Reinforcement of Damaged Bridge Pier by Scouring Using Steel Pipe Piles

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ABSTRACT

This report introduces a case where railways bridge piers were damaged by scouring and restored using steel pipe piles. The Kumanouegawa Bridge of JR Kyushu was damaged by flooding in July, 2012, one of the bridge piers settled and tilted to the upper stream. Regarding the permanent repair intended for train operation at a normal speed after the immediate repair intended for the resumption of train operation at a slow speed, it was judged to be optimal to install steel pipe piles into the river bed in such a manner that they surround the footing of existing foundation and to connect them with the side surface of footing by reinforced concrete. In the actual construction, since the height of the lower surface of the girder of the bridge from the river bed is only about 4.0 m, the driving method of the piles had to be applied even at a construction site with low-height space. For this reason, steel pipe piles, were installed by press-in method which enables construction in this small space. The driving of the steel pipe piles was started in winter when the water level of the river was low, and the construction of the connecting concrete was finished about one month later.

Key words: *Steel Pipe Piles, Reinforcement, scouring, Bridge pier*

1. Outline of the project

1.1. Kumanouegawa Bridge

The Kyudai Line on which Kumanouegawa Bridge stands is a railway line crossing northern Kyushu that has linked Kurume Station in Kurume City in Fukuoka Prefecture with Oita Station in Oita City in Oita Prefecture since 1934 when it was fully opened (**Fig. 1**). Kumanouegawa Bridge is located between Ukiha Station and Chikugo Oishi Station in the Kyudai Line as a bridge crossing the Kumanouegawa River, which is a main river in the Chikugogawa river system.

Fig. 1 Locatoion of Kyudai line

Kumanouegawa Bridge was constructed in 1931. Its superstructure is a seven-span deck-type deck girder with a total bridge length of 71.18 m, and a maximum span length of 9.14 m. Its substructure consists of six elliptical bridge piers supported by a spread foundation.

1.2. Outline of the disaster

The Northern Kyushu Downpour of July 2012 recorded a maximum hourly rainfall of 78.5 mm and a maximum continuous rainfall of 336.0 mm, causing severe damage in northern Kyushu. On the Kumanouegawa River, as shown in **Fig. 2**, the water level rose as high as it almost reached the crest of the bridge piers under the impact of this downpour. At Kumanouegawa Bridge, the foundation was scoured, and the fine-grain component of the bottom surface ground was sucked out at the elliptical bridge pier P2 with a footing thickness of 0.6 m and a bridge pier height of 3.76 m, causing the bridge pier to settle (about 300 mm) and lean (49/1,000 rad upstream and 21/1,000 rad toward Oita Station) (**Fig. 3**). The revetment near the bridge pier P1 was washed away. It has been pointed out that bridge

Fig. 2 View during the flood

piers P3 to P6 that were not damaged by the flooding had been prone to be destabilized by past scouring, and various countermeasures including those by the foot protection method had been taken. However, the bridge pier P2 had been shorter than the other bridge piers and had been covered with an earth cover from its footing crest to a height of about 1.5 m, so countermeasures had not been taken at this bridge pier.

1.3. Immediate repair for slow train operation

Regarding the repair of the damaged bridge pier P2, such tentative work as is described in the following was done to quickly reopen the bridge for slow-moving train operation before the work to be done for train operation on the bridge at the prescribed speed.

・Clarifying the natural frequency by an impact vibration test to confirm the state of the bottom surface of the foundation

・Preloading work for removing the looseness on the bottom surface of the foundation.

・Repairing the concrete of the bearing supports

・Trial driving by a test train

After completing the above-mentioned work, a train was run across the bridge at a slow speed of 15 km/h during which time the displacement of the bridge pier P2 was monitored. The train operation resumed at the slow speed 1.5 months after the disaster.

2. Repair method for usual train operation

2.1. Site condition

As stated above, the bridge pier P2 was a short bridge pier, and it was only possible to ensure overhead working space of about 4.0 m under the girders. Also, during the

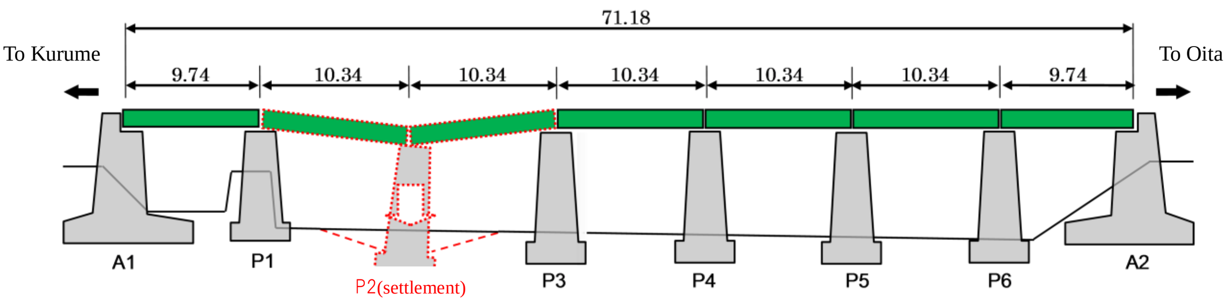


Fig. 3 Overview of the damaged bridge pier

permanent reconstruction work, although traveling slowly, trains were already crossing the bridge, requiring that the work be done directly under the bridge piers while trains were in operation. Also, the work done for the retrofit bridge pier P2 was to be done in the river, which necessitated blocking the river partially by a cofferdam, and as a result of the consultations with the river manager, approval for executing the retrofit was obtained on the condition that the retrofit be executed in a short period during the dry season.

2.2. Ground condition

Fig. 4 shows the results of boring near the bridge pier P2. The boring locations is, as shown in **Fig. 5**, directly under the bridge girder between the bridge pier P2 and the bridge pier P3 of Kumanouegawa Bridge.

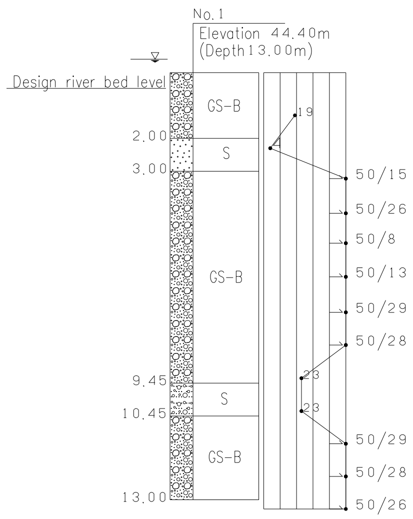


Fig. 4 Borehole log

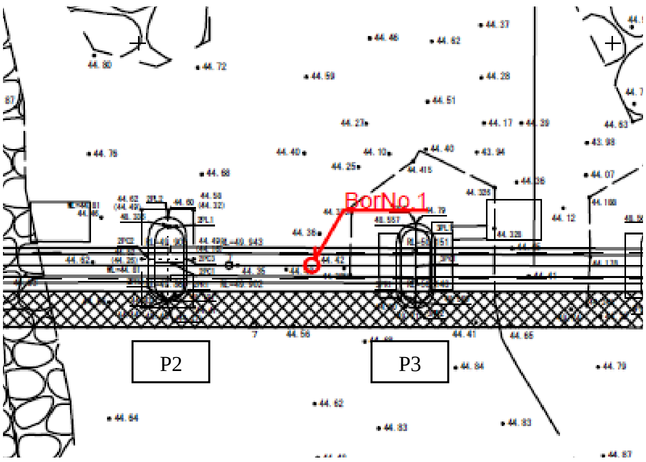


Fig. 5 Location of boring

At this location, there is a gravel layer mixed with round stones with a *N*-value of 19 near the design riverbed level, but there is also a sandy layer with a *N*-value of 4 from 2.0 m to 3.0 m below the designed riverbed level. Below the sandy layer, there is another gravel layer mixed with round stones with a *N*-value over 50, and the diameter of some of the round stones exceeds 300 mm.

2.3. Required performance

The following two points were designated as the required performance of the reinforcement methods to be used to restore the damaged bridge piers.

[1] Form a foundation that will be stable under the action of scouring of the bridge piers during future flooding of the same severity.

[2] Form a foundation that will obstruct the cross section of the river to less extent than the adjoining bridge piers.

2.4. Structural type and piling method

As specific foundation retrofitting work methods for the bridge pier P2, [1] ground improvement on the bottom surface of the foundation and [2] retrofitting the foundation using steel sheet piles were considered. [1] was removed from the choices of little expectation of rainforcement. Because the foundation of the bridge pier P2 was a spread foundation and the embedded depth after the disaster was extremely shallow, it would be difficult to ensure adequate resistance against future flooding by executing only ground improvement work. It was concluded that [2] reinforcement of the foundation with steel sheet piles could sharply improve the bearing capacity at the time of a future flood or sinking of the riverbed, because it has been applied many times in the past and the foundation is supported by a gravel layer containing round stones below the sandy layer with a *N*-value of 4 located from 2.0 m to 3.0 m under the designed riverbed level, as stated in Section 2.2 above. However, as stated in Section 2.1, because, at the bridge pier P2, workspace of only approximately 4.0 m in height could be ensured under the girders, and the execution would have been impossible without using an auger capable of crushing round stones larger than 300 mm in diameter, as mentioned in Section 2.2. This problem was

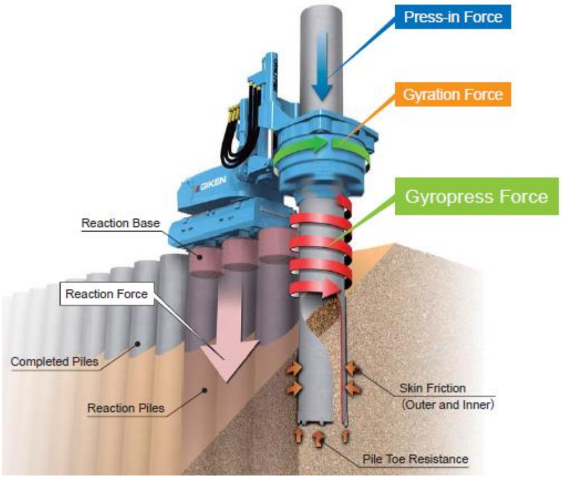
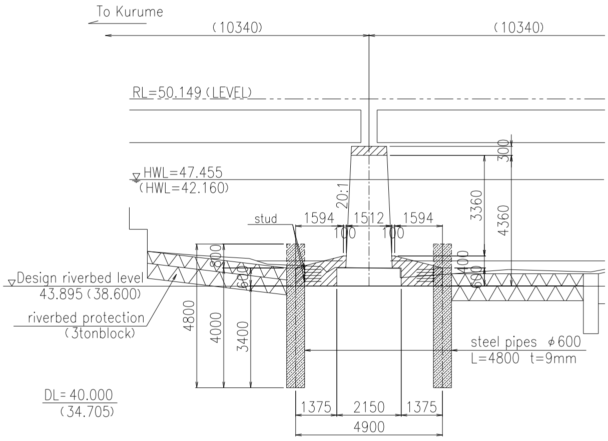
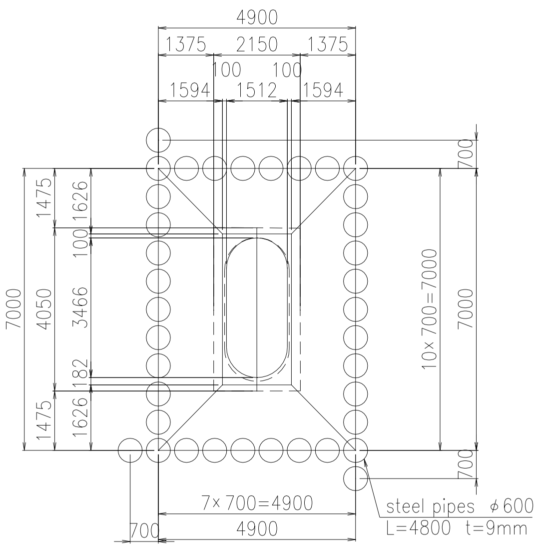


Fig. 6 Overview of the gyropress work method



(a) Front view



(b) Plan view

Fig. 7 General drawing of the restoration

resolved by adopting the gyropress work method using steel pipes instead of steel sheet piles, as shown in **Fig. 6**, permitting the execution in the reduced space.

At first, execution using steel pipes only near the girders where the workspace was narrow and execution using steel sheet piles at other locations were considered. However, it is possible to reduce the thickness of the footing if the number of steel pipes is increased and their diameter is reduced. This is a structure that would not greatly obstruct the river cross-section, so steel pipes were installed on the entire surface of the bridge pier, as shown in **Fig. 7**, and the tops of the steel pipes were connected to the bridge pier with reinforced concrete. The restoration of P2 was completed with 37 steel pipes 600mm in diameter and 4.0 m long.

3. Press-in piling

3.1. Layout

Fig. 8 shows the layout of the machines that pressed in the steel pipe sheet piles, and **Fig. 9** is a photo of the

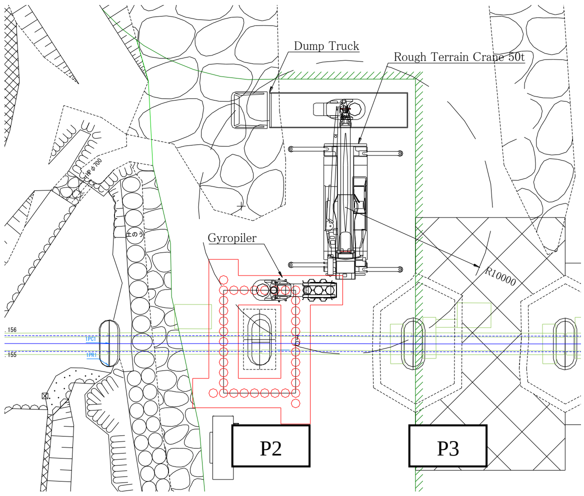


Fig. 8 Layout of the restoration execution machines

Fig. 9 View of the steel pipe pile press-in work

execution. For this execution, part of the river was blocked with a cofferdam, as explained in Section 2.1. The cofferdam was executed by arranging large sandbags so that they enclose the bridge pier P2 and construction machinery, as shown in **Fig. 8**.

Fig.10 is a photograph of the work completed.

Fig. 10 Work completed

3.2. Limit value of tilting

During press-in of the steel pipes, trains started to run across the bridge at a slow speed, as explained in Section 2.1. If the bridge pier P2 had tilted under the impact of the press-in of the steel pipes, the tracks might have been displaced, so, during the execution, the tilting was continually measured to check its values against the control values.

The control values were calculated based on the track's maintenance reference values and warning values, work stoppage values, and limit values, were set as shown in **Table 1**.

3.3. Monitoring data

Fig.11 shows the fluctuation of the tilting of the bridge pier P2 of the Kumanouegawa Bridge after the

Table 1. Control values of tilting during the restoration work

	Longitudinal level irregularity of the track	Alignment irregularly of the track	Tilt in the line direction	Tilt at right angles to the line	River level
Warning Value	9mm (22.0mm×0.4)	9mm (22.0mm×0.4)	0.08°	0.08°	–
Work stop Value	15mm (22.0mm×0.7)	15mm (22.0mm×0.7)	0.13°	0.13°	–
Suspention Value	22mm (22.0mm×1.0)	22mm (22.0mm×1.0)	0.20°	0.20°	3.4m

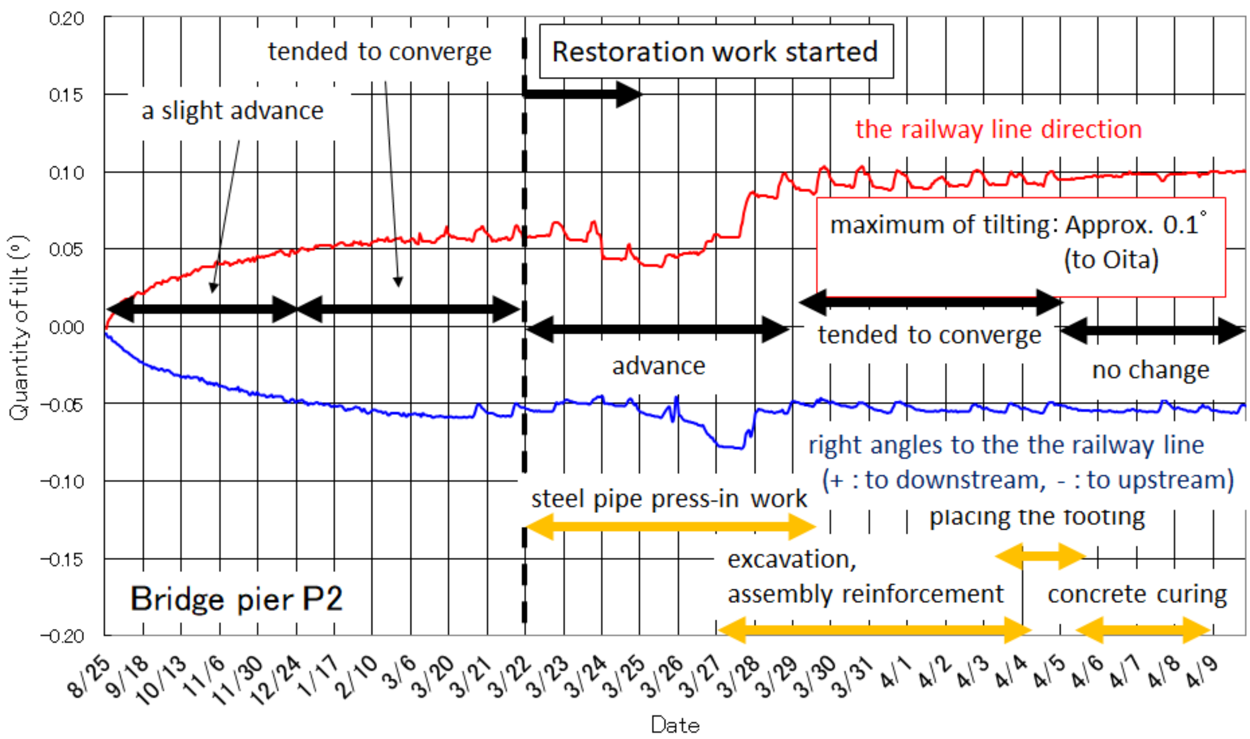


Fig. 11 Change in tilting

completion of the immediate work. When trains were first allowed to cross the bridge at a slow speed after the execution of the immediate work, a slight advance of tilting upstream and toward Oita Station was seen. About four months later, tilting tended to converge at about 1/1,000 rad (approximately 0.06°) in both the direction of the railway line and the direction at right angles to it.

After the restoration work started, the advance of tilting (tilting toward Oita and upstream) was seen during the steel pipe press-in work and during the excavation between the steel pipes and the body concrete after the completion of the press-in work. Nevertheless, even the cumulative tilting never exceeded 1.6/1,000 (approximately 0.1°), which means that the work-stopping value was not reached and that the work was completed successfully without obstructing the train service. After the steel pipes and the body were connected by reinforcing bars following the completion of the excavation, the progress of the measured values showed a tendency to converge. This is considered to be a result of the integration of the steel pipes and the body.

Later, the measured values did not change very much until the slow train operation was discontinued after completion of the restoration.

3.4. Productivity

The ground supporting the bridge pier P2 was, as explained in Section 2.2, a gravel layer containing round stones whose diameter exceeded 300 mm, but the adoption of the gyropress work method allowed the press-in of the steel pipe piles without any impact by the round stones and other objects. Specifically, although the construction work was done under a bridge where trains were operated, 5piles were installed per day, which led to the completion of the press-in of 37 steel pipes in 8 days.

4. Concluding remarks

This report introduced the case of Kumanouegawa Bridge in the Kyudai Main Line operated by JR Kyushu as an example of the permanent restoration of a bridge damaged by flooding.

Thanks to the restoration of Kumanouegawa Bridge, the structure will be able to withstand future floodings of similar severity, and it will keep the obstruction of the river cross-section to a minimum. In addition, this was a case where the construction of a steel pipe pile foundation structure was completed using a gyropiler as a method for constructing structures when only a small construction space is available.

The retrofitting was completed without any accidents in a work period of about one month, during which time the tilting and settlement of the bridge pier were monitored constantly, so that the train operation at the prescribed speed could be resumed on Kumanouegawa Bridge. None of the displacement, deformation and other abnormality of the bridge at the prescribed speed were found.

The authors hope that this report will be of use as a reference concerning the restoration of bridge piers damaged by flooding.

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