Press-in piling applications: Social infrastructure development using the Implant Method

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ABSTRACT

The 'press-in piling' is a piling technique whereby steel tubular piles or steel sheet piles (hereinafter referred to as 'piles/sheet piles'), which are manufactured in a factory, are penetrated in the ground. The press-in piling machine grips several piles/sheet piles that have already been installed into the ground and uses their extraction resistance as a reaction force to install the following pile/sheet pile into the ground with static load generated by hydraulic rams, which has unique features such as low vibration and noise and limited ground disturbance. Based on the unique features of the press-in piling, various equipment, piling techniques and retaining walls are being developed. This paper describes the usefulness and applications of the press-in piling in the renovation of social infrastructure in Japan, where a diversified society and preparation for natural disasters are required.

Key words: *Press-in piling, the GRB System™, the Implant™ Structure, the Implant™ Method, infrastructure development*

1. The current and future challenges of social infrastructure and natural disasters in Japan

Social infrastructure that is more than 50 years old, including road bridges, tunnels, river management facilities (e.g. sluice gates), sewerage pipelines and the quay walls[1)] are shown in **Table 1**. The proportion of these infrastructure facilities that are more than 50 years old after construction will increase at an accelerating rate in the next 10 years. Therefore, the strategic maintenance, management and renewal of infrastructures that are ageing rapidly, based on economical and sustainable measures with the understanding and agreement of the public, is a challenge in Japan.

Additionally, natural disasters caused by heavy rain, earthquakes, tsunamis and so on are reviewed. A breakdown of the frequency of natural disasters in Japan shows that typhoons account for the highest number of occurrences (57.1%), followed by earthquakes and floods. On the other hand, earthquakes, which can cause estimated losses over a wide area if they occur, account for more than 80% of the damage, followed by typhoons and floods. In terms of the number of natural disasters and the amount of damage, the number of occurrences has been increasing with fluctuations. In recent years, the heavy rainfall in July 2008 (heavy rainfall in western Japan) caused extensive damage in a wide area. With regard to such heavy rainfall, the number of occurrences of heavy rainfall exceeding 50 mm of precipitation per hour has increased 1.4 times over the last 30 years. It raises concerns that floods are expected to continue to occur more frequently in the future as a result of climate change.[2)]

The establishment of sustainable construction techniques and resilient structures for disaster relief and/or prevention work are also vital concerns in Japan.

Table 1. Proportion of social infrastructure that is more than 50 years old since construction[1) Amendment]

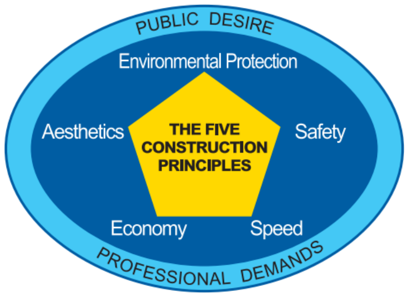
	Mar-18	Mar-23	Mar-33
Road Bridges	Approx. 25%	Approx. 39%	Approx. 63%
Tunnels	Approx. 20%	Approx. 27%	Approx. 42%
River Management Facilities	Approx. 32%	Approx. 42%	Approx. 62%
Sewage Pipes	Approx. 4%	Approx. 8%	Approx. 21%
Harbour Quay Walls	Approx. 17%	Approx. 32%	Approx. 58%

*1 Approx. 730,000 bridges (2.0m long and over)
*2 Approx. 11,000 tunnels
*3 Approx. 11,000 facilities（ex. Water gates）
*4 Total length: approx. 470,000 km
*5 Approx. 5,000 walls（4.5m water depth or less）

2. 'Five Construction Principles', an evaluation method for construction projects in the use of the five principals[3)]

The social issue with regard to the construction industry is to develop safe and secure social infrastructure and establish a recycling-oriented, sustainable society in response to global-scale problems such as population growth and the intensification of natural disasters caused by global warming. Under these social situations, the practicability and foresight of the construction method selection, its suitability and appropriateness for the purpose, have a significant impact on the environment and society in construction. Therefore, a multi-angle evaluation, including not only construction cost but also other perspectives, should be essential when selecting construction methods and structural forms. For instance, the adoption of evaluation methods such as cost-benefit analysis, environmental impact assessment and integrated evaluation method, and/or the use of concepts such as new public management and life cycle costs in asset management.

In selecting construction methods, an objective evaluation method is required that should consider not only the specialist viewpoint of a stand-alone evaluation of the construction project, but also the viewpoint of the public and the global environment. The 'Five Construction Principles' has been proposed as one of these objective evaluations. This idea consists of the five principles of environmental protection, safety, speed, economy and aesthetics, as shown in **Fig. 1**, with evaluation items and index for carrying out quantitative analysis of each principle.



Environmental Protection: Construction work should be environmentally friendly and pollution-free.
Safety: Construction work has to be carried out in safety and comfort, with a method of the highest safety criteria.
Speed: Construction work should be completed in the shortest possible period of time.
Economy: Construction work must be done rationally with an inventive mind to overcome constraints at the lowest cost.
Aesthetics: Construction work must proceed smoothly and the product should portray cultural and artistic flavour.

Fig. 1 Concept of the Five Construction Principles[3)]

The development of equipment, piling techniques and structures related to the press-in piling is being carried out with a view to satisfy these five principals in a highly balanced manner, and quantitative evaluations based on the Five Construction Principles are carried out in the development process. This provides an objective and numerical basis for the establishment of the Construction Revolution[3)], which introduces new structures and construction methods that are conducted more rationally with a novel and inventive mind compared to conventional methods and structures.

3. Piles/sheet piles and the press-in piling machines SILENT PILER™

3.1. Piles/Sheet piles

A pile is a type of deep foundation installed in the ground to transfer the load of the superstructure to the ground. Sheet piles, on the other hand, are a name for plate piles with interlocks on both sides of the plate piles, and the term is thought to derive from wooden piles cut in the shape of feathers of an arrow. The sheet pile retaining walls are also believed to have a long history, dating back to Roman times. [4)]

Piles and sheet piles are indispensable materials for construction, and a variety of materials and shapes have been developed to date to suit different applications and operating environments. Among these, pre-fabricated piles and manufactured sheet piles are widely used in Japan due to their high rigidity, quality and the relatively short period required for construction.

3.2. Hydraulic pile press-in and extraction machine SILENT PILER

With regard to installation of prefabricated piles/sheet piles, the construction machine for installing and extracting piles/sheet piles that has been developed compactly, focusing on the 'superiority of the press-in piling principle'[3)], is the hydraulic pile press-in and extraction machine SILENT PILER (**Fig. 2**). This type of press-in piling is also categorized as the walk-on-pile type press-in piling.[5)]

Fig. 2 SIRENT PILER™

The unique feature of the SILENT PILER is that the machine grips several piles/sheet piles that have already been driven into the ground and pushes and pulls the following pile/sheet pile into the ground with hydraulic static load. The idea originated from the experience that the force required to pull out a pile/sheet pile installed into the ground is much higher than the driving force due to recovered shaft friction, suction and interlock resistance. This gave an idea to link a construction pollution-free piling machine that grips piles/sheet piles already installed into the ground to obtain a large extraction resistance force as a reaction force.

Based on this idea, the SIRENT PILER KGK-100A, a hydraulic pile press-in/extraction machine designed for installing steel sheet piles, was developed in 1975. As of today, the number of units produced has exceeded 3,000 and the machine has been installed in over 40 countries and regions.

4. GRB System™ and penetration techniques

4.1. GRB System (Non-staging system)

Hydraulic pile press-in/extraction machines (hereinafter referred to as press-in piling machines) obtain a reaction force from the already embedded piles/sheet piles, which integrate with the earth, and carry out the installation while moving on the top of piles/sheet piles. With further development based on it, the GRB System[6)] was developed as a press-in piling system which carries out all piling procedures such as pile transportation, pile pitching and press-in work on top of installed piles.

The basic configuration of the GRB System is shown in **Fig. 3**. The system consists of the main body of the press-in piling machine at the front, the Power Unit with the UNIT RUNNER™ as a hydraulic power source, the CLAMP CRANE™ to pitch piles/sheet piles and the PILE RUNNER™ to convey piles/sheet piles from the storage yard. All system equipment is self-supported by holding existing installed piles with no risk of overturning. Temporary working platforms or detour roads are not required even with unstable ground condition, in narrow location, on water, on slope, and under other restricted site conditions since the range of work is minimized to just the width of the machinery.

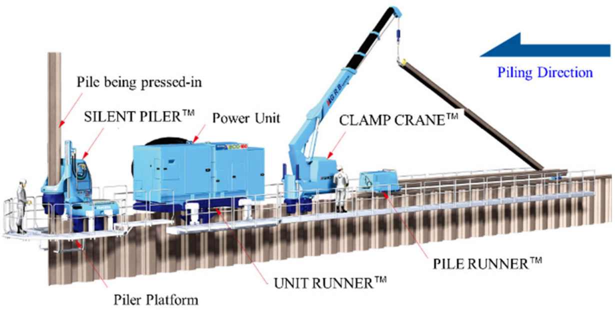
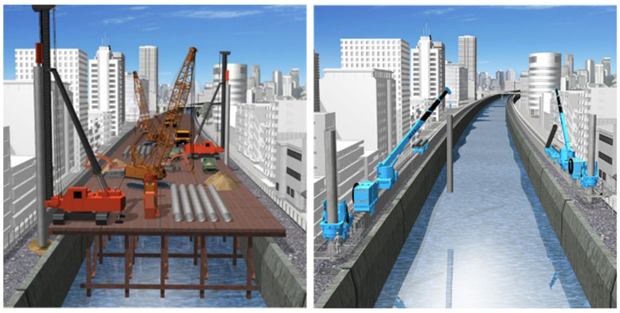


Fig. 3 GRB System™

A comparison with a conventional method for river revetment works is shown here in **Fig. 4**. The conventional method requires a temporary platform to secure the working space for the construction machinery.

On the other hand, the GRB System does not require a temporary platform along the pile/sheet pile installation and can efficiently construct the retaining wall required for revetment. This piling system has been adopted in Japan as the 'Non-staging system'[6] until now.



a. Conventional piling system b. GRB System™

Fig. 4 Comparison of conventional piling system and the GRB System™ for urban river bulkhead construction

4.2. Rotary Cutting Press-in Piling

In the press-in piling, which uses hydraulic static loads to embed piles/sheet piles into the ground, the feasibility of installation depends on the working situation such as type of piles/sheet piles, press-in force and ground conditions. For example, some ground conditions, such as dense sandy soil or gravels containing cobbles, may make penetration of piles/sheet piles difficult. If the strength of the pile/sheet pile is increased for such hard ground and a construction machine with higher press-in force is utilized, the piling work can be carried out, but the material and construction costs will increase.

In such cases, various penetration techniques in the press-in piling have been developed to reduce the penetration resistance of the ground and minimize the press-in force and conduct efficient piling work within a max reaction force from the existing pile/sheet piles. One of these is the Gyropress Method™[7] (hereafter referred to as Rotary Cutting Press-in piling), in which steel tubular piles are installed into the ground.

Rotary Cutting Press-in piling is a pressing technique where tubular piles with pile toe ring bits are rotated and simultaneously pressed-in (**Fig. 5**). It enables tubular piles to be installed through existing structures or buried obstructions. Therefore, construction costs and time can be minimized simultaneously due to the avoidance of enabling removal works.

Following the tubular pile installation, closure piles such as equal angles or small diameter pipes can be inserted to prevent soil collapsing from the active-land-side between the piles (**Fig. 6**).

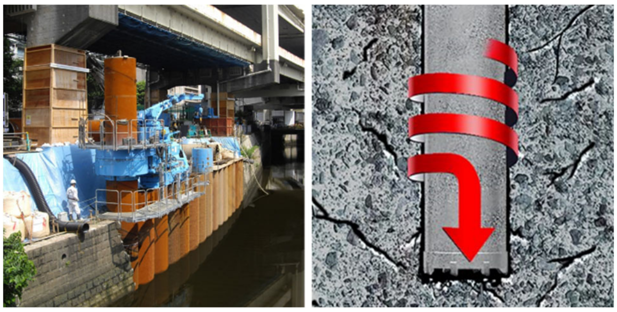


Fig. 5 Rotary Cutting Press-in piling: Gyropress Method™

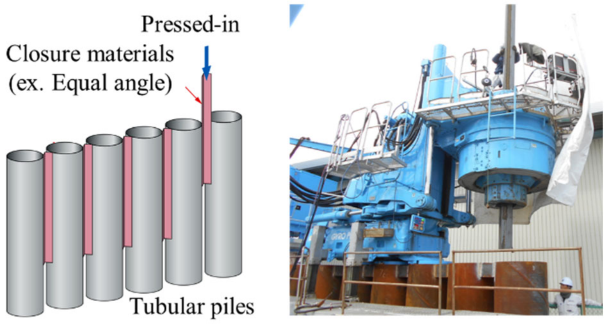


Fig. 6 Closure Materials (Ex. equal angle)

5. Implant™ Structure and Implant™ Method

As an effective countermeasure against the ageing issue of social infrastructures and frequent natural disasters stated in **Section 1**, this section introduces the Implant Structure and Implant Method using the press-in piling.

5.1. Implant Structure(s)

The major earthquake and subsequent tsunami triggered by the 2011 off the Pacific coast of Tohoku earthquake caused severe damage to jetties made from concrete blocks and caissons, as well as coastal levees that were built on ground and coated with concrete and other materials. While many levees were damaged in the same way, double-sheet-pile-wall structures used as temporary barriers in Iwate Prefecture, were reported to have maintained function and survived without collapsing, even when the tsunami far exceeding their height hit them. The report states that the structures remained functional and did not collapse.[8] The steel sheet piles used at these locations were commonly hat-shaped or U-shaped steel sheet piles, and although there was some washing-out of the fill soil and scouring of the ground in front of the sheet pile due to the tsunami, the sheet piles with the tie bars connecting the tops of sheet piles could remain. The structural stability of the sheet piles against tsunamis was roughly assessed from subsequent investigations and numerical simulations of the external tsunami forces.[9)]

This structure with two rows of steel sheet piles embedded into the ground can be regarded as an Implant Structure (**Fig. 7**), which is a deep-rooted structure consolidated with the earth. Every one of the structural members produced at the plant has high rigidity and quality, and depending on the size of the material and penetration depth into the ground, it is a resilient structure that demonstrates high rigidity against external forces in the vertical and lateral directions, forming a persistent structure.

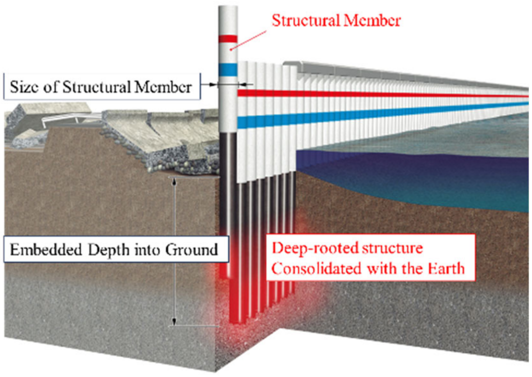
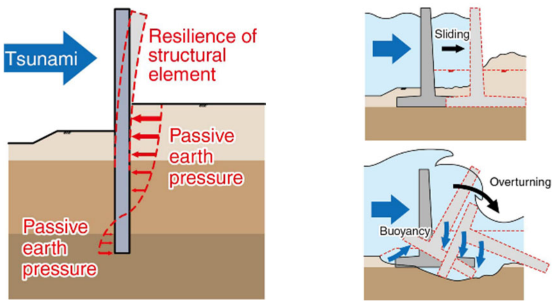


Fig. 7 Implant Structure(s)

It is considered that the sheet pile walls of the Implant Structure confined the soil in the temporary cofferdam, thereby reducing the impact of the seismic force and liquefaction simultaneously. As a result, the settlement of the structure was minimized. A comparison of the Implant and footing structures is shown in **Fig. 8**.



a. Implant Structure b. Gravity structure

Fig. 8 Implant Structure(s)

Coincidentally, the 2011 off the Pacific coast of Tohoku earthquake demonstrated the resilience of the Implant Structure and the fragility of the footing structure that resists external forces with the weight of concrete blocks and caissons placed on the ground.

5.2. Implant Method

The Implant Method is a method of constructing Implant Structures using the Rotary Cutting Press-in piling and the GRB System, which utilizes the excellent features of press-in piling. By simply pressing-in structural members at the plant into the earth from above the ground, it saves space and enables early buildings without temporary work. Through a simple and rational construction method using compact system equipment that minimises the range of impact of the work, and high-quality structural members, changes to the topography are minimised and the environmental impact is kept to a minimum in construction. Moreover, moving or removal can be done with ease by extracting structural members, and so this is a construction method that embodies function-oriented structures in line with a recyclable life cycle, such as reusing removed materials for another purpose.

6. Applications of the Implant Method

The number of applications of the Implant Method is steadily increasing in infrastructure development. Here, some case studies of various structures are introduced.

6.1. Case study of coastal levees: Implant Levee

An earthquake in the Nankai Trough, Japan, is predicted to have a 70% to 80% probability of occurring within the following 30 years. Therefore, as an immediate preparation to minimize damage from the earthquake and tsunamis, a total of 18 km of coastal levees were reinforced in Kochi Prefecture.

In the earthquake, liquefaction was assumed to cause the settlement of coastal levees significantly, and there were concerns that they would not be able to fully function against the ensuing tsunami. If the coastal levees were not upgraded to a liquefaction-resistant structure, the tsunami would overcome the collapsed levees, enter the landward side, and cause massive damage. Implant Levees were used for this liquefaction and seismic countermeasures.

The reinforcement of existing levees prevents their failure due to liquefaction and land subsidence caused by earthquakes, and the height of the levees can be raised at the same time, therefore immediately strengthening high water and flood countermeasures are crucial. The Implant Levee consists of (i) twin sheet pile walls or (ii) continuous tubular pile walls.[10] For further function, the twin sheet pile wall with bulkheads in the embankment is able to enhance its shape maintenance function (this structure is referred to as the Implant Lock Levee).

The most appropriate one can be selected at the design stage based on the requirement for the structure, the surrounding environment, the construction cost and period. Case studies of them are shown in **Fig. 9** and **Fig. 10** for the Kochi coastal embankment improvement work – Nino and Nii Construction Zone (Kochi City, Kochi Prefecture). In the case of the Nino construction zone, a relatively large area could be secured as a working space and the top of the embankment was planned to be used as a road after the construction, so a twin sheet pile cofferdam was selected due to economic reasons. On the other hand, the Nii construction zone had a narrow space in the hinterland between the national road, which is also utilized for emergency transport and the preservation beach available for the upgraded levee. Hence, a steel tubular pile wall with high rigidity was selected. This

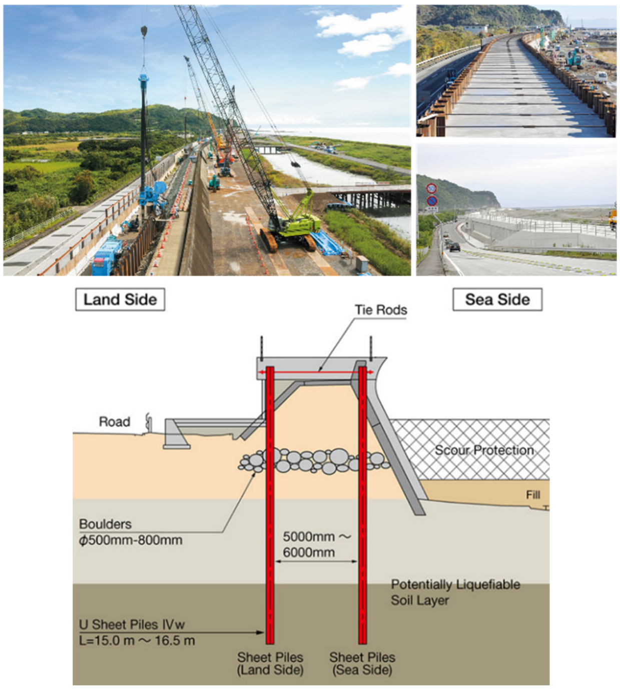


Fig. 9 Nino Construction Zone: Twin sheet pile cofferdam

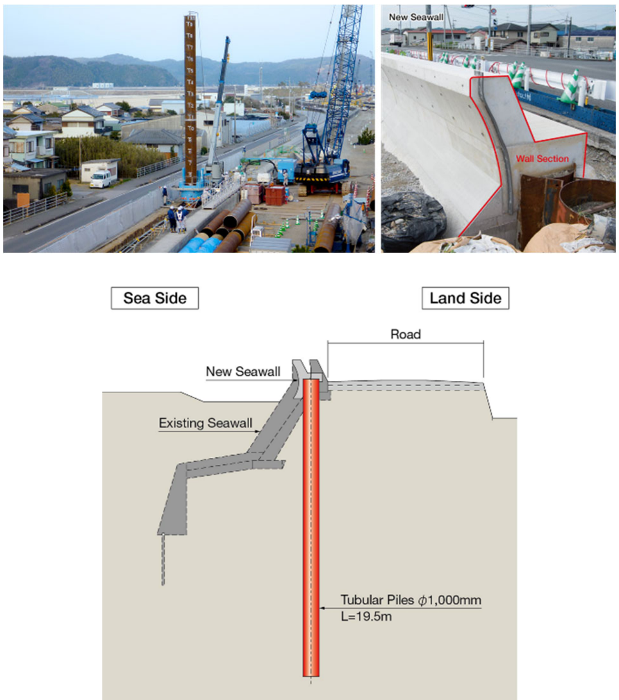


Fig. 10 Nii Construction Zone: Tubular pile wall

enabled the improvement of the existing levee to be completed without disturbing existing traffic.

6.2. Case study of sea wall: Implant Breast wall

In "Concept of design of breast walls considering tsunami (provisional version)"[11], "resilient structure" refers to a structure that a) is less likely to be totally destroyed even if damaged by unexpected tsunamis higher than frequent ones, b) extends the time by the total destruction as long as possible, and c) enables early recovery. Concerning breast walls, it is also necessary to "consider a resilient structure", and in addition, "In principle, the tsunami considered in the design of coastal protection facilities is smaller than the largest class of tsunami, so it is assumed to overflow, and it is necessary to devise a structure that is less likely to be totally destroyed by a tsunami and that can extend the time to total destruction as long as possible" in the guidance. **Fig. 11** shows an example of the improvement points for a resilient structure mentioned in the guidance, and **Table 2** shows an example of the countermeasure for each point as a resilient structure.[11]

A structure that follows this resilient structure concept is the Implant Breast wall (**Fig. 12**), constructed using the Implant Method. The height of breast walls can be regulated phase by phase. For instance, the breast wall

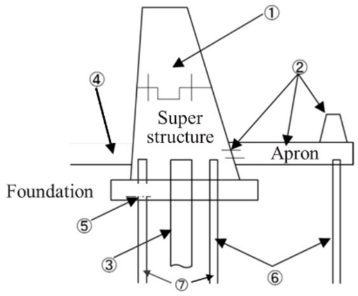


Fig. 11 Improvement points for resilient structures

Table 2. Permanent measures for resilient structures

No	Part: Permanent measurement
1	Super structure: Reduction of damage risk by the use of tenons and additional bars.
2	Apron: Widening of thickness of pavement against overflowing, Reinforcement by the integration with the superstructure, Artificial-hydraulic-jumping.
3	Foundation: Reinforcement by piles against sliding and overturning.
4	Foundation: Prevention by pavement against scouring and soil collapsing.
5	Foundation: Cement injection into ballasts against scouring and soil flowing.
6	Counter measurement against scouring: Prevention by steel sheet piles against scouring and soil flowing from the ground under the foundation.
7	Counter measurement against scouring: Prevention by steel sheet piles against uplift pressure by seepage flow

can be risen additionally, in case of higher sea level caused by climate change in future. (**Fig. 13**).

Fig. 14 shows a case study of its application. In this case, a combined wall (steel tubular piles and hat-shaped sheet piles) was installed behind an existing breast wall.[12] The tubular piles were embedded into the support layer and the structure was designed to support the weight of the upgraded levee as a pile foundation.

The tubular piles and sheet piles were integrated with the existing breast wall using reinforced concrete, and the breast wall was raised and widened to the planned height and width. One of the features of this construction method is that the piles/sheet piles can be installed in a narrow space and do not require the acquisition of land in the hinterland. Furthermore, the structure can be constructed using precast concrete

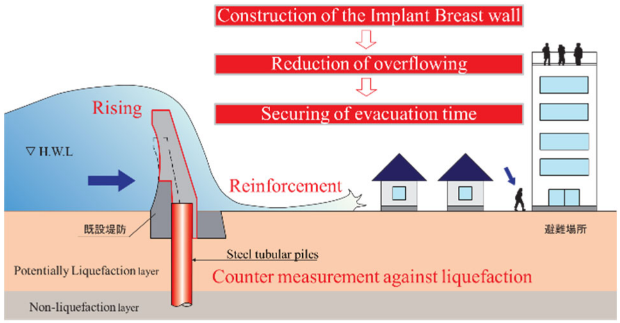


Fig. 12 Implant Breast wall (Sea wall)

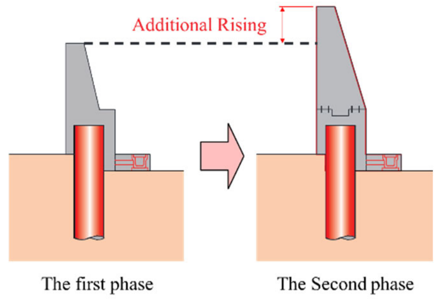


Fig. 13 Rising phase by phase (Conceptual design)

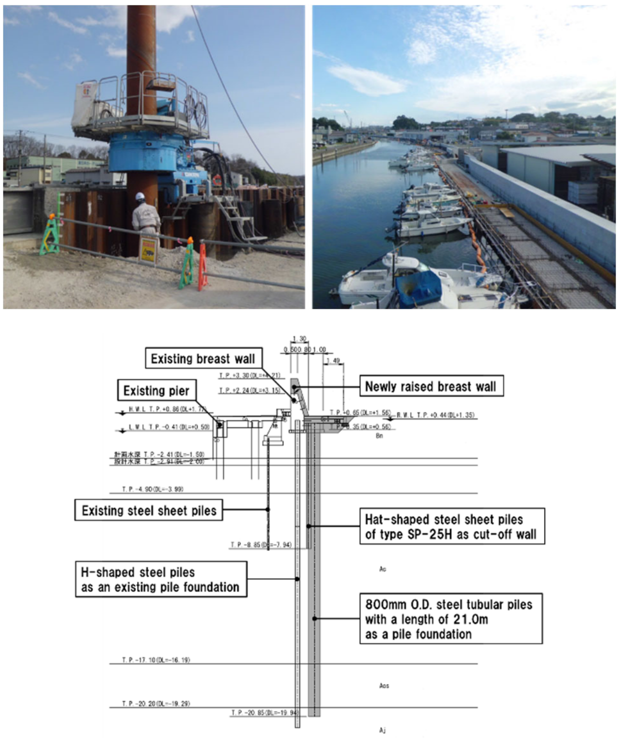


Fig. 14 Case study of Implant Breast wall of Rising type [12]

members instead of cast-in-place concrete for the superstructure (**Fig. 15**). It has the advantage of ensuring high quality and significantly reducing the construction period. In Japan, the number of applications is on the increase due to recent demand in the construction industry, the shortage of craftsmen to handle cast-in-place

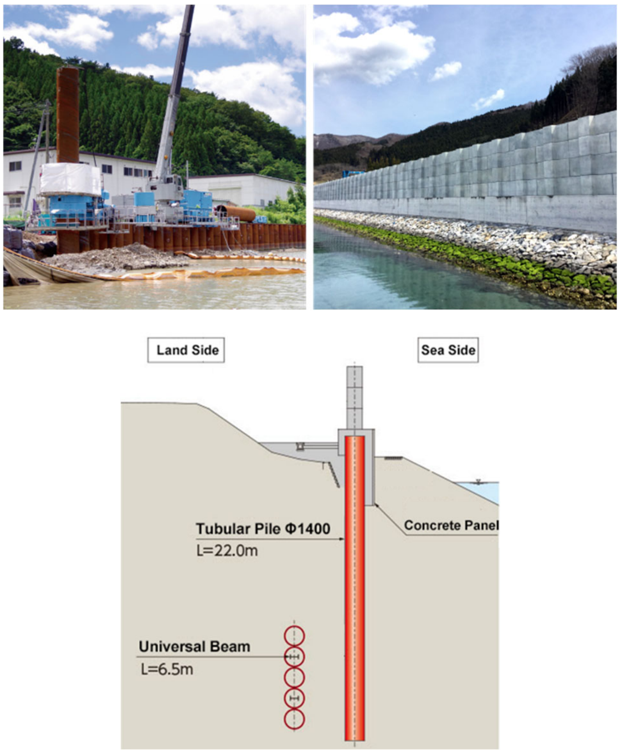


Fig. 15 Case study of Implant Breast wall with precast supuer structure

concrete due to the ageing of the workforce, and the ease of management with prefabricated products.

6.3. Case study of retaining wall(s): Implant Retaining wall(s)

A retaining wall, which is a structure designed to restrain soil, is a relatively rigid wall used for supporting soil laterally so that it can be retained at different levels on the two sides. A cantilevered structure constructed using the Implant Method is an Implant Retaining wall. The installation of ground anchors to reduce the displacement of the pile/sheet pile heads and the use of lightweight fill as backfilling materials allow the selection of steel tubular piles/sheet piles that meet the performance required for the newly constructed wall.

Implant Retaining walls are often used in the road and rail sectors for road and rail widening. The construction of footing structures made of reinforced concrete require complex construction processes i.e. temporary retaining walls, bulk excavation, shoring and backfilling etc. On the other hand, the Implant Retaining wall is directly installed into the ground forming an extremely resilient structure with a minimal footprint and construction process. Furthermore, the system equipment is relatively compact and the working space for the installation of the piles/sheet piles can be minimized. In addition, the advantage of the press-in piling, which is vibration-free, makes it possible to minimize the impact caused by the construction work (*i.e.* deformation). For this reason, it has been used in many construction projects where displacement of existing structures is an issue (*e.g.* railway construction).

In the case of multi-level construction of flat cross railways, the use of the Implant Method reduces the requirement for complicated detour rail trucks and long-term restrictions to secure the working space in construction. **Fig. 16** shows the relocation project of the railway, which is a case study of the Implant Retaining wall for the railway widening. **Fig. 17** shows the standard cross section of the tubular pile installation. [13)]

In this project, there were concerns about the anchor-type retaining wall because it was confirmed in the ground investigation that some of the rock layers were unsuitable for ground anchors. Furthermore, the working space was on a slope adjacent to a railway in service and residential buildings. Under these difficult

Fig. 16 Relocation project of the railway: Implant retaining wall for the rail widening

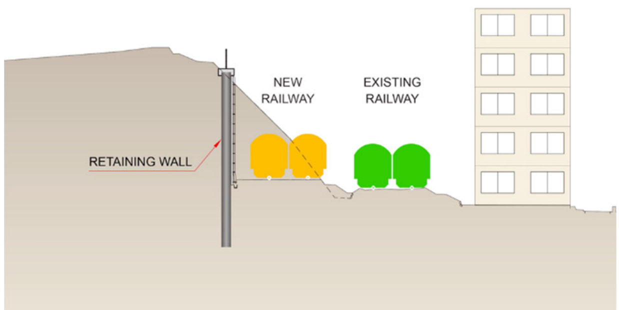


Fig. 17 Standard cross-sections

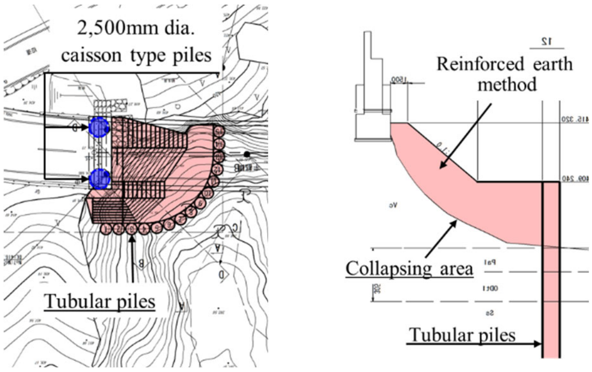
working conditions, an Implant Retaining wall consisting of continuous tubular piles was adopted, using the Rotary Cutting Press-in piling with the GRB System which does not require a temporary platform and can conduct the piling work in narrow areas.

6.4. Case study of disaster renovation work

The frequency of heavy rainfalls is increasing in Japan, and there is concern that flooding and landslides may occur more often in the future. The Implant Method can also be applicable for disaster renovation work resulting from such natural disasters, taking advantage of its features.

Heavy rainfall caused by a typhoon, resulting in landslides over a wide area in front of the abutment. The existing stream was heavily washed out with a large volume of soil, difficult to install a temporary platform for restoration. Reinforcing the ground surrounding the abutment was essential. As a permanent countermeasure, steel tubular piles with a 1,500mm diameter were installed as a permanent cofferdam and the ground in front of the abutment was improved with the reinforced earth method. The pile layout and standard cross section of the tubular piles are shown in **Fig. 18**. This measure increased the ground bearing capacity in front of the abutment and reduced the horizontal displacement, enabling the existing abutment to continue to be used without other countermeasures such as additional piles or replacement of a new bridge.

For installation, there was a necessity to embed tubular piles into sandstone with an extrapolated SPT N-value of 750 and over. For this reason, a Rotary Cutting Press-in piling was adopted, using tubular piles with pile toe ring bits. In addition, the GRB System was



a. Layout of steel tubular piles b. Standard cross-section

Fig. 18 Steel tubular pile layout for the rehabilitation

also utilized due to a lack of working space for heavy machinery under the bridge. **Fig. 19** shows the installation of the tubular piles. After the tubular piles were installed, flat steels were welded between piles as closer materials and the space with filled by the reinforced earth method. **Fig. 20** shows the comparison of the situation of before and post construction.

Fig. 19 Installation of tubular piles

Fig. 20 Comparison of before and post construction

7. Concluding remarks

This paper describes issues related to the development of social infrastructure in Japan, construction techniques of the press-in piling, introduction of the Implant Structure and Implant Method, some case studies in the improvement of infrastructures (coastal levees, breast/sea walls, and retaining walls), and the usefulness of the Implant Structure and Implant Method for disaster renovation work as a permanent measure.

The development of infrastructures and disaster renovation works has often faced difficulties in terms of huge cost and long duration because of the need for a large temporary platform and backfilling to secure the working place. In addition, the impact on the surrounding environment, caused by land acquisition and large-scale earthworks, should be carefully considered.

In contrast, the Implant Method, which meets the Five Construction Principals (Environmental protection, Safety, Speed, Economy and Aesthetics), can be considered an effective method that provides neighbouring residents with safety and security, and reduces the disruption in traffic relating to the economy and society. The establishment of a 'Construction Revolution' to introduce practical, novel and inventive structures and construction methods should be a 'new evaluation' for future infrastructure development worldwide.

Finally, it is hoped that the Implant Method and some case studies introduced in this paper will serve as a reference for all researchers and practical engineers involved in the diversified development of infrastructures, and that they will also be used in various ways for preparation against natural disasters.

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* The Gyropress Method is a joint development between GIKEN LTD. and NIPPON STEEL CORPORATION.