Case Study of Underwater Press-in Method of Steel Sheet Piles under Restricted Headroom beneath a Railroad Bridge

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ABSTRACT

The *Musashi* Canal is a facility which diverts water from the *Tone* River to the *Arakawa* River. In 40 years of use since its completion, the canal had various challenges. To tackle those challenges, the *Musashi* Canal Reconstruction Project was implemented from 2010 till 2015. There were, however, extremely severe construction conditions in the project site. Firstly, the construction work needed to be implemented without any interruption of serving water since it was a very crucial water resource for the *Tokyo* Metropolitan area. Secondly, it was never allowed to affect the railway service of *JR-Takasaki* Line which is an artery of transportation for the metropolitan area and crossing over the canal. To implement the reconstruction under these constraints, we developed a new steel sheet pile press-in technology. In detail, there were four major improvements on a sheet pile press-in machine and development of a special steel sheet pile which has two specific functions. Sheet piling has already been used at a lot of construction sites. However, there was a limit on its use at sites where only narrow work space in a vertical direction is allowed. With the use of this new technology, this disadvantage has been overcome successfully and it is expected that the technology would be further improved and developed through future rehabilitation and renewal projects.

Key words: *canal reconstruction, press-in machine, sheet pile, mechanical joint, lateral interlocking*

1. Project outline

The *Musashi* Canal with the total length of 14.5 km is a concrete lining canal which flows through *Gyoda* City and *Konosu* City in *Saitama* Prefecture and diverts water from the *Tone* River to the *Arakawa* River as shown in **Fig. 1 and 2**. It was constructed in March, 1967, to solve the problem of water shortage in the metropolitan area during the period of rapid economic growth. The *Musashi* Canal is still supplying municipal water throughout the year to about 13 million people living in 18 wards and 18 cities of *Tokyo* Metropolis and in 20 cities and 8 towns of *Saitama* Prefecture, which supports society and economy of the metropolitan area as a crucial lifeline.

However, the *Musashi* Canal which had been in use for about 40 years was facing the following challenges.

- Recovering its capacity of conveying water which had decreased by 30% due to wide range land subsidence and deterioration of canal itself

- Strengthening earthquake resistance assuming a future large scale earthquake
- Strengthening drainage of inland flood water in consideration with urbanization along the canal etc.

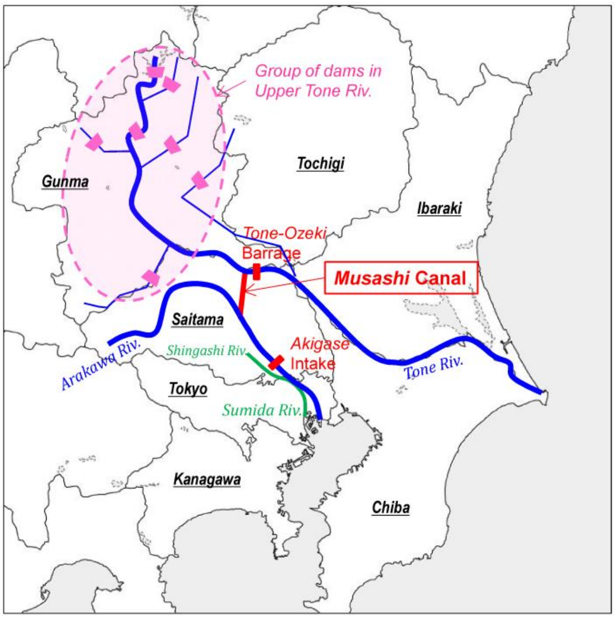

Fig. 1 Location of the *Musashi* Canal

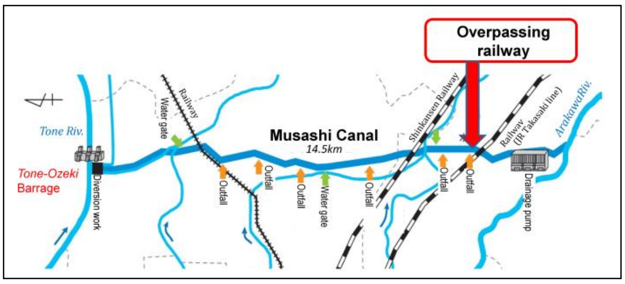

Fig. 2 Location of construction site

To tackle these challenges, the "*Musashi* Canal Reconstruction Project" had been implemented for seven years from 2009 till 2015. The reconstructing work was to convert the existing trapezoidal canal with 150mm-thick plain concrete lining into a double-lane rectangular canal which was made of reinforced concrete.

The *Musashi* canal had been serving as an important lifeline for the metropolitan area and was not allowed to interrupt its service for a long period. Consequently, major repairing works could not have been carried out even if the canal would have been severely damaged. For this reason, the existing canal was drastically restructured into the double lane canal which enabled to check and repair one side of the canal in a planned manner with serving water on another side. Also, the double lane can reduce life cycle costs by extending life of the facility.

2. Background of developing the new technology of press-in sheet piles under water

This project was implemented under the very severe constraint that the facility needed to be totally reconstructed with the conveyance of domestic water for the metropolitan area continuously, which was the function of the existing facility. In particular, a hard work at the point of intersection of JR-*Takasaki* Line and the *Musashi* Canal (about 100m long) was foreseen from its planning phase.

Two stage diversion was adopted for the reconstruction work of the 14.5 km-long canal, which enables construction of both sides of the canal in turn. Firstly, all bridges and roads which would hinder the reconstruction work were diverted. Then, by placing steel sheet piles into the canal center lengthwise, removal of the existing canal and construction of the new canal became possible using one side as a dried working area while conveying municipal water on the other side as shown in **Fig. 3**.

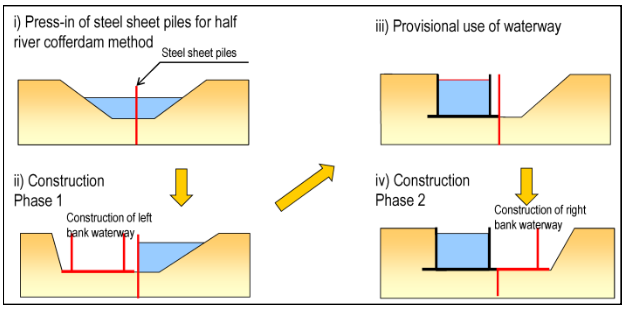

Fig. 3 Process of reconstruction by two stage diversion

However, only the *Mida* bridge crossing over the *Musashi* Canal was not able to be removed since it was located on JR-*Takasaki* Line which is a major artery connecting *Hokuriku*, *Shinshu* and North-*Kanto* regions with the metropolitan area. More than 300 trains go across the bridge at 5 to 10-minute intervals. Given social and economic importance of the railway service, it was necessary to implement the reconstruction work with the bridge remaining and with the service secured.

On the other hand, the canal of reinforced concrete double flume could not be constructed in this place because of physical interference by the abutments of the *Mida* Bridge. Bypassing the canal to other places was also unrealistic due to densely built-up residential areas nearby the construction site. Consequently, the design for this section was changed to be of the double siphon.

Under these circumstances, steel sheet piles needed to be placed at the center of 20m wide canal in flowing water under the railway bridge as shown in **Fig. 4**. Specific conditions are shown below, which were unprecedentedly severe ones even in the world. In order to handle these challenges, it was inevitable to develop new innovative technology on placing sheet piles.

<Conditions>

i) First priority for the safety and stability of railway transportation

ii) The extremely limited clearance with 1.5m height between the bottom of bridge and the surface of the water with the flowrate of 20m^3/sec and the velocity of as high as 2.0m/sec

iii) Underwater press-in of steel sheet piles with only 1.0m clearance between the head of sheet piles and the bottom of bridge

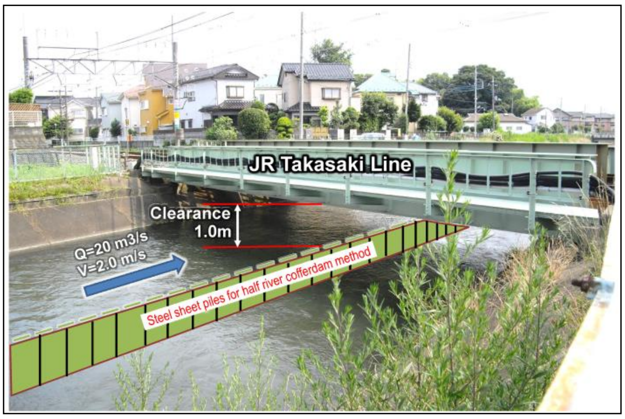

Fig. 4 Construction conditions

3. Development of new technology

The newly developed technologies of this time can be summarized as following two subjects.

i) Development of the main body of a press-in machine for use under extremely low clearance

ii) Development of special steel sheet piles and a hoisting device for them

3.1. Development of the main body of a press-in machine for use under extremely low clearance

The press-in machine for use under the extremely low clearance (hereinafter referred to as "Press-in machine") is a system which enables all of hoisting, pitching and press-in operations concerning steel sheet piles within the clearance limit of 1.0m (between the top of the steel sheet pile and the bottom of the bridge) as shown in **Fig. 5 and 6**. This Press-in machine incorporates four features improved from conventional press-in machines.

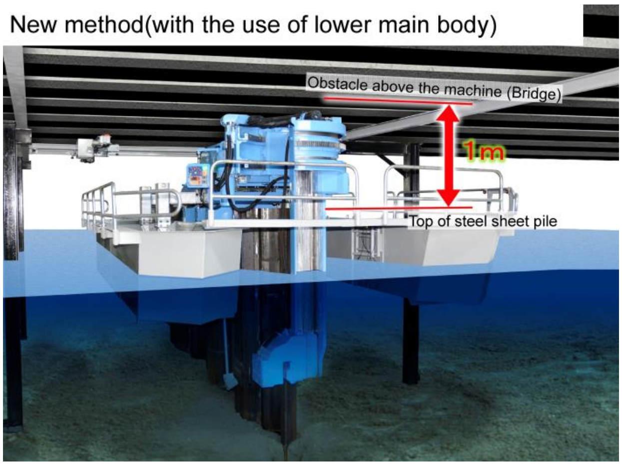

Fig. 5 New method

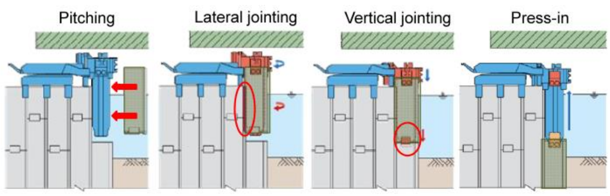

Fig. 6 Process of press-in operation by new method

i) Lower machine body

- The mechanism of conventional press-in method is that a press-in machine of 2,520mm in height placed on the top of settled steel sheet piles clamping 3 or 4 points of web of sheet piles from which the machine can receive reaction force. A sheet pile is brought into the machine by a crane and pressed into the ground chucking with a settled sheet pile.
- In a conventional way, at least 3m added clearance is required taking into account the height of machine and the space for rotation of crane which is used for serving a new sheet pile from above. In addition, sheet piles can be pressed in only from

higher place than settled sheet pile heads.

- By overcoming these technical challenges, the new press-in machine with a lower body was developed. The height of this machine including the press-in stroke was low enough to be set in the clearance of 1.0m and it could place a steel sheet pile from below the top of settled sheet piles.

ii) Horizontally movable function

- The conventional machine is equipped with self-moving function, but it needs to raise itself above the top of sheet piles beforehand by clamping webs of settled sheet piles.
- Developing a new type of clamps which grip joints of steel sheet piles made possible horizontal self-movement as shown in **Fig. 7** without raising itself.

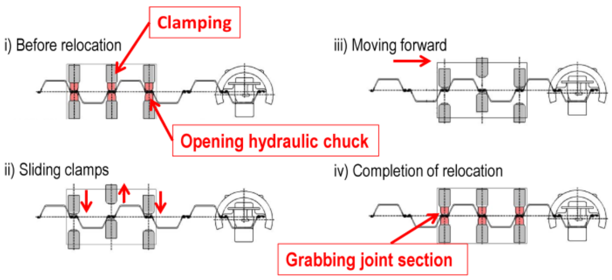

Fig. 7 Horizontal movement of press-in machine by new method

iii) Press-down function

- The conventional press-in machine could not grasp steel sheet piles under the water surface, since it clamped the piles directly by a stroke jack.
- By pushing down the press-down rail using the stroke jack, press-in action of steel sheet piles under the water surface with the moving jack clamping them became possible as shown in **Fig. 8**.

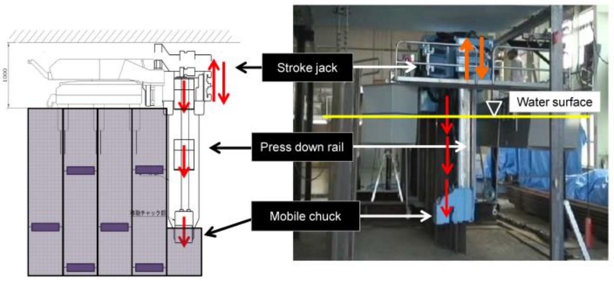

Fig. 8 Mechanism of press-in a steel sheet pile in new method

iv) Pitching a steel sheet pile

- In the case of the conventional press-in machine, steel sheet piles were pitched from above using a crane.
- Pitching of a steel sheet pile from the side of the press-in machine became possible by developing a pitching equipment named open chuck as shown in **Fig. 9 and 10**.
- As a result, it became possible to pitch a pile longer than the height of clearance above the machine using underwater space.

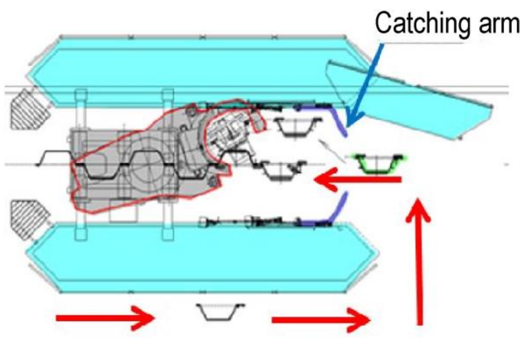

Fig. 9 Pitching a steel sheet pile

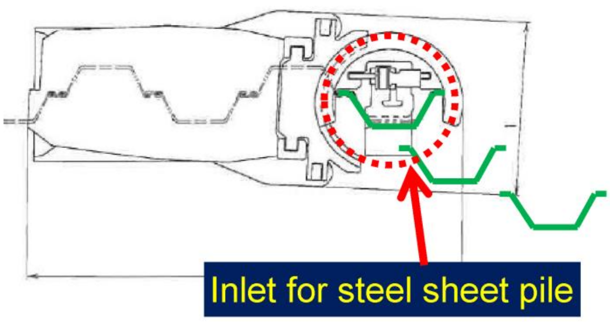

Fig. 10 Open chuck

These developments made more space available and enabled a longer steel sheet pile to be placed into underwater. Furthermore, improvement of construction speed was attained by reducing the number of vertical jointing parts of the steel sheet piles.

3.2. Development of special steel sheet pile

Adjacent steel sheet piles are normally connected with each other by inserting an interlocking part of one pile vertically into an interlocking of the other pile. However, the special steel sheet pile was developed to be fitted from lateral direction by horizontal feed joints in S-shape as shown in **Fig. 11**, so that the function of the new press-in machine to pitch steel sheet piles in the horizontal direction (named "open chuck function") can be made use of.

Additionally, it was necessary to increase the number of vertical joints for the work under limited clearance since only a short sheet pile was available and it needed to be added one by one for the required length. Furthermore, at the construction site, underwater welding in a rapid stream running at 2.0m/sec was required. To cope with these difficulties, together with the development of the new press-in machine, the special steel sheet pile employing a mechanical vertical joint was developed, which makes usable the new machine's function of placing a sheet pile down into water and also makes underwater vertical jointing possible. As a result of this development, no more welding operation in rapidly flowing water is required and overall safety and performance on construction were greatly improved. Moreover, the employed joint has the structure of one-touch joint and water cut-off performance is secured as shown in **Fig. 12**.

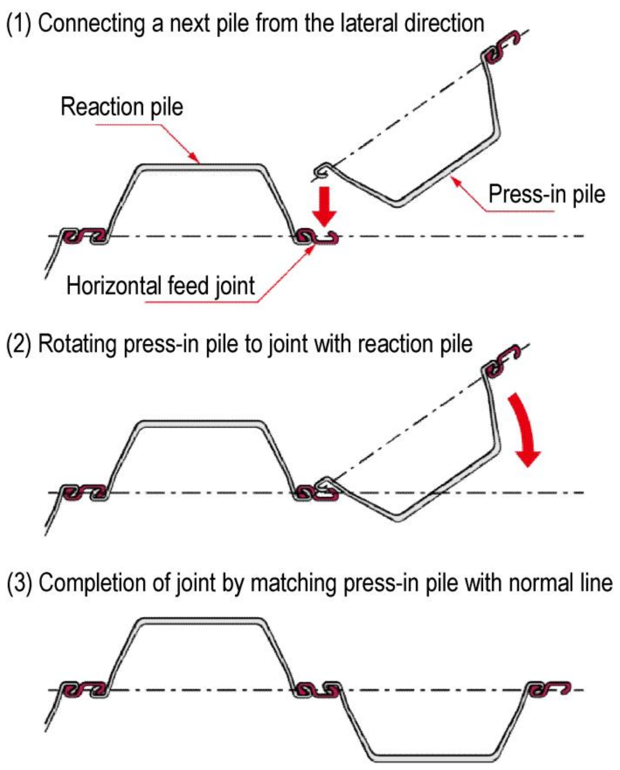

Fig. 11 Development of special steel sheet pile (#1 horizontal feed joint)

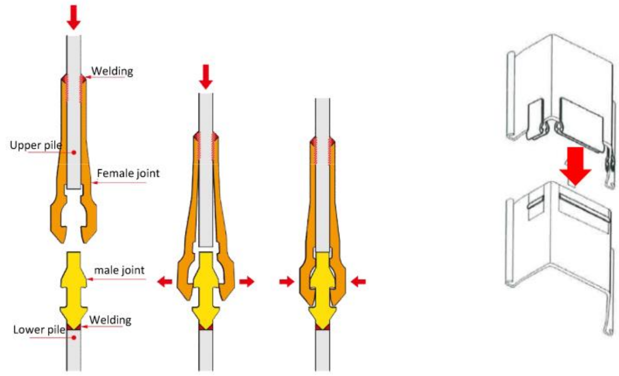

Fig. 12 Development of special steel sheet pile (#2 mechanical vertical joint)

As a supplement, bending strength of the special steel sheet pile and tensile strength of the vertical joint were confirmed to be satisfactory by the full-scale bending strength test. Furthermore, to secure required water cut-off performance, water-swelling rubber was employed for connecting parts of each steel sheet pile as a leakage countermeasure and water-swelling sealing material was applied to section parts as shown in **Fig13**.

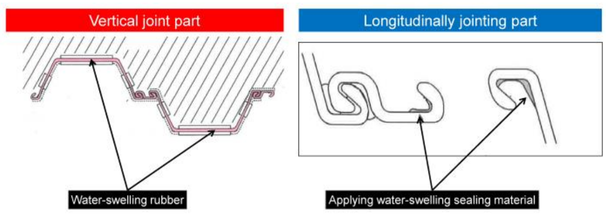

Fig. 13 Development of special steel sheet pile

3.3. Development of auxiliary equipment for placing

i) Special steel sheet pile hoisting device

Dedicated rails for hoisting a sheet pile and a placing device were also developed in parallel so that special steel sheet piles could be placed safely, and underwater placing could be performed easily on the canal under the bridge. This is a system to serve a steel sheet pile by moving the hoist in the front/rear and left/right directions along the two rails laid between support pillars placed into the canal and the foot of the bridge.

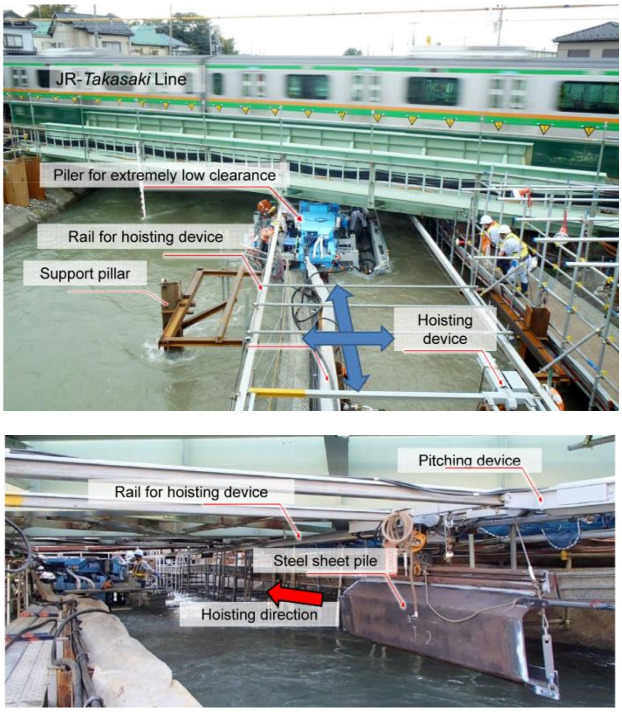

Photo 1. Special steel sheet pile hoisting device

ii) Openable catching arm

The *Musashi* Canal has a rapid stream with the flow velocity of 2.0m/sec and there was some concern that a steel sheet pile would be tilted by the stream when being placed, and that it might not be placed exactly vertically. To avoid this, it was decided to newly develop an openable catching arm to prevent a tilt and sway of steel sheet piles. Closing the catching arm enables a steel sheet piles to be placed correctly preventing any tilt and sway as shown in **Fig. 14**.

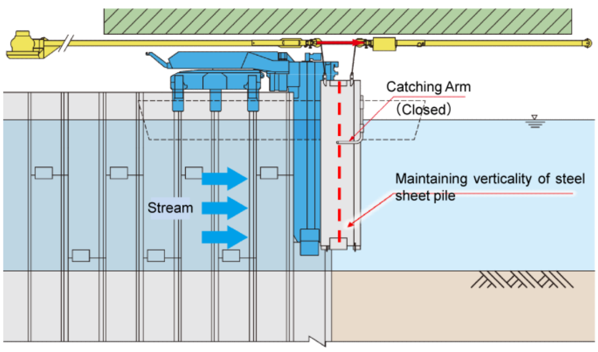

Fig. 14 Catching Arm

iii) Oil leakage countermeasures

The *Musashi* Canal is a facility to supply domestic water to 13million residents of *Tokyo* Metropolis and *Saitama* prefecture. Right after running down the canal, water flows into the *Arakawa* River, then is taken at *Asaka* Water Purification Plant (right bank side: *Tokyo* Metropolis) and *Okubo* Water Purification Plant (left bank side: *Saitama* Prefecture). Once an oil leakage accident happens, it immediately leads to interrupting intake at both of the water purification plants, so strict countermeasures against oil leakage are required.

At the site of construction work, all externally exposed parts of hydraulic hoses related to the press-in machine were completely cured and waterproof structure was employed for the main body of the press-in machine including hydraulic moving parts.

4. Troubles and solutions during construction

4.1. Press-in capacity of the new machine for use under extremely low clearance

During pressing a sheet pile in by the newly developed machine, it was observed that larger reduction of pressing power than that of the conventional press-in machine.

The new machine clamps settled steel sheet piles at different points from those clamped by the conventional press-in machine. Comparing the normal vector of both clamped reaction base and press-in point, it was found that there is some gap. This gap caused some loss of press-in power by giving the lateral external force to the machine and tilting steel sheet pile on which the press-in machine sat as shown in **Fig. 15**. Given this lesson learned, it should be noted that loss of press-in performance needs to be taken into account when a work plan is made.

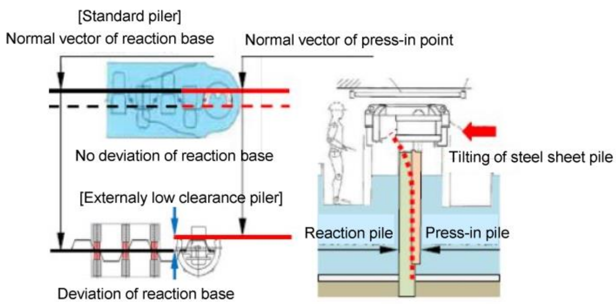

Fig. 15 Loss of press-in performance of press-in machine

4.2. Securing construction quality of underwater jointed parts

As already mentioned, a special steel sheet pile was jointed with an adjacent steel sheet pile by horizontal feed joints first, then it was lowered into and jointed under water with the steel sheet pile settled previously by vertical mechanical joints. The integrated sheet pile was further pressed into the ground. For securing the construction quality, it was confirmed by an operator of the press-in machine by checking a monitor image which was taken with an underwater camera and presented on a laptop PC.

Although confirmation work was under a very severe condition as well as construction, like high flow velocity of 2.0m/sec and constant turbidity which allowed only 30cm visibility, joints could be sufficiently confirmed by attaching LED lights to the underwater camera and protecting its front lens by an acrylic board.

4.3. Breakup of lining concrete

The special steel sheet pile needed to be pressed in after breaking up lining concrete (plain, t=250mm) of the bottom floor of the existing canal. For this process, it was planned to break lining concrete in advance using another specific steel sheet pile whose edge was processed and reinforced in the shape of cutting edge in parallel with the use of a water jet. Then, the special steel sheet pile could be pressed in.

Actual construction work could be carried out almost as planned, but there were cases which took more press-in time than planned. Judging from the situations visually confirmed after closing and drainage of the canal, the probable cause of this could be considered that some of concrete pieces destroyed in advance had dropped into holes made by the water jet and caused extra placing for press-in work of steel sheet piles.

4.4. Securing space for operation

Placing work had to be done in a stream with flow velocity of 2m/sec and also in extremely low clearance of 1.5m from the water surface to the bottom of the bridge. To secure the space for workers to support placing piles, boat-shaped pontoons were deployed at both sides of the press-in machine as shown in **Photo 2**, which was equipped with an openable working passage to connect the work spaces on both sides and allow smooth movement between each side.

Photo 2. Space for workes

5. Summary

In this construction work, in order to overcome unprecedentedly difficult conditions of construction in the world, we tackled development of a comprehensive new technology including press-in a steel sheet pile below water surface and horizontal movement of the press-in machine, which was technically based on the press-in method with the use of the Silent Piler.

As a result of this, the conventional concept of jointing steel sheet piles could be changed with the use of the newly developed horizontal feed joint which can be fitted in the lateral direction, and also with the use of mechanical vertical joint which can be joined in water quickly.

Using this newly developed technology, construction works that had to be given up in the past due to low clearance could become possible and this technology would be used at a lot of construction sites. Furthermore, the application to “renewal work of urban infrastructure which has complicated three dimensional shape” and “indoor retaining work” can be considered. It is expected that through recognition by many people further improvements will be made on these technologies, which will make them more useful ones.

It is anticipated that this paper would be a good opportunity for this technology to be broadly recognized by many people.

References

Hasegawa, S., Takada, M. and Takata, K. 2014. Press-in Method of Steel Sheet Piler for Use under the Extremely Low Clearance beneath the *JR* Railroad

Bridge, Proceedings of 69th Annual meeting, Japan Society of Civil Engineers, VI-447, pp. 893-894.

Kunitomi, H. and Takata, K. 2015. Case Study on Press-in Machine of Steel Sheet Piles under the Extremely Low Clearance on the Canal beneath the Railroad Bridge, Proceedings of 70th Annual meeting, Japan Society of Civil Engineers, VI-606, pp. 1211-1212.

Japan Construction Method and Machinery Research Institute. 2012. Report on the Full-scale Bending Strength Test of the Steel Sheet Pile Wall with Employing both mechanical Vertical Joint and Horizontal Feed Joint (Comparison of the Strength with Conventional Steel Sheet Pile).