained soil through the gaps, a closure pile is normally installed in each gap between piles. Equal angle section or small diameter pipe is normally used as the closure pile. On the project, equal angle sections (200mm x 200mm) were used. Fig. 12 shows the installation sequence of closure piles.

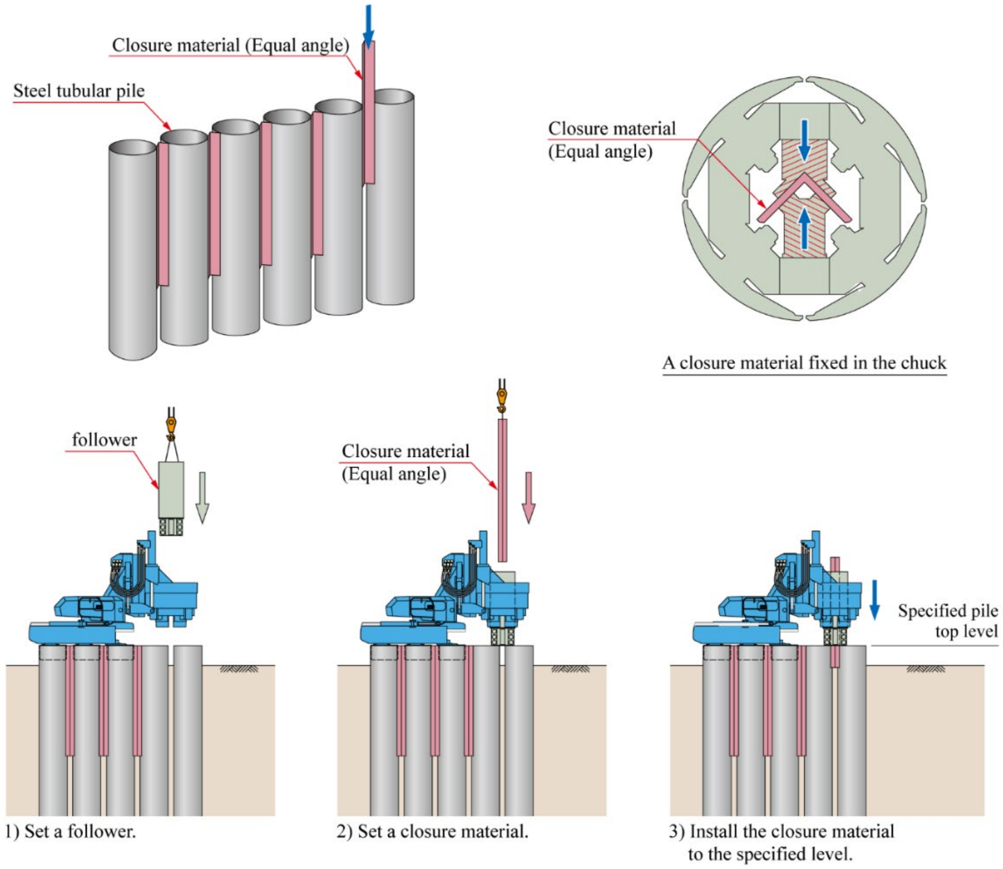

Fig. 12. Installation Sequence of Closure Pile

The installation period of the total of 37 piles was 51 days, including mobilization and demobilization of all equipment and pile materials. Regarding pile installation, the average daily production rate was 0.8 piles/day (2 splices each pile).

2) Excavation and installation of ground anchors
After installing the tubular pile retaining wall, a primary excavation was undertaken to establish the commencing surface for the installation of ground anchors. Ground anchors were then installed using an anchor drilling machine (Fig. 13).

Fig. 13. Installation of Ground Anchors

After the installation of all the ground anchors, a secondary excavation was carried out to establish the final formation level as shown in Fig. 15. Blinding concrete was then cast on the formation level. The lateral deflection of the tubular pile retaining wall was monitored throughout the excavation works in accordance with the allowable deflection limits shown in Table1. The maximum actual deflection was 28mm, which was less than the specified allowable deflection limit. Also, the actual axial force of ground anchors was less than the design axial force as shown in Table 2. These results prove the validity of the retaining wall design.

Table 1. Allowable Lateral Deflection of Tubular Pile Retaining Wall

Primary Reference Value	25.6mm (80%)
Secondary Reference Value	32mm (100%)

Table 2. Axial Force of Ground Anchors

Design Force	360kN/m
Actual Force	320kN/m

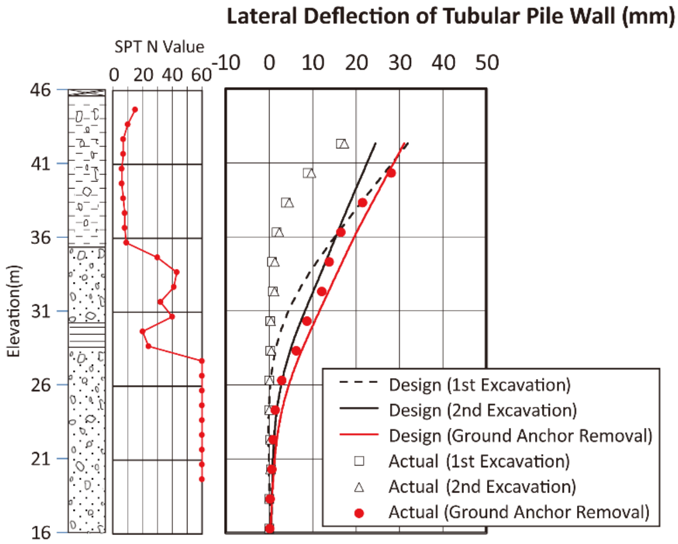

Fig. 14. Monitoring Results of Lateral Deflection


Fig. 15. Bulk Excavation after Ground Anchoring (left) and Completion of Excavation (right)

3) Welding of shear studs

After laying the blinding concrete, shear studs and reinforcing bars were welded onto the tubular piles utilizing stud welding guns. Regarding the weld inspection, additional weld inspections were carried out on finished stud welds, as the diameter of shear studs and reinforcing bars was 19mm. In Japan, weld inspections are exempted if the stud diameter is 16mm or smaller. Laboratory bend testing and tensile testing were carried out on the welded specimens. As for the on-site inspection, 100% visual inspection and 1/100 bend tests (displacing the head of the studs by striking them with a hammer) were conducted on the finished stud welds.

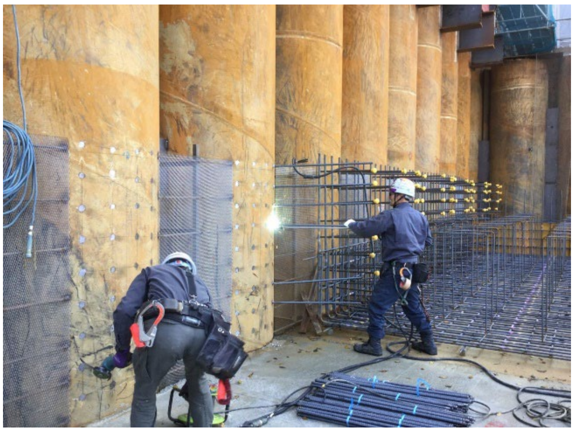

Fig. 16. Lower Stud Welding in Progress (left) and Completed Lower Stud Welding (right)

4) Formwork and concrete placement

After welding all the shear studs and reinforcing bars onto the tubular piles, formwork and scaffolding were set up (Fig. 17 and 18). The concrete retaining wall was then cast. Grade Fc24 concrete, with a standard service life of 65 years, was used on the project.

Fig. 17. Formwork and Scaffolding

Fig. 18. Perspective Aerial View of Excavation

5) Landscaping
Landscape gardening was included in the design of the L-shaped RC wall, as the wall is located in front of hotel guest rooms (Fig. 19).

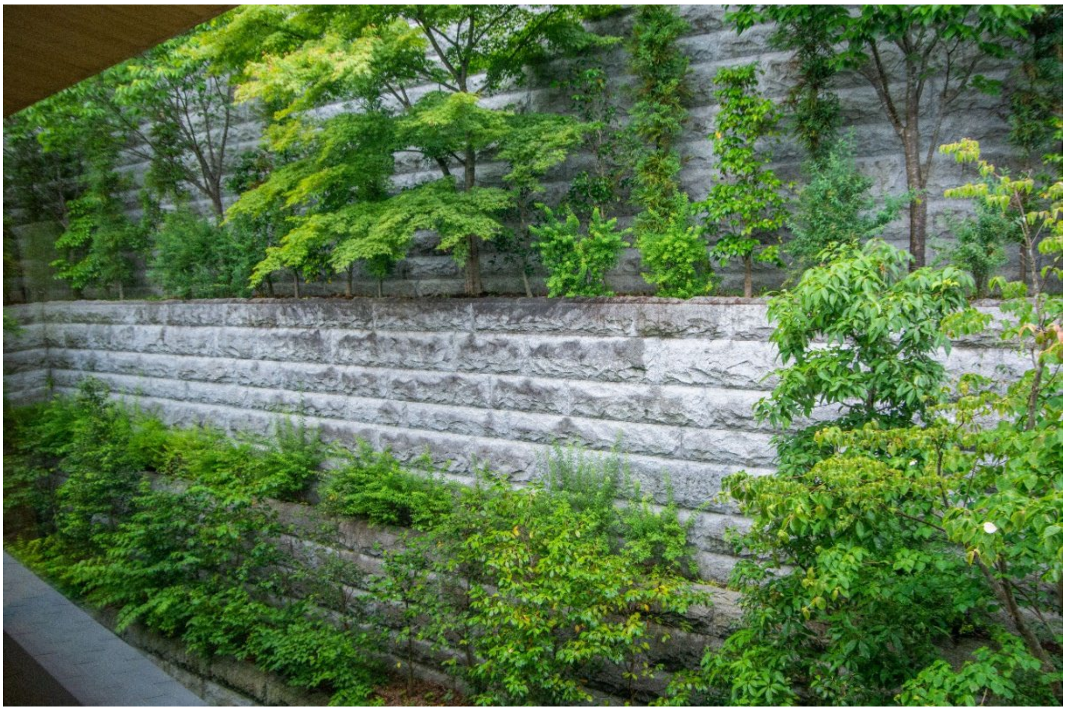

Fig. 19. L-shaped RC Wall and Landscaping

7. Conclusions

In retaining wall construction and basement construction projects, it is ideal if temporary retaining walls can also be used as permanent substructures. However, most temporary retaining walls currently used in Japan do not satisfy structural criteria of permanent substructure, which is required by the Japanese Building Standards Act. In addition, there is no such standard for temporary/permanent dual use retaining walls designated by the Architectural Institute of Japan at the moment. Therefore, temporary retaining walls and permanent substructures are generally unrelated entities in design and construction. Temporary/permanent dual use retaining walls can broadly be applied in the future construction scene in Japan, if their guidelines are authorized by the Architectural Institute of Japan. However, it normally takes a long time to approve the guideline. For the time being, it would be prudent for advocates of temporary/permanent dual use retaining walls to obtain a “Building Technology Performance Evaluation Certification” from the “General Building Research Corporation of Japan (GBRC)”, and submit it to a “District Construction Surveyor” on each project. In addition, it is also important to provide design & construction manuals and case histories, when disseminating new methodologies.
In contrast, temporary/permanent dual use retaining walls are widely used outside of Japan, regardless of whether they are steel or RC. However, like in Japan, steel-RC composite retaining walls are not common. In general, steel walls and RC walls are used alone, not as composites. If steel walls are covered with concrete liner walls, these concrete liners are normally non-structural members and applied for cosmetic reasons. Therefore, the design and construction guidelines of composite retaining walls also need to be standardized outside of Japan.
Needless to say, if a temporary retaining wall and a permanent substructure are composited, not only the stiffness of the completed substructure can be increased, but also both the structural performance and functions of the substructure can be compatible. In addition to structural optimization, the retaining wall material product range will be broadened and retaining wall material supply chain will be improved. We expect that the composite retaining wall structure will be recognized around the world.

REFERENCE

Kisoko Vol.46, No10, 2018.10