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Press-in piling applications: Breast walls composed of steel tubular piles and combined wall

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ABSTRACT: The disaster rehabilitation work for the Nakanoshima district damaged by the 2011 off the Pacific coast of Tohoku Earthquake was a project carried out for the purpose of constructing the breast wall, quay and related facilities. The most challenging task was the reconstruction of the 542.2m breast wall. Key requirements were [1] build the breast wall in a narrow space, and [2] minimize noise and vibrations during construction not to impact the adjacent buildings and existing piers. To meet these requirements, about 80% of the target length was a structure based on the foundation using a combined wall composed of steel tubular piles and sheet piles, while about 20% of the length formed a structure of cantilever-type steel tubular pile retaining wall. The construction used the rotary press-in piling, Combi-Gyro Method, and Non-staging System. By sharing the project experience, this paper illustrates the advantages of the press-in piling method.

1 INTRODUCTION

In Japan, the 2011 off the Pacific coast of Tohoku Earthquake in March 2011 and the accompanying tsunami damaged many breast walls (seawalls) (NILIM, 2014). For disaster prevention and mitigation in case of assumed big earthquakes such as Nankai Trough Earthquake (JMA, 2020), which is predicted to occur with a probability of 70 to 80% within 30 years, it is urgent to reconstruct the damaged walls as soon as possible and to strengthen the reconstructed walls for disaster prevention. One of the effective piling technologies to overcome that issue is the walk-on-pile type press-in piling.

The Nakanoshima (C) Disaster Rehabilitation Work for the Breast Wall and Other Facilities (hereinafter referred to as the Nakanoshima Disaster Rehabilitation Work) reported in this paper mainly aimed to reconstruct the damaged breast wall and to enhance their functions. For the structure of the reconstructed breast wall, the project selected [1] steel tubular pile retaining wall due to the ground and construction conditions, and [2] a structure that has a combined wall for foundation made up of Hat-shaped steel sheet piles (hereinafter referred to as Hat sheet piles) for cut-off wall and steel tubular piles (hereinafter referred to as tubular piles) for horizontal resistance to raise the wall height by widening the existing breast wall. This paper presents a case study of the rotary press-in piling, the Combi-Gyro Method, and the Non-staging System, selected in the project as an installation method of tubular piles and sheet piles for constructing breast wall.

2 OVERVIEW OF THE PROJECT

2.1 *Location and purpose of the project*

The 2011 off Pacific coast of Tohoku Earthquake and subsequent tsunami damaged the breast wall of the Teizan Canal, in the Nakanoshima district managed by Miyagi Prefecture (Figure 1). For this reason, the disaster rehabilitation work was projected to reconstruct the existing 542.2-meterlong breast wall and to construct the small vessel quay, pier, and related facilities.

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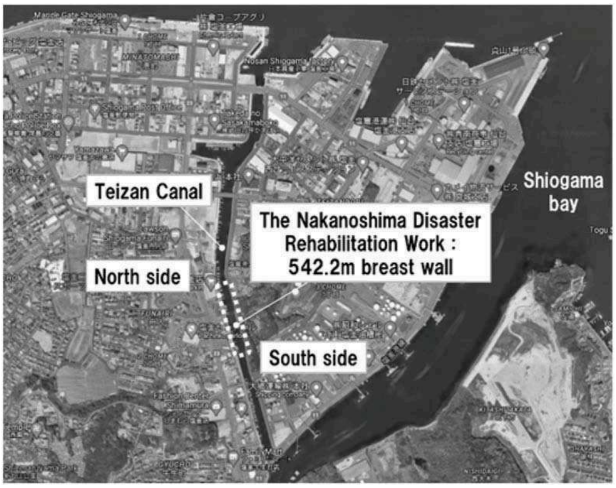

Figure 1. Location Map: Nakanoshima Disaster Rehabilitation Work (Map: https://www.google.co.jp/maps).

2.2 *Construction conditions*

Private land on the north side or a road on the south side runs side by side behind the existing breast wall, and in addition a pier (Figure 2) to moor small leisure vessels was provided in front of the existing breast wall. As a side note, this pier and its facility had been observed to suffer from subsidence of about 50cm due to the massive earthquake in 2011, for which an application for the disaster rehabilitation work had been submitted as a separate project. This would cause a bottleneck to early reconstruction of the pier because adjustment is required between two works if reconstruction of breast wall impacts the pier. For this reason, the project needed to select a structure form and a construction method that would not impact the reconstruction of the pier in the design phase of reconstructed breast wall.

2.3 *Ground condition*

Figure 3 shows the soil profile (Soil Section C-1) of the district.

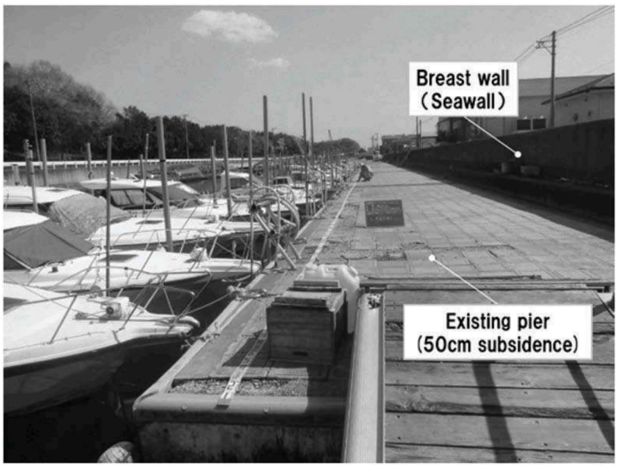

Figure 2. Existing breast wall (seawall) and pier.

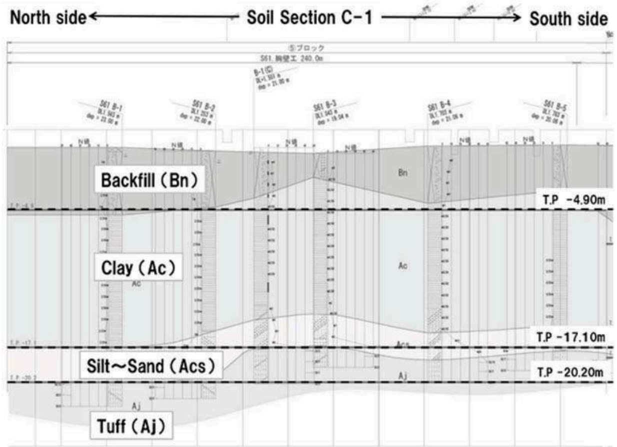

Figure 3. Soil profile: Soil Section C-1.

The geological survey found that the geology is characterized by the distribution of backfill layer (about 4.90m thick) in the surface layer, thick soft clay (about 4.90m thick) with a SPT *N*-value of 0 to 4 in the next layer, and a deep distribution of the bearing stratum (tuff of T.P. 17.10m to T.P. 20.20m or deeper).

The lack of a bearing stratum in the shallow depth limited the structural form of breast wall to pile foundation or cantilever-type continuous wall, excluding spread footing as it was not suitable.

3 STRUCTURAL REVIEW

3.1 *Structural form*

As shown in 2.3, under the ground conditions of thickly deposited cohesive soil, it was necessary to apply a foundation form such as a pile foundation or a cantilever-type continuous wall. As the construction section had an existing pier on the canal side (2.2), it was difficult to establish a temporary platform for installing a leader rig mounted press-in system assisted by augering (hereinafter referred to as conventional pile driver, Figure 4). Even on the land side, it was difficult to secure about 10m working width for the conventional pile driver in the hinterland of the existing breast wall (hereinafter referred to as hinterland).

Due to these constraints, it was necessary to select a cantilever-type structure using steel sheet piles (hereinafter referred to as sheet piles) and/or tubular piles, and a structural form that allows "piling by self-walking on the previously installed piles" for installing sheet piles and/or tubular piles. Given the above, three types of forms were reviewed: [1] Tubular pile foundation and cast-in-situ concrete superstructure after removing the existing breast wall, [2] Tubular pile retaining wall without removing the existing breast wall before the pile installation, and [3] Raised structure formed by widening the existing breast wall.

Figure 4. Leader rig mounted press-in system assisted by augering (Yamashita et al. 2010).

3.1.1 *Proposal 1: Tubular pile foundation and cast-in-situ concrete superstructure after removal of existing breast wall*

This form is a proposal to remove the existing breast wall and to newly construct the breast wall at the same position (Figure 5). As it was difficult to extract the existing H-shaped steel piles, the installation position of the new breast wall had to be moved to the landward side to avoid overlap with the installed tubular piles.

Removal of the existing breast wall was required and there were concerns of a longer construction period due to the larger number of work processes compared to the other two proposals. In addition, moving the piling location of tubular piles to the landward side will exercise the largest impact on the roads and private land in the hinterland compared to the other two proposals, which deemed this inapplicable for the project.

3.1.2 *Proposal 2: Tubular pile retaining wall without removing the existing breast wall before the pile installation*

This form is a proposal to leave the existing breast wall, install the tubular piles on its front side, and build the tubular pile retaining wall by installing concrete coping on the pile heads (Figure 6). The revetment in front of the existing wall had to be removed to avoid interfering with the tubular pile installation.

There will be no impact on the roads and private land in the hinterland since the tubular pile retaining wall will be built in front of the existing breast wall. However, there was concern that tubular piles would interfere with the floating part of the existing pier. In contrast, this proposal features a shorter construction period than Proposal 1 since the breast wall is built with tubular piles and concrete coping.

The 88-meter-long construction section in the north side in the construction area had an existing pier in front and adjacent private land in the hinterland. For this reason, the raised structure, by widening the existing breast wall, (Proposal 3) was determined to be inapplicable; instead, this structural form was selected for the construction section as it can suppress interference with the pier by installing a tubular pile in the 1.2m space between the existing breast wall and the pier.

3.1.3 *Proposal 3: Raised structure formed by widening the existing breast wall*

This form is a proposal to raise and widen the existing breast wall since the existing wall suffered minor damage and to install tubular piles as the pile foundation (Figure 7) for enhanced lateral bearing capacity, and reducing the hinterland by 35cm, which is the widen width of the breast wall.

The structural form enables tubular pile installation by installing cut-off sheet piles (Hat sheet piles) behind the breast wall in advance and then having the complete set of piling machinery to self-walk on the pre-installed piles. In addition, the construction cost was estimated to be reduced to about 40% compared with the other two proposals.

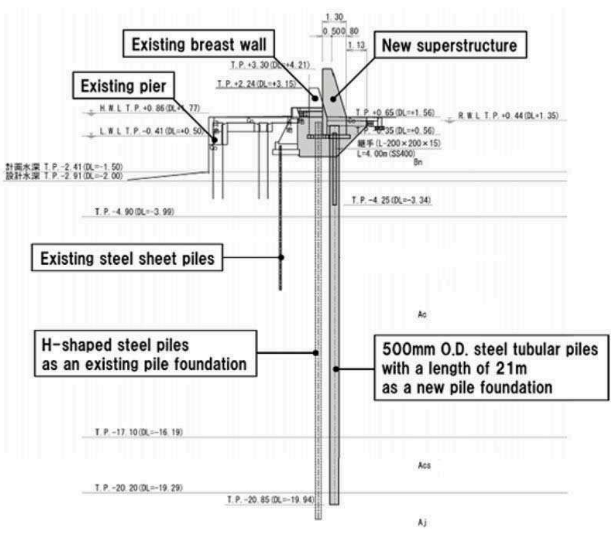

Figure 5. Proposal 1: Tubular pile foundation and cast-in-situ concrete superstructure.

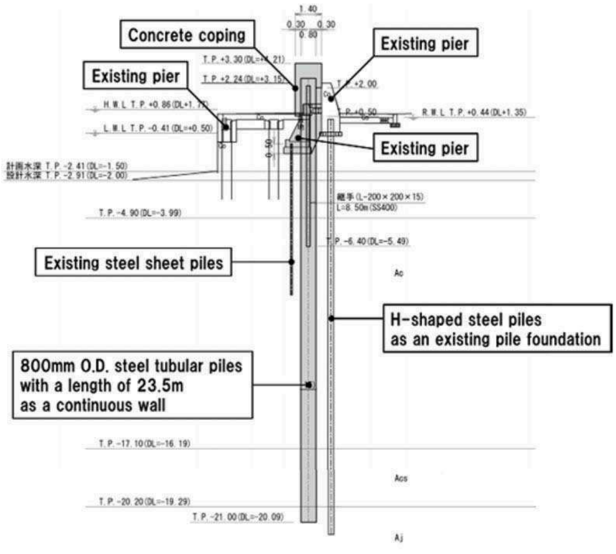

Figure 6. Proposal 2: Tubular pile retaining wall.

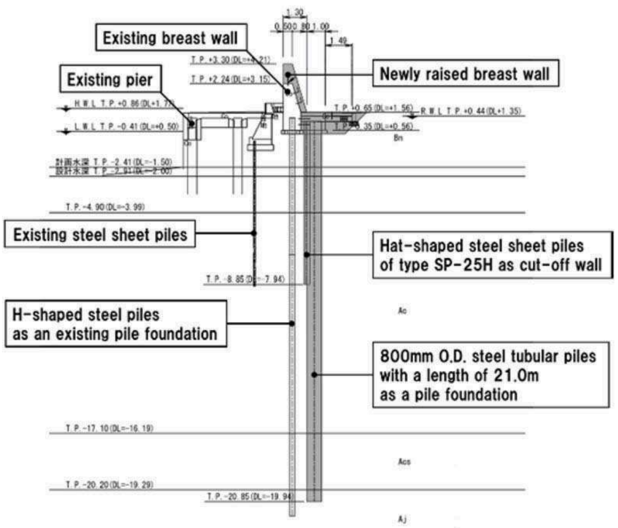

Figure 7. Proposal 3: Raised structure by widening existing breast wall.

Based on the above, this structural form was selected for the 454.2-meter-loncg construction section in the construction area.

4 INTRODUCTION OF PILING METHOD AND SYSTEM

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 soils, but also to harder grounds consisting of bedrocks or containing underground obstacles (such as reinforced concrete structures) since the tubular piles cut and penetrate into those materials to the planned installation depth (Figures 8 and 9). It is applicable for tubular piles whose outside diameter is from 600mm to 2,500mm (IPA, 2016).

4.2 *Combi-Gyro Method*

The Combi-Gyro Method is a technology of press-in piling for walls that uses a combination of tubular piles and Hat sheet piles (hereinafter referred to as combined wall). The first step of the piling procedure is to press-in a Hat sheet pile. The next step in this method is, by replacing the dedicated chuck for sheet piles with one for tubular piles, to grip a tubular pile, to install it by the rotary press-in piling on the pre-installed sheet piles to gain reaction force. This piling procedure will install a combined wall (IPA, 2016) (GIKEN & NIPPON STEEL, 2017).

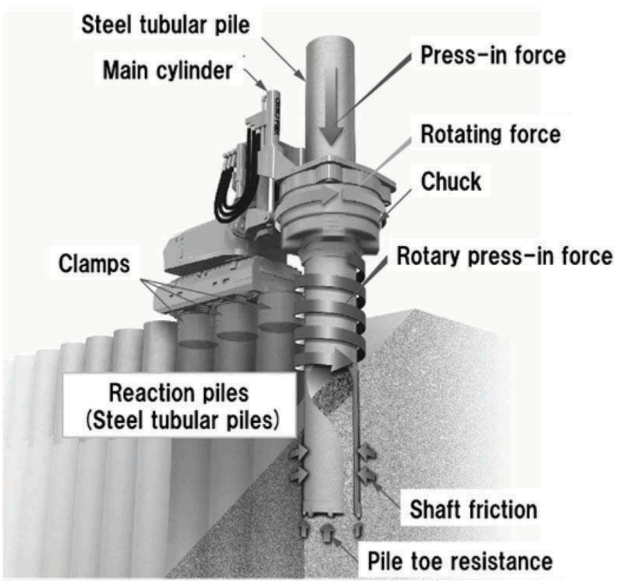

Figure 8. Rotary press-in piling (Gyropress Method).

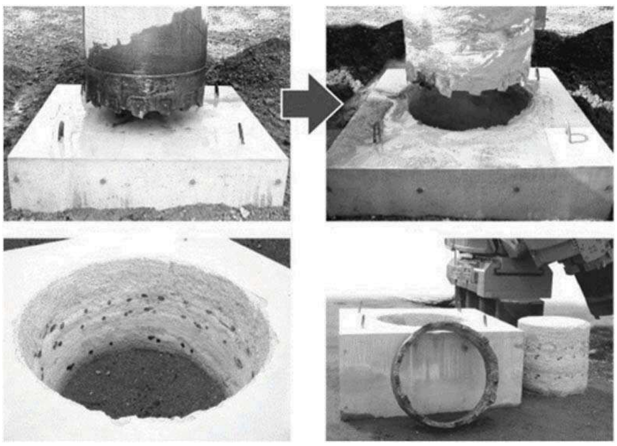

Figure 9. Reinforce concrete cutting.

Figure 10 Shows the combined wall after the installation in the site.

4.3 *Non-staging System*

The Non-staging System, which enables all the continuous operation including transportation, pitching and press-in pilling of tubular piles and sheet piles to be carried out on the pre-installed piles, can limit the areas affected by the piling work to those occupied by the machinery on pre-installed piles and those used for the working base. Also, the machines are self-supporting by gripping the installed pile, and the risk of falling is extremely low (IPA, 2016).

Machine layout of the Non-staging System in rotary press-in piling is shown in Figure 11.

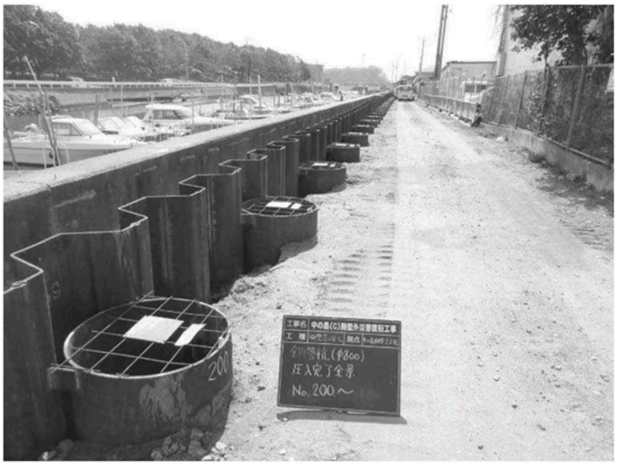

Figure 10. Combined wall composed of Hat sheet piles and tubular piles.

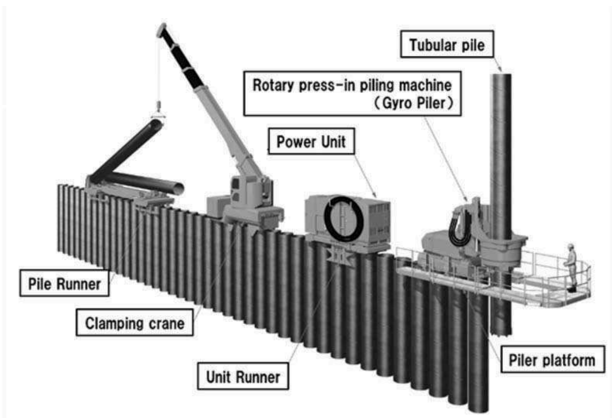

Figure 11. Machine layout of non-staging system in rotary press-in piling.

5 INSTALLATION OF TUBULAR PILES AND COMBINED WALL

5.1 *Construction plan*

This construction section illustrates the construction of the continuous tubular pile wall and the combined wall included in the Nakanoshima Disaster Rehabilitation Work carried out from 2015 to 2016 as a press-in piling application.

This project used tubular piles (SKK400, 800mm O.D., a length of 23.5m, 1 splice, 95 piles) for continuous tubular pile wall, and tubular piles (SKK490, 800mm O.D., a length of 5.0 to 21.0m, non or 1 splice, 159 piles) and Hat sheet piles (25H type, a length of 8.5 to 11.0m, 471 sheets) for the combined wall.

Figure 12 shows the target length and construction sections of each structure while Table 1 shows the quantity of tubular piles and Hat sheet piles required for this project.

5.2 *Procedure for tubular pile installation (Continuous wall)*

In Construction Section 1, the continuous wall of tubular piles was installed by means of rotary press-in piling and the Non-staging System according to the following procedure:

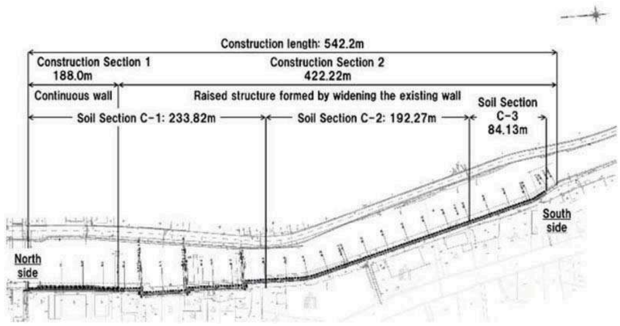

Figure 12. Target length and construction sections.

Table 1. Quantity of tubular piles and Hat sheet piles.

Construction Section	Specification	Remarks
1	Tubular pile - 800mm O.D., a length of 23.5m, 12mm thick, 1 splice, 95 piles	Steel tubular pile retaining wall
2	Tubular pile - 800mm O.D., a length of 5.0m to 21.0mm, 16mm thick, non or 1 splice, 159 piles (pile foundation)	Combined wall
	Hat sheet pile SP-25H, a length of 8.5 to 11.00m long 471 sheet(cut-off-wall)	

1) Transport the piles and equipment to the working base and install the service crane.
2) Press-in sheet piles as reaction piles. (Figure 13)

3) Fix a Reaction Stand for tubular piles with the reaction piles. (Figure 14)
4) On the Reaction Stand, assemble the rotary press-in piling machine (hereinafter referred to as Gyro Piler), which was brought into the site in three parts. (Figure 15)
5) Rotary press-in piling of tubular piles with the Gyro Piler and crane. (Figure 16)
6) Install the Non-staging System, including a clamping crane, a Power Unit with Unit Runner, etc., on pre-installed tubular piles. (Figure 17)
7) Lay the pile transportation trackway and the Pile Runner on the pier. (Figure 18)
8) Install the tubular piles using the Non-staging System. (Figure 19)
9) After completion of all tubular pile installation, remove the pile transportation trackway, and let the Gyro Piler and clamping cranes self-walk backward to the working base.

Figure 13. Press-in sheet piles as reaction piles.

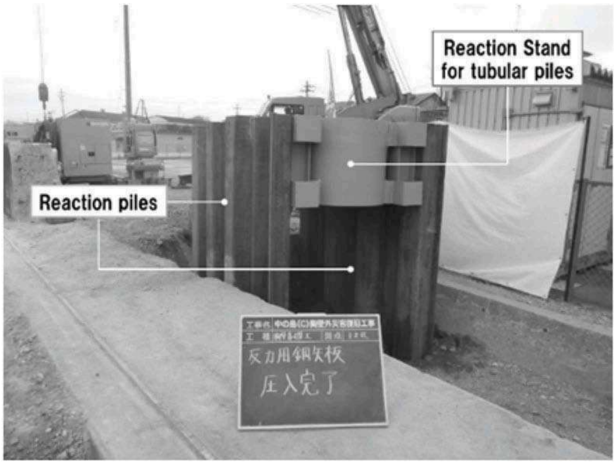

Figure 14. Installation of reaction stand for tubular piles.

Figure 15. Assembly of Gyro Piler.

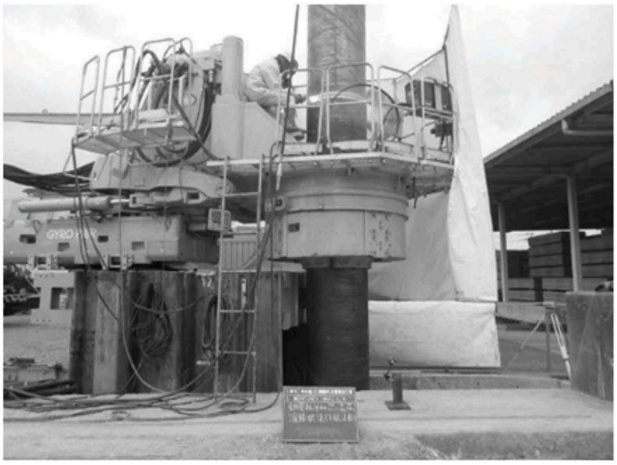

Figure 16. Rotary press-in piling of tubular piles.

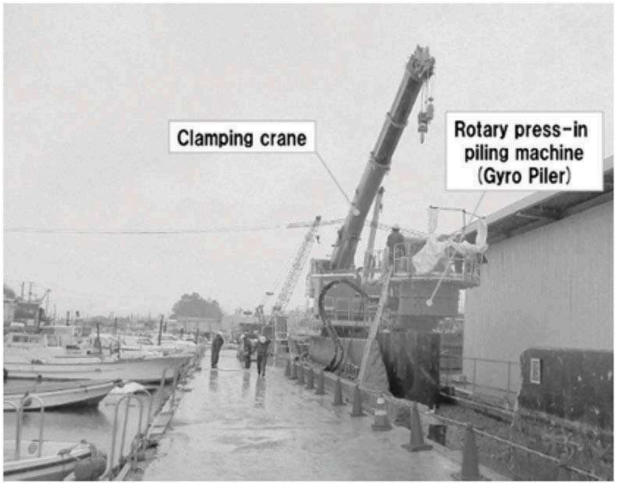

Figure 17. Installation of a clamping crane.

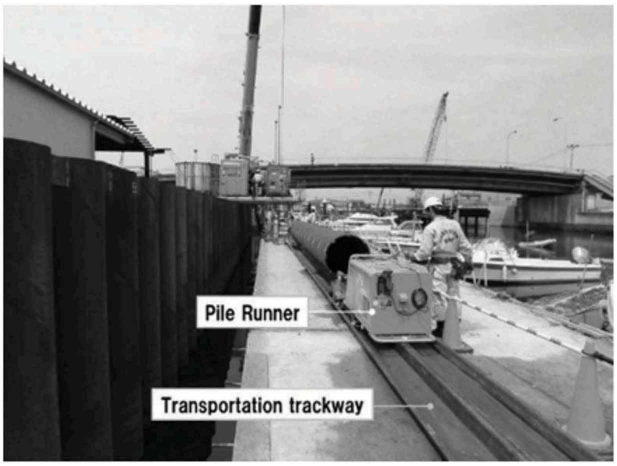

Figure 18. Pile runner and transportation trackway on pier.

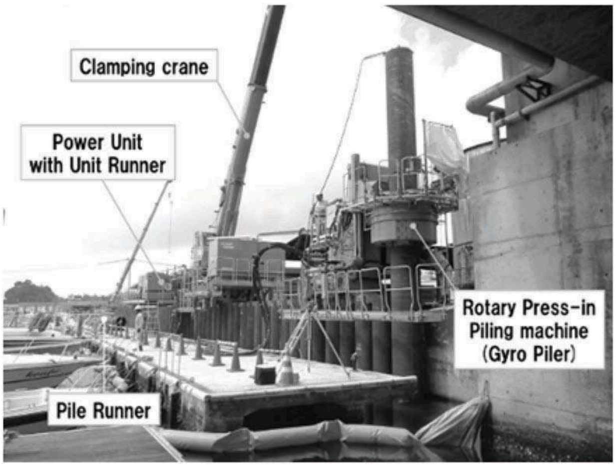

Figure 19. Non-staging system (tubular piles/continuous wall).

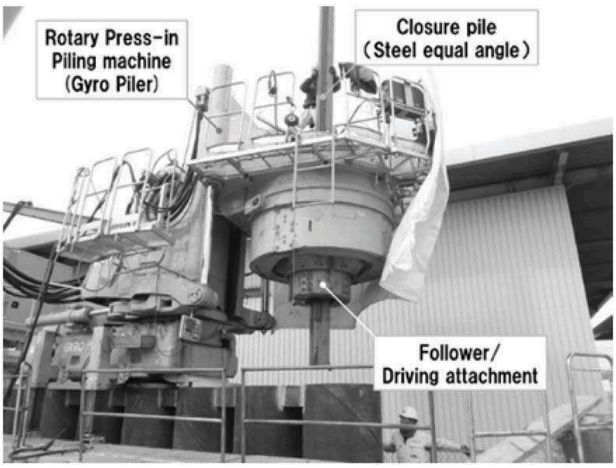

Figure 20. Installation of closure piles.

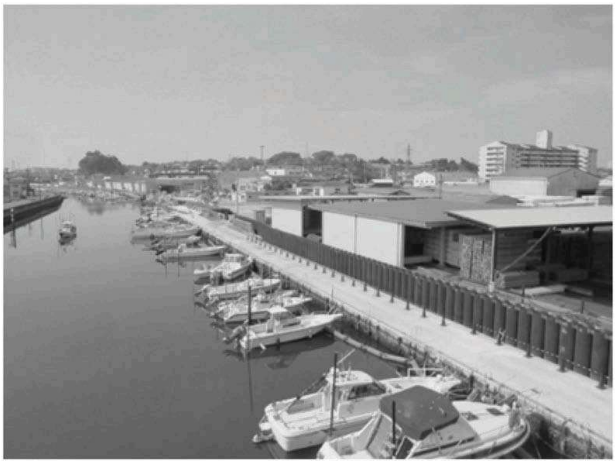

Figure 21. Steel tubular pile retaining wall.

10) Disassemble and remove the Gyro Piler and clamping crane.
11) Dismantlement and removal of equipment.

Spacing between tubular piles was ensured by press-in piling of closure piles with the Gyro Piler equipped with a follower/driving attachment. (Figure 20)

The steel tubular pile installation for the continuous wall with the rotary press-in piling was completed in about 2 months from March to May in 2016. (Figure 21)

5.3 *Procedure for installing combined wall (cut-off sheet piles and pile foundation)*

In Construction Section 2, the combined wall was installed using the Combi-Gyro Method and Non-staging System according to the following procedure:

1) Transport the piles/sheet piles and equipment to the working base and install a crane.
2) Standard press-in or press-in assisted with augering of Hat sheet piles using the Combi-Gyro Piler attached to a dedicated chuck for Hat sheet piles and the crane. (Figure 22)
3) Install the clamping crane and Power Unit with Unit Runner on the pre-installed piles.
4) Lay the pile transportation trackway and Pile Runner on the pre-installed piles. (Figure 23)
5) Install Hat sheet piles with the Non-staging System.
6) After completion of all of the Hat sheet pile installation, replace the dedicated chuck for the Hat sheet piles of Combi-Gyro Piler with the dedicated one for tubular piles.
7) Start backward self-walking and install the tubular piles with the Non-staging System. (Figure 24)

8) After completion of all tubular pile installation, the Non-staging System arrives at the working base.
9) Disassemble and remove the Combi-Gyro Piler and clamping crane.
10) Dismantle and remove all equipment.

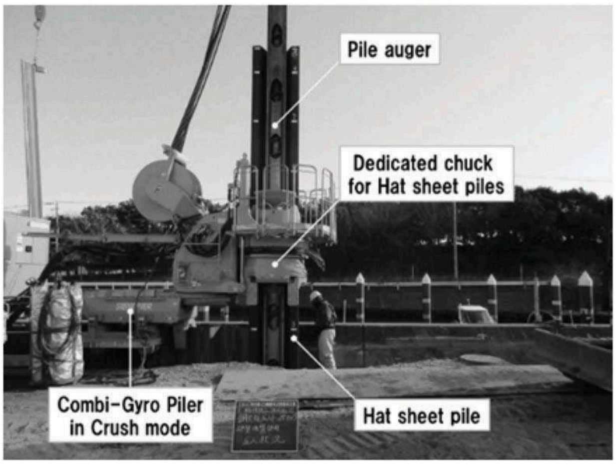

Figure 22. Press-in assisted with augering of Hat sheet piles.

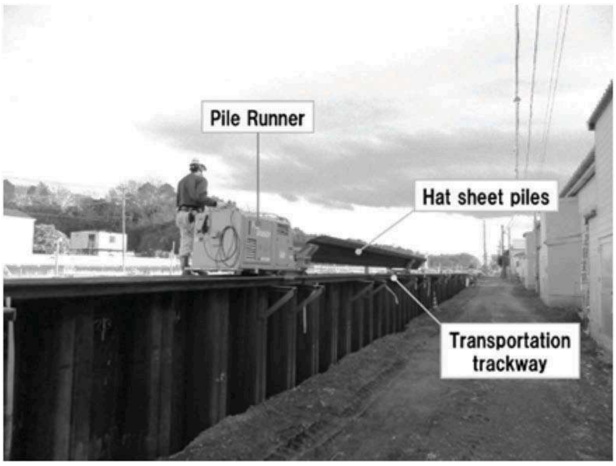

Figure 23. Pile Runner and pile transportation trackway on installed sheet piles.

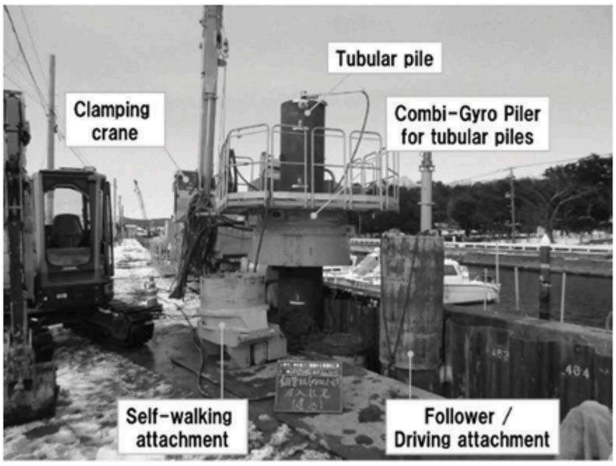

Figure 24. Non-staging System (Tubular piles as a primary structure of combined wall).

Hat sheet piles were installed in about 2 months from November 2015 to January 2016. Then tubular piles were installed in about 3 months until April of the same year to build the combined wall in a total of 5 months. (Figure 10)

5.4 *Quality control of installed piles/sheet piles*

Quality control was carried out on required parameters concerning dimensional accuracy, to ensure the installation of Hat sheet piles and tubular piles comprised with the standards and criteria specified by the client/owner (TRDB, 2020) (JRA, 2007). The results are as follows.

5.4.1 *Tubular piles*

Tables 2 to 5 show the results of measuring [1] height of pile top level, [2] deviation in plan, [3] inclination, and [4] embedded length of installed tubular piles. It was confirmed that sufficient piling accuracy was ensured for each measurement item.

5.4.2 *Hat sheet piles*

Tables 6 to 11 show the results of measuring [1] height of pile top level, [2] deviation from the planned line, [3] inclination (rightward/leftward and piling direction), [4] embedded length, and [5] wall length of Hat sheet piles. It was confirmed that sufficient piling accuracy was ensured for each measurement item.

Table 2. Assessment: Height of pile top level (Tubular piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
Pile top level	mm	±50.00	-1.02	15.00	-33.00	7.58	254	pass

Table 3. Assessment: Deviation in plan (Tubular piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
Deviation in plan	mm	100.00	17.75	55.00	00.00	11.36	254	pass

Table 4. Assessment: Inclination (Tubular piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
Inclinatio	%	2.00	0.14	1.00	00.00	0.35	254	pass

Table 5. Assessment: Embedded length (Tubular piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
Embedded length	mm	0 or over	39.59	73.00	14.00	7.80	254	pass

Table 6. Assessment: Height of pile top level (Hat Sheet Piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
Pile top level	mm	±50.00	-13.30	35.00	-10.00	12.30	24	pass

Table 7. Assessment: Deviation from the planned line (Hat sheet piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
Deviation from thethe planned line	mm	±100.00	-20.50	17.00	-65.00	18	24	pass

Table 8. Assessment: Rightward/Leftward inclination (Hat sheet piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
Inclination	degree	±10/ 1000	1.62	7.00	-6.00	3.00	24	pass

Table 9. Assessment: Inclination in the piling direction (Hat sheet piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
Inclination	degre	±10/ 1000	1.70	7.00	-2.00	2.60	14	pass

Table 10. Assessment: Embedded length (Hat Sheet Piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
Embedded length	mm	0 or over	56.70	80.00	35.00	12.3	24	pass

Table 11. Assessment: Wall length (Hat sheet piles).

Item	Unit	Control value	Mean value	Max. value	Min. value	Standrad deviation	Sample no.	Assesment
wall length	mm	0 or over	54.30	300.00	0.00	101.30	7	pass

6 SUPERSTRUCTURE WORK

After the completion of the steel tubular pile retaining wall (5.2), the combined wall composed of cut-off wall and pile foundation (5.3), the concrete coping work with cast-in-situ concrete and the breast wall superstructure work were carried out from March 2016 to March 2017 to complete the project (Figures 25 and 26).

7 SUMMARY

The case study of breast wall reconstruction in the disaster rehabilitation work reported in this paper demonstrates the following advantages of the rotary press-in piling, Combi-Gyro Method, and Non-staging System:

- With the rotary press-in piling, it is possible to install tubular piles as bearing piles, by cutting and penetrating the tuff (bearing stratum) without removing the existing structure (breast walls) in advance.
- The Non-staging System allows tubular piles and sheet piles to be installed in, even under the construction conditions deemed difficult with the other piling method (e.g. conventional pile driver). This provides good grounds for determining the structural form based on the construction conditions.
- By using pre-fabricated tubular piles and sheet piles, high-quality and high-strength tubular pile retaining wall, cut-off wall and tubular pile foundation can be constructed.
- Tubular pile retaining wall, cut-off wall (Hat sheet pile) and pile foundation (mono tubular piles) constructed with the rotary press-in piling or Combi-Gyro Method meet the control values at a high level in pile top level, deviation in plan/ deviation from the planned line, inclination, embedded length and other dimensional factors.

As is often the case with disaster rehabilitation work to reconstruct facilities adjacent to canals such as breast walls (seawalls), it is difficult to secure sufficient work space in narrow areas surrounded by adjacent buildings with many restrictions on construction conditions. Nevertheless, the project must keep the facilities around the construction site functional, bring about safety and security during construction, and be economically efficient to complete the construction in a short time. For addressing these issues, the advantages of the rotary press-in piling, Combi-Gyro Method and Non-staging System were demonstrated at the site.

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

ACKNOWLEDGMENTS

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Figure 25. Newly constructed breast wall as seawall (North side).

Figure 26. Newly constructed breast wall as seawall (South Side).

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