Emergency Repair of Flood-damaged Bridge Pier Foundations with Pressed-in Piles

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ABSTRACT
Flooding often causes severe scour around bridge pier foundations, causing suspension or slowdown of rail service on bridges. Normally, the damaged structures will need to be repaired as quickly and safely as possible to resume the rail service. However, many bridge piers are located under rail girders with small overhead clearances. The damaged pier foundations of such bridges are highly sensitive to vibrations from the repair construction itself. To make the matter more difficult, the soil conditions around the damaged piers are often gravels and/or boulders brought by flooding or by an originally-planned placement to protect against scour. Repair of damaged bridge pier foundations sometimes requires casting of reinforced concrete around them inside cofferdams made of steel sheet piles or pipe piles. To build these cofferdams, conventional pile driving such as diesel or vibratory hammer methods are not easily applicable without additional time-consuming and costly auxiliary methods to mitigate the aforementioned difficult site conditions. On the other hand, the hydraulic Press-in Pile Driving Method, which generates extremely low vibration, works very efficiently in low headroom and hard soil conditions because of the way the system works. The first case study is about an emergency rail bridge pier foundation repair project in Fukuoka Prefecture in Japan. The second case study discusses an extremely low headroom (3.3 feet, i.e., 1.0 meter) sheet pile driving in an aqueduct under a railway girder in Saitama Prefecture in Japan.

INTRODUCTION
Railway bridge piers and abutments are often exposed to high level of flood water, which causes severe scour around them. The damage may settle and/or tilt the foundations involved. In addition, the overhead clearance under the girders and the vibration control are the major constraints for the repair work. Cofferdams made of steel sheet piles or pipe piles around the piers or abutments are often constructed for the repair, while driving them into the ground near the damaged foundation will require special attention to the structural integrity of the foundation during construction. The Press-in Pile Driving Method, a low-noise and extremely low-vibration pile driving method, has been safely utilized for railway bridge foundation repairs and waterway reconstruction work under railway bridges even in extremely low headroom conditions.

PRESS-IN PILE DRIVING METHOD
The Press-in Pile Driving Method typically utilizes a reaction force derived from a few previously installed piles to hydraulically press in the next pile. The pile driving equipment of this type works on top of already installed piles and moves forward on its own as shown in Figure 1. Because this method does not use vibratory or percussive force to drive the pile, it is regarded as an environmentally-friendly pile driving method. Its advantages are:

1. Low noise and practically vibration free (1). It enables pile driving projects close to houses, schools, hospitals, and other sensitive structures as well as in the areas where sensitive fish and/or animals are around. The low-vibration feature was the primary reason that the method was chosen for repair of the damaged bridge pier foundation in the first case study discussed later in this paper.

2. The equipment size is relatively small and its clamping points are much lower than those of other pile driving methods. These features enable the equipment to work in physically tight working conditions, both horizontally and vertically, such as an area under railway girders or right next to them as shown in the second case study.
3. With attachments, it can drive piles into hard soil effectively. A high pressure water jet attachment or a continuous flight auger attachment allows the piles to be driven simultaneously as the attachment loosens the hard soil.

4. It can achieve much more accurate and safer pile installation due to a combination of better control of the piles and lower clamping points compared with other pile driving methods. Driving as long as 95-foot (29-meter) long sheets into dense sand to construct a cofferdams was successfully achieved on a separate project.

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**Figure 1 Sequence of “Self-walk” by the Press-in Pile Driver**

**JR KYUSHU RAILWAY COMPANY KUMAKAMI RIVER BRIDGE FOUNDATION REPAIR, FUKUOKA PREFECTURE, JAPAN**

One of the piers of the Kumakami River Bridge on the Kyudai Line in Fukuoka Prefecture, Japan was heavily damaged by typhoon-caused flooding in July 2012, resulting in deep scour around the foundation. The railway service was suspended at the time of the flooding until temporary repair was completed, however, train speed on the bridge after resumption of service had to be kept low, waiting for the permanent repair.

The pier’s original footing protection was lost to scouring. The soil conditions at the pier were mainly boulder-mixed gravelly sand with a 3.5-foot (1.1 meters) thick sand layer at 6 feet 8 inches (2.0 meters) below the ground surface. N-values were above 60 at 10 feet (3.0 meters) below the ground level and beyond as shown in Figure 2. The railway company was concerned about the safety during the repair work due to a combination of the work’s proximity to the girder carrying live rail traffic and the sensitive foundation. The overhead clearance under the girder was less than 11 feet and 4 inches as shown in Figure 3. The permanent repair was to build a cofferdam with 16-foot-long (4.8-meter) pipe piles and to fill the inside with reinforced concrete as shown in Figure 4.

Gyro-press pile driver was chosen for driving pipe piles into boulder-mixed gravelly sand under the girder. Gyro-press is a variation of the Press-in Pile Driving Method, particularly for pipe piles. Figure 5 shows the mechanism of Gyro-press pile driver, which clamps onto already-driven piles to install a new pile by a combination of press-in and rotational forces. A sacrificial cutting shoe is welded at the bottom end of each pile to facilitate driving.
Although this project did not require heavy-duty cutting shoes, piles could be installed into an existing concrete structure or very hard soil by using those with heavy-duty cutter bits as shown in Figure 6. Eight piles under the girder were spliced twice each due to the limited headroom, while those outside the girder were driven full length without splices.

![Figure 2 Soil Conditions and Dimensions of Pipe Piles](image-url)
Figure 3 Cross-Section of Repair Work (Unit: mm)

Figure 4 Plan View of Repair Work

Figure 5 Gyro-press Pile Driver
The temporary footing protection had been placed as shown in Figure 7. After its removal as part of the preparation for the permanent repair work, the Gyro-press pile driver drove pipe piles expediently to form a cofferdam without affecting the sensitive foundation as shown in Figure 8. Re-bars were placed inside the cofferdam as shown in Figure 9 and finally concrete was cast (Figure 10).
The Musashi Aqueduct is an 8.8-mile (14.5 kilometers) long concrete-lined waterway at about 40 miles (65 kilometers) northwest of Tokyo, Japan. With its opening back in 1967, overall rehabilitation work is currently
conducted in order to repair the structural deteriorations and also to enhance its seismic capacities. It crosses the East Japan Railway Company’s busy Takasaki line where the overhead clearance for the aqueduct rehabilitation work was mere 3.3 feet (1.0 meter). See Figure 11 for the pre-construction conditions of the site.

The project at the rail bridge was to build double barrel concrete syphon boxes underneath the diagonally crossing railway steel girder (approximately 115 feet long, i.e., 35 meters). The syphon structure’s inner cross sectional dimensions were two units of 13.1 feet (4.0 meters) wide and 13.8 feet (4.2 meters) high rectangles (Figure 12). The soil conditions at the site were mostly soft silt and medium sand with the highest N-value of about 30 in the middle of the sheet pile penetration.
The aqueduct had to carry a certain amount of water at all times. Therefore, the construction was done by the multi-stage diversion method, utilizing sheet pile walls driven into the aqueduct floor parallel to the direction of flow. The center sheet pile wall had to be driven first in an overhead clearance of 3.3 feet or 1.0 meter (between the top of the installed sheet piles and the bottom of the girder) in rapid water flow of up to 5.5 feet (1.7 meters) per second. Figure 13 is a schema showing the relationship between the very low headroom Press-in sheet pile driver, sheet piles, and the railroad girder.

![Figure 13 Sheet Pile Driving Work Under the Railway Girder](image)

There were two semi-submerged boat-shaped stages where the operator and other workers could work safely on both sides of the equipment under the railway girder. Short sections of U-shaped sheet piles were mechanically jointed both horizontally and vertically in the running water by the pile driver. The development of this sideway interlocking system allowed the use of sheet piles almost as long as the distance between the girder and the floor of the aqueduct \(^{(3)}\). Four splices were made to install 29.1 feet (8.9 meters) long sheet piles as designed. The hydrophilic tape affixed in the groove of joints minimized the water seepage through the joints.

Normally, the press-in piling equipment moves by the chuck holding onto a halfway installed pile, then lifts itself up and moves forward or backward the rest of the body as necessary. In the case of this pile driver, there was not enough headroom for lifting the upper portion of the machine. Instead, this equipment moved forward or back by independently adjusting horizontal positions of the clamps so the clamps would not interfere with the sheet piles during the move. This function eliminated the need for lifting any part of the pile driver or a service crane to move it during the press-in operation under the rail girder.

As stated earlier, the sheets were driven mostly in soft silt and medium sand. A high pressure water jet attachment was used to facilitate the press-in operation.

Figure 14 shows the pile driver being assembled on a platform prior to use. Figure 15 shows the pile driver pressing in the sheet piles under the railway girder. Figure 16 shows the completed center sheet pile wall with
the diverted aqueduct flow behind the sheet piles. Figure 17 shows half of the syphon structure built in the
dried side of the aqueduct with diverted flow on the other side of the center wall.

Figure 14 Assembly of Very Low Headroom Press-in Sheet Pile Driver

Figure 15 Driving a Sheet Pile Within a 3.3 feet Clearance
CONCLUSIONS
Railway bridge piers are subject to settlement due to flooding or other causes and railway operators could lose a large amount of revenue without prompt and safe repair. The Press-in Pile Driving Method provides an expedient and very safe repair solution by practically vibration-free driving of pipe piles and sheet piles even in hard soil or in a very low headroom situation. Sheet piles can be pressed in as narrow as a 3.3-foot (1.0-meter) overhead clearance in a fast current without disrupting the rail service on the bridge above it.

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REFERENCES
Emergency Repair of Flood-damaged Bridge Pier Foundations with Pressed-in Piles

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Overview
1. Background
2. Press-in Pile Driving
3. Case Study No. 1, Oita Japan
4. Case Study No. 2, Saitama, Japan
5. Conclusions

Background
Causes of Bridge Pier Foundation Failure
1. Scour by flooding.
2. Settlement.
3. Sliding or falling.
4. Detachment from the load bearing layer.
5. Separation at concrete joints.
6. Deterioration of concrete members.
7. Pier failure by seismic force.
8. Seismically-induced liquefaction.

Concept of Bridge Pier Repair with Sheet or Tubular Piles
Railway Technical Research Institute (Japan)

Advantages of Repair with Sheet or Tubular Pile Cofferdam Foundations
1. Increased loading capacity, vertically and horizontally. Also suited for aseismic upgrade (prevents liquefaction).
2. More economical & shorter construction period compared to adding piles.

What is the Press-in Pile Driving Method?
Use hydraulic force to push piles into the ground.
So, it is practically vibration-free.
A Los Angeles Area Contractor’s Statement on Press-in Piling

CASE STUDY NO. 1
JR Kyushu Railway Company
Kumakami River Bridge
Foundation Repair Project
Fukuoka Prefecture, JAPAN

Project

Soil Conditions

Plan View of the Repair Work

Cross-Section of the Repair Work
CASE STUDY NO. 2
East Japan Railway Company
Musashi Aqueduct Renovation Project
Saitama Prefecture, JAPAN

Cross Section of Syphon Structure and Soil Conditions

Sequence of Syphon Structure Construction

Plan View of the Project

Sheet Pile Delivery System Under the Railway Girder
Vertical and Horizontal Joints

Sheet Pile Stockpile

Interlocking a Horizontal Joint

Horizontal Joint Mechanism

Horizontal and Vertical Joints

Joint Locations

(Unit: mm)
Conclusions

1. Bridge pier repair with sheet or tubular pile cofferdams is highly effective and economical.
2. Press-in pile driving can provide an expedient and very safe repair solution for emergency railway bridge repair even in a very low overhead clearance.

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Question?