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Press-in piling applications: Seawall pile foundation work

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ABSTRACT: In the design phase of the seawall reconstruction project reported in this paper, there was concern that the new seawall was too close to the port facilities. Because of this, it was difficult to secure space to reconstruct the seawall. In addition, vibrations created during construction had to be minimized to prevent interference with an automatic tide-gauge station. Considering these conditions, the following decisions were made: [1] Steel tubular piles shall be used as pile foundations for the seawalls; [2] Rotary press-in piling shall be selected due to the pile installation through existing structures; and [3] A combination of the Skip Lock System, which enables mono-pile installation, and the Non-staging System, which enables piling work on the installed piles shall be used. This paper aims to review the advantages of press-in piling, by reporting the outlines of the project, the structure design and the plan and implementation of the construction.

1 INTRODUCTION

The occurrence of the Great East Japan Earthquake in March 2011, which caused the devastating damage and left more than 20,000 people dead and missing in 12 prefectures, still remains vivid in the memory of many people. The Central Disaster Prevention Council of Japan has estimated the damage by an earthquake of maximum magnitude in the Nankai Trough. According to the estimate, some areas along the pacific coast from Shizuoka Prefecture to Miyazaki Prefecture will possibly be hit by massive seismic waves with an intensity of seven, and wider areas adjacent to those hardest hit areas will suffer strong seismic waves with an intensity of upper six to lower six. In addition, wide areas along the pacific coast from the Kanto to Kyushu regions will be hit by massive tsunamis with a height exceeding 10 meters (JMA, 2020).

Under such circumstances, it is a pressing issue to restore damaged port facilities quickly and make new structures more resilient to disasters than before. Walk-on-pile type press-in piling is one of the piling technologies that can address this issue effectively. The following are increasingly being selected at many construction sites: [1] Rotary press-in piling (Gyropress Method), a pile installation method that rotates a steel tubular pile (hereinafter referred to as tubular pile) with pile toe ring bits, and presses it into the ground and through any existing structures. [2] The Skip Lock System, which enables the installation of tubular piles at certain intervals. [3] The Non-staging System, which enables piling work in a limited space by a travel crane that can move on the installed piles.

This paper reports a reconstruction project on the damage to Kamaishi's fishing port from the Great East Japan Earthquake. It was difficult to secure space for the dismantling and removal of existing structures and the construction of a new seawall, because part of the planned new seawall was too close to the port facilities. In addition, vibration during the construction had to be minimized to avoid interfering with the automatic tide-gauge station near the construction site. Under these conditions, tubular piles were installed to form the foundations of the new seawall using [1] Rotary press-in piling, [2] the Skip Lock System, and [3] the Non-staging System. Details of the construction work are described as follows.

2 OUTLINES OF THE PROJECT

2.1 *Objectives of the disaster rehabilitation project in Kamaishi's fishing port*

The Great East Japan Earthquake in 2011 and the following tsunami with a maximum height of 6.7 meters in Kamaishi, Iwate Prefecture, seriously damaged Kamaishi's fishing port (Figure 1) and its facilities (managed by the Iwate Prefectural. Government) as

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Figure 1. Kamaishi's fishing port in Iwate Prefecture, Japan (Map: https://www.google.co.jp/maps).

well as the surrounding area. To restore the functioning of the damaged Kamaishi port, a disaster rehabilitation project for the fishing port was planned with the aim of reconstructing a 1.9 linear km long seawall and related facilities. The project commenced in the fiscal year of 2011, and the construction work started in the fiscal year of 2013, with the aim of completing it in September 2020.

The disaster rehabilitation project reported in this paper aimed at constructing a new seawall, a land lock gate, a sluice gate, and other facilities that would replace the damaged structures.

2.2 *Construction conditions*

Since the Kamaishi Port Joint Government Office building occupied the land next to the damaged seawall, there was no space available for the installation and operation of heavy machinery. In addition, there was an automatic tide-gauge station that occupied part of the construction site facing the sea, so it was difficult to secure workspace with access on water by a temporary platform and a rubble mound, or preparing a barge.

Furthermore, it was considered difficult to secure enough working space for the installation of equipment and materials, needed for the dismantling and removal of the damaged structures, and the construction of the new seawall. This is because part of the new seawall was too close to the Kamaishi Port Joint Government Office facility.

Moreover, vibration in construction had to be minimized to avoid interfering with the constant tide level monitoring at the automatic tide-gauge station.

2.3 *Ground conditions*

The locations of collected borehole logs are shown in Figure 2 (B-1, B-29, and B-30), and the geological cross section at the construction site is shown in Figure 3.

An investigation of the soil revealed the following ground conditions: relatively soft alluvial deposits (composed of silty sand, fine sand, organic soil, and gravel with silt) lie in a range of 30.13 meters (No. B-1) to 16.04 meters (No. B-29) above mean sea level, and a layer of slate (extrapolated SPT *N*-values of 100 to 500) lies under the alluvial deposits. Based on this information, a pile foundation was selected as an effective foundation for the new seawall.

3 SEAWALL DESIGN

3.1 *Structure type*

This project is a disaster rehabilitation work for the damaged seawall. For the superstructure of the new T-shaped sea wall, prefabricated reinforced concrete unit and/or cast-in-situ reinforced concrete were adopted. At the same time, a pile foundation composed of two-row tubular mono piles was adopted as a foundation type (Figure 4).

Three different tubular piles with outside diameters of 800, 1,000, and 1,200mm were examined in the feasibility study for the construction of the pile foundation (Table 1). Installing 1,000 mm diameter tubular piles at a 2.5 meter spacing from centre to centre (C/C) was concluded to be most effective after comparing them in terms of the width occupied by the superstructure, and construction costs and duration.

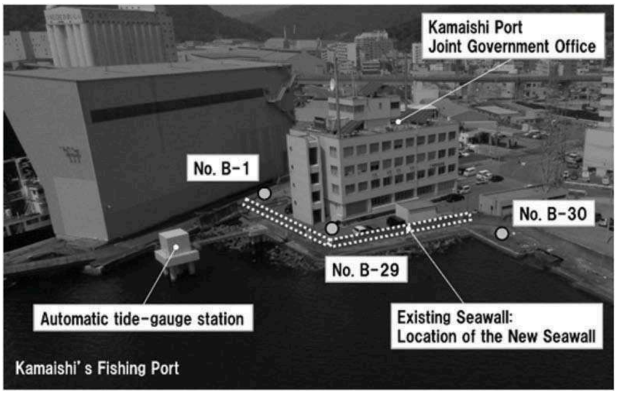

Figure 2. The site before the disaster rehabilitation, including numbers of borehole logs.

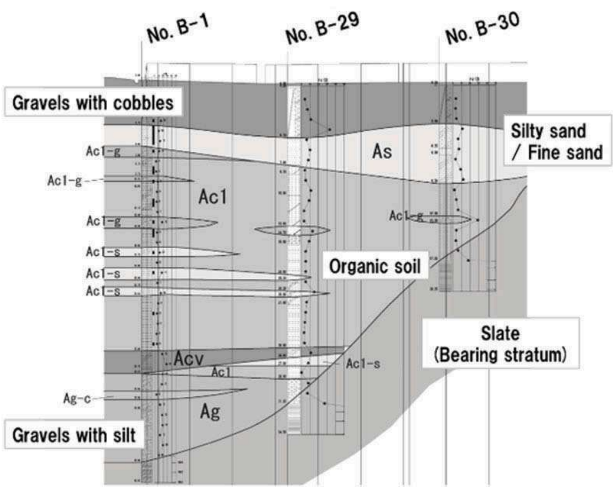

Figure 3. A geological cross section at the site.

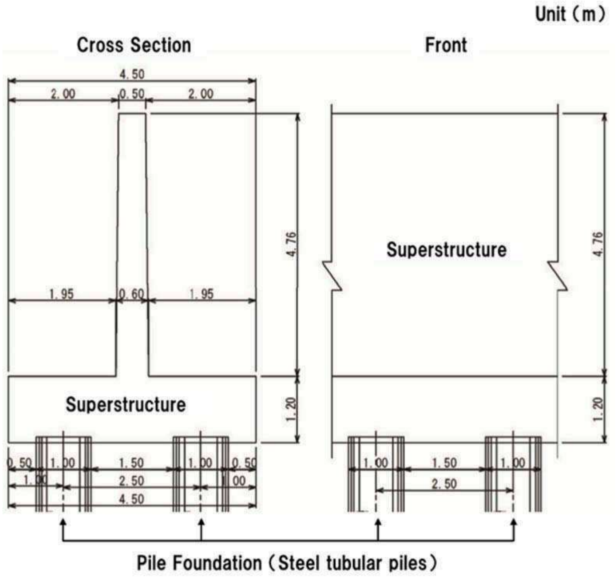

Figure 4. The design of the new seawall (Tubular pile diameter: 1,000 mm, Spacing from C/C: 2.5 m).

Table 1. A comparison of tubular pile diameters on a 10 m long section.

	Option #1	Option #2	Option #3
Spec. of steel tubular piles			
Diameter (mm)	800	1000	1200
Thickness (mm)	19	10	12
No. of lows	2	2	2
Spacing from C/C (m)	2.00	2.50	3.00
Displacement at the wall top			
Due to tsunami (cm)	1.425≤1.500	1.425≤1.500	1.425≤1.500
Due to earthquake (cm)	0.465≤1.500	0.465≤1.500	0.465≤1.500
Superstructure width (m)	3.60	4.50	5.40
Construction cost	1.15	1.00 (base)	1.04
Construction period	#3 plus 21 days	#3 plus 10 days	Shortest
Assesment	Acceptable	Good	Acceptable

3.2 *Guidelines and conditions for the pile foundation design*

The following guidelines were used for the structural design of the new seawall.

- River Improvement and Management Division, Water and Disaster Management Bureau of the Ministry of Land, Infrastructure, Transport and Tourism. 2012. *Guidelines for the Examination of the Seismic Capacity of River Structures*. (in Japanese)
- Fishing Port and Village Management Department, Agriculture, Forestry, and Fishery Division, Iwate Prefecture. 2012. *Guidance for the structural design of coast protection facilities (measures against tsunamis) for fishing port coasts (draft)*. (in Japanese)
- Japan Road Association. 2012. *Guidelines for Road Earthwork, Retaining Wall Construction, 2012 Edition*. (in Japanese)

Table 2. Design conditions for the pile foundation.

Bearing method	End-supported pile
Pile head type	Rigid connection type (either rigid connection or hinge connection type with greater crosssectional force to be selected at the design phase)
Pile toe type	Hinge
Safety factor for allowable bearing capacity (End-supported pile)	3.0 for normal conditions, 2.0 for L1 earthquakes, and 2.0 for L1 tsunamis
Pile layout	Minimum pile edge distance: 1.00 x pile diameter Minimum distance between the centers: 2.50 × pile diameter Maximum distance between the centers: 10.0 × pile diameter, or 4 m (whichever is smaller)
Allowable corrosion depth of steel	1mm (for sections submerged under water or the ground, all of the time)

The design conditions for the pile foundation are shown in Table 2. The values in the table were based on Part I Common Specifications and Part IV Specifications for Base Structures of the Specifications for Highway Bridges (JRA, 2012) and the Pile Foundation Design Handbook (JRA, 2015).

4 TUBULAR PILE INSTALLATION METHOD

4.1 *Rotary press-in piling (Gyropress Method)*

Rotary press-in piling is a technology to press-in a tubular pile with pile toe ring bits while rotating it. It is applicable not only to cohesive, granular or gravelly ground, but also to hard ground such as rock mass and underground obstacles (such as reinforced concrete structures) since the tubular piles cut and penetrate into those types of ground to the specified pile installation depth (Figures 5 and 6). It is applicable to a tubular pile with an outside diameter of 600 to 2,500mm (IPA, 2020).

When it is desirable to install tubular piles at a specified interval, not in a continuous wall arrangement, the spacing from C/C can be extended up to a distance 2.5 times larger than the diameter of the tubular pile (D) by using the Skip Lock System (Figure 7).

4.2 *The Non-staging System*

By using the Non-staging System, which enables all the piling processes including the transport, pitch, and pressing-in of piles to be carried out on the previously installed piles, areas affected by the piling work space can be limited to those occupied by the width of the machinery operated on the pre-installed piles, and those used for the construction base. In addition, the machinery, by gripping the pre-installed piles, is self-supporting, and the risk of them falling over is extremely low (IPA, 2020).

The machine layout of the Non-staging System used at the site in this report is shown in Figure 8.

4.3 *Reasons for the piling method selection*

For the selection of a tubular pile installation method, the combination of the aforementioned technology and systems were compared with the combination of pre-boring by the all-casing method and the impact driving of tubular piles (hereinafter referred to as the conventional piling method).

Considering the construction conditions in this project described in 2.2, a temporary platform or a rubble mound needed to be installed for the workspace if a conventional piling method was used. After a comparative analysis in terms of construction time and costs, the rotary press-in piling of steel tubular piles combined with the Skip Lock System and the Non-staging System was selected.

5 PILE FOUNDATION WORK

5.1 *Construction plan*

The pile foundation work carried out in the disaster rehabilitation project at Kamaishi's fishing port from 2017 to 2020 is reported in the following section as a press-in piling application.

The construction plan of this project was to install tubular piles (a total 58 of SKK400 piles with an outside diameter of 1,000mm and a length of 19.5 to 39.0m and each having from 0 to 12 splices) as pile foundations after dismantling and removing the damaged seawall. After that, T-shaped wall by cast-in-situ reinforced concrete was built as a superstructure, completing the new seawall.

The steel tubular pile layout and a standard cross section are shown in Figures 9 and 10.

5.2 *Underground obstacles*

Before installing the tubular piles, a temporary earth retaining wall was constructed with steel sheet piles, and existing structures were dismantled and removed. Figure 11 shows the dismantling and removal work of the existing seawall.

Aged revetments, stacked blocks, and cast-in-situ concrete under the ground were difficult to completely remove, so they were left as they were. After carrying out pre-cutting by a rotary press-in piling machine (hereinafter referred to as Gyro Piler), the tubular piles were pressed-in until they reached the bearing stratum (slate).

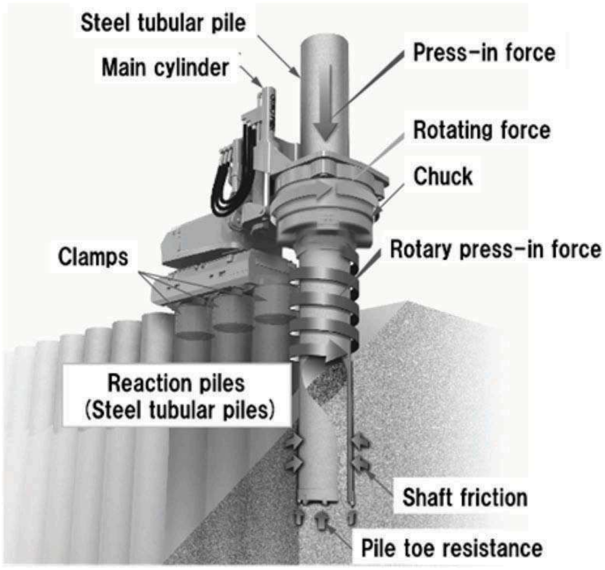

Figure 5. Rotary press-in piling (Gyropress Method).

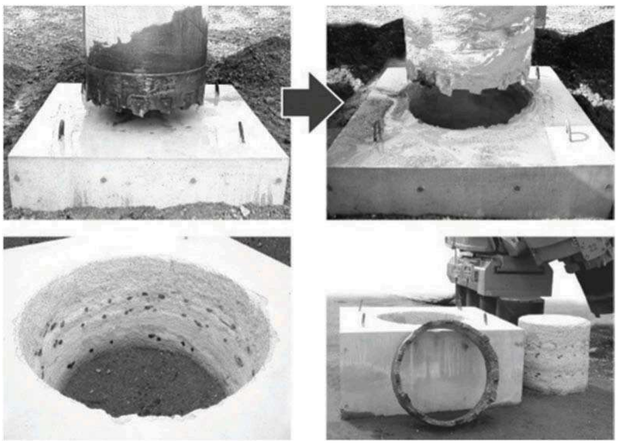

Figure 6. Reinforced concrete cutting.

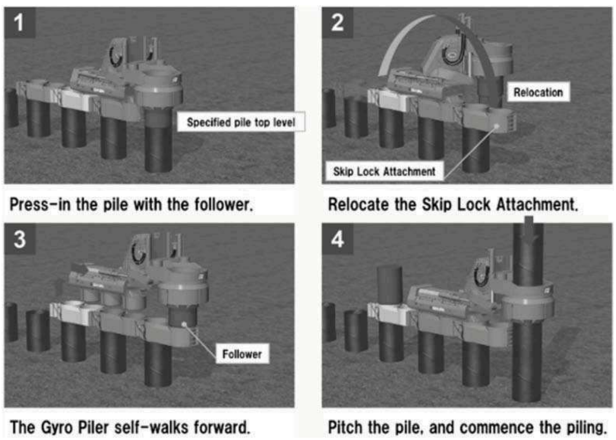

Figure 7. Pile installation procedures with the skip lock system.

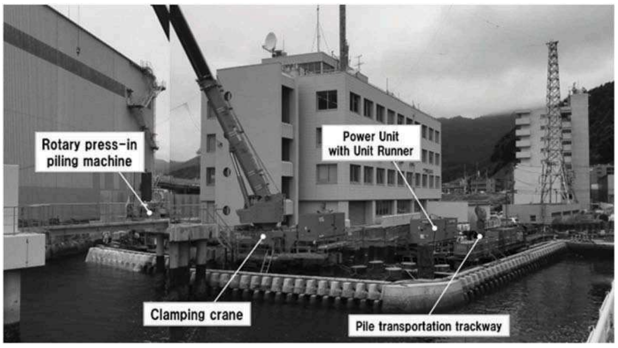

Figure 8. The machine layout of the non-staging system.

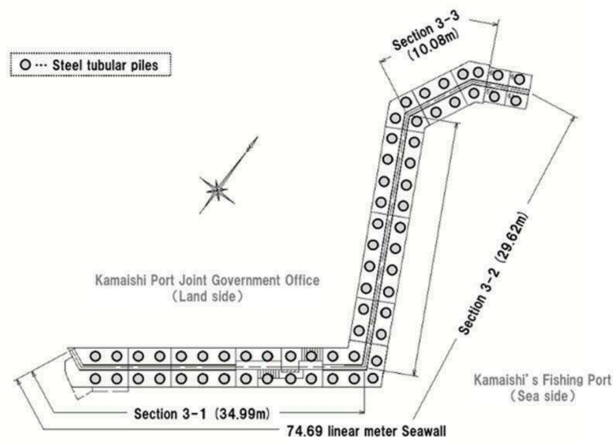

Figure 9. The layout of the steel tubular piles.

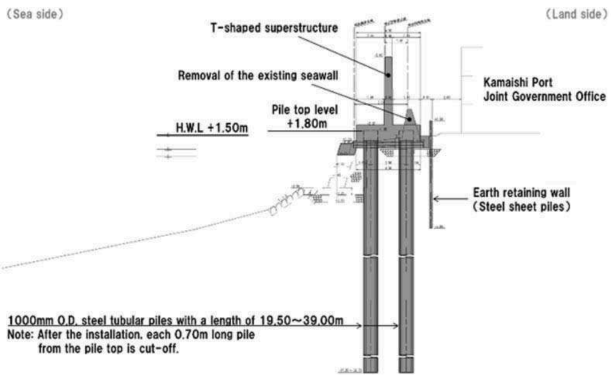

Figure 10. Standard cross section: Section 3-1.

Figure 11. Removing the existing seawall and afterwards.

5.3 *Piling procedure*

The installation of tubular piles by the rotary press-in piling was carried out according to the following procedure.

1) Equipment and piles were transported to the site, and a crane barge was installed above water adjacent to the site.
2) Install steel sheet piles as reaction piles (Figure 12).
3) Install a Reaction Stand for tubular piles and fix it to the reaction piles (Figure 13).
4) Assemble the Gyro Piler, which was brought to the site in three parts, on the Reaction Stand.
5) Install the tubular piles using the Gyro Piler, the Skip Lock System and the crane barge (Figures 14 and 15).
6) Install the Non-staging System on the pre-installed tubular piles (Figure 16).
7) Install a transportation trackway on land along the pile line in section 3-2 (Figure 17).
8) Install the tubular piles using the Non-staging System (Figure 18).
9) After installing the piles remove the transportation trackway, and move the Gyro Piler and the clamping crane backward by self-walking to the location where they can be disassembled and removed, after the completion of all pile installation.
10) Disassemble and remove the Gyro Piler and the clamping crane.
11) Remove all materials and equipment.

The tubular pile installation by rotary press-in piling was completed in three months from May to August in 2018.

Figure 12. Pressing-in steel sheet piles as reaction piles.

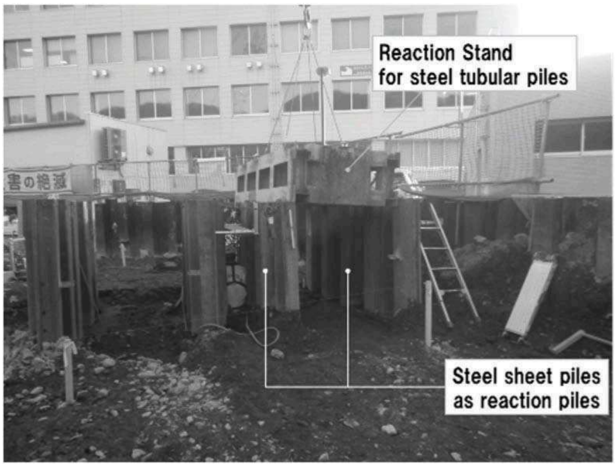

Figure 13. Installation of a reaction stand for tubular piles.

Figure 14. Steel tubular pile installation: Section 3-2.

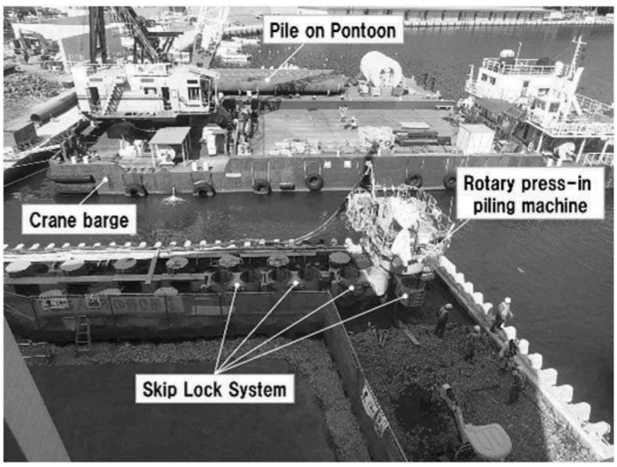

Figure 15. Steel tubular pile installation at the corner.

Figure 16. Assembling a clamping crane.

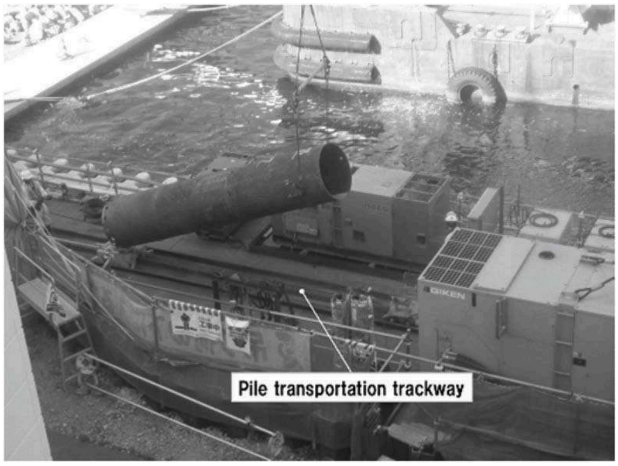

Figure 17. The pile transportation trackway.

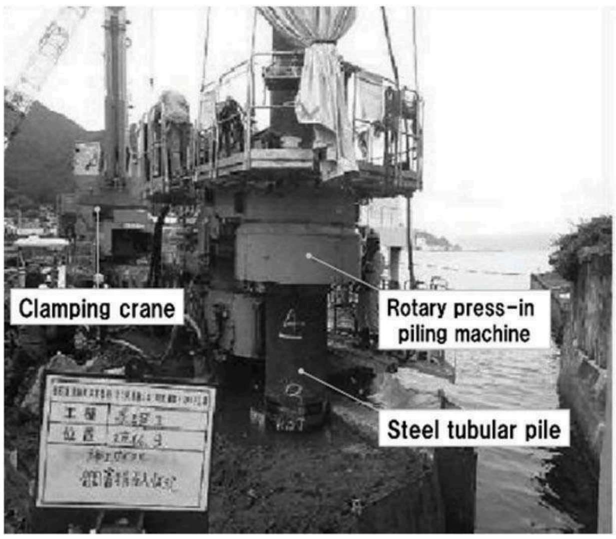

Figure 18. Tubular pile installation using the non-staging system.

5.4 *Quality control of installed tubular piles*

Quality control was carried out on the following construction parameters concerning dimensional accuracy, to ensure the installation of tubular piles complied with the standards and criteria specified by the client/owner (TRDB, 2020) (JRA, 2015): 1) height of the top level, 2) deviation in plan, and 3) the inclination.

5.4.1 *Height of the top levels*

In this project, the top level of each tubular pile was set at T.P. 1.80 meters (design value) to avoid the equipment and materials submerged during the pile installation. The top level of the tubular piles was controlled to meet the control value with a reference level of ±50.00mm tolerance using an elevation measuring instrument (Total Station) at the end of each press-in piling.

The control value and actual measurements (mean value, maximum plus and minus values, and standard deviation) of the installed piles' top level are shown in Table 3. The top levels ranged from 33.00 to 12.00mm with a mean of 17.00mm and standard deviation of +11.61mm, which also means that the pile toes could reach the specified level of bearing stratum.

The data demonstrated that the tubular mono piles installed by the rotary press-in piling with the Skip Lock System could achieve a high level of compliance with the reference level.

5.4.2 *Deviations in plan*

Inspections for deviations in plan of the tubular piles were conducted for all installed tubular piles at this site using a measuring instrument (Total Station). The inspection results are shown in Table 4.

The required control value was within 100mm. The measurement data showed that deviations in plan of the tubular piles were in the range of 1.00 to 57.00mm, with a mean of 19.00mm per pile and a standard deviation of ±13.04, which demonstrated sufficient piling accuracy.

5.4.3 *Inclinations*

The inclination of the installed tubular piles was measured by a measuring instrument (Total Station) and a spirit level. The results are shown in Table 5. The control value for the inclination was within 2 degrees.

The measurement data showed that the inclination of the installed tubular piles was in a range of 0.10 to 0.7 degrees with a mean of 0.41 degrees per pile and a standard deviation of ±0.14, which demonstrated the successful installation of the tubular piles.

Table 3. Assessment: Height of the top levels.

Item	Unit	Control value	Mean value	Max. value	Min. value	Standard deviation	Sample No.	Assesment
Pile top level	mm	±50.00	-17.00	12.00	-33.00	±11.68	58	Pass

Table 4. Assessment: Deviations in plan.

Item	Unit	Control value	Mean value	Max. value	Min. value	Standard deviation	Sample No.	Assesment
Deviation in plan	mm	100.00	19.00	57.00	1.00	±13.04	58	Pass

Table 5. Assessment: Inclinations.

Item	Unit	Control value	Mean value	Max. value	Min. value	Standard deviation	Sample No.	Assesment
Inclination	degree	1.00	0.20	0.60	0.00	±0.14	58	Pass

6 SUPERSTRUCTURE WORK

After completion of the pile foundation work, the construction of the superstructure, made of reinforced concrete, was carried out.

It was preferable to use precast reinforced concrete members instead of cast-in-situ reinforced concrete, from the overall consideration of workability at the site and construction time and cost. However, a precast concrete seawall was concluded not to be suitable for these sections because the installation of a temporary platform and a rubble mound for heavy machines, which was essential for the handling of precast concrete members, was difficult along the piling location. As a result, a T-shaped seawall made of cast-in-situ reinforced concrete was adopted (Figure 19).

The in-situ concrete work for the superstructure was carried out for each section from May 2019 to January 2020. After completion of the superstructure, wave-dissipating concrete blocks and steps were installed. This project was completed in February 2020 (Figures 20 and 21).

7 CONCLUDING REMARKS

In this case study, the following advantages were demonstrated for the combination of the rotary press-in piling, the Skip Lock System, and the Non-staging System, in the pile foundation work for the construction of a seawall in a disaster rehabilitation project:

- By combining the rotary press-in piling with the Skip Lock System, tubular mono piles can be installed, which had been considered to be difficult with press-in piling.
- It is possible to press-in tubular piles into slate (bearing stratum) and install end-supported piles without removing underground obstacles (e.g. aged revetments, stacked blocks, and reinforced concrete) beforehand.

Figure 19. Construction of the superstructure on installed piles.

Figure 20. The newly constructed seawall: Section 3-1.

Figure 21. An aerial view of the newly constructed seawall.

- Tubular pile foundations can be constructed in ports and harbours without requiring temporary platforms and rubble mounds in cases where the Non-staging System is used.
- It is possible to construct a high-strength and high-quality pile foundation by using prefabricated tubular piles.
- Mono tubular piles installed using the rotary press-in piling in combination with the Skip Lock System are capable of meeting the control values for top levels, deviations in plan, and inclinations with sufficient margin.

In disaster rehabilitation projects for port and harbour facilities such as seawalls, it is often the case that space provided for the construction work is limited due to the presence of structures adjacent to the construction site, or the narrowness of the site itself. And a lot of time and cost have to be spent on the installation of large-scale temporary platforms and/or rubble mounds. In such situations effective measures need to be devised to keep the facilities around construction sites functional, ensure safety and security in the construction process, and to avoid interfering with the movement of ships. The advantage of rotary press-in piling, the Skip Lock System, and the Non-staging System, in addressing the aforementioned issues has been proven through this project.

Finally, we hope that the press-in piling application reported in this paper will serve as a reference for similar disaster rehabilitation projects.

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