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# Survey of Bridge Damages Due to a Heavy Rain in Northern Part of Kanto Region, Japan



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## ABSTRACT

Many kinds of damages due to the deterioration of structural member, earthquake, scour and ground deformation have occurred at the bridge foundations in Japan. Among them, the scour damages during floods are extensive. First, in this paper, the authors present the actual situation on the damage due to the bridge scour in Japan, particularly highlighting of damages occurred due to the heavy rain on August of 1998 in Fukushima and Tochigi prefectures (Northern Part of Kanto Region). Then, they try to analyze the characteristics of the foundation type incident to be damaged by scour.

## 1. INTRODUCTION

A concentrated intensive rainfall in the northern part of Kanto region at the end of August 1998 brought a cumulative rainfall of 1,200 mm and a maximum rainfall of 90 mm/hour, causing serious damages in the region (Fig. 1). Not only did the number of dead, the number of missing people, and the number of dwelling damaged all reach levels rarely seen in recent years, the rain inflicted severe damages on the road traffic infrastructures with inundations, sediment disasters, and damaged bridges forcing the closing of both expressways and national highways (hereafter, N.H.), etc. at 645 locations. This paper summarizes results of the survey of bridge damages caused by the rainfall.

## 2. SURVEY RESULTS

### 2.1 Outline of Damages

It was confirmed that 14 of 16 bridges examined in this survey had been damaged in some way. The damages are presented in Table 1.

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A breakdown of the type of damage reveals that bridge abutments were damaged at 11 bridges and that damage to bridge piers occurred at 3 bridges.

One characteristic of this disaster is that the access road behind the abutment was washed away at 10 of 11 bridges that suffered abutment damages with the only exception being the Kumagawa Bridge. Among these bridges, the bodies of the left bank abutment of the Yosasa Bridge (N.H. No.4) and of the right bank abutment of the Kurokawa Bridge (Prefectural Road) were also washed away, allowing the spans they supported to collapse. At the Habuto Bridge, scouring caused the downstream side of the abutment to settle down and tilt. Damage to piers was, in all cases, settlement and tilting caused by scouring.

## 2.2 Characteristics of the Damage

### 2.2.1 Washing Away of the Access Road behind an Abutment (Yosasa Bridge, N.H. No.294)

The Yosasa Bridge is a simple RCT girder bridge with four spans and a total length of 37.4 m across the Yosasa River (constructed in 1927). The foundations of both abutments and piers are spread foundations.

This deluge washed away the soil behind the abutment on the right bank along with a 60 m long section of the access road (Photo 1). Moreover, on the left bank side, soil was washed away (length of 10 m) on the downstream side of access road. The examination of the superstructure revealed that part of the railing was damaged by overflow water, but no damage was found on the body of the substructure. The following process caused the damage to the soil behind the right bank side abutment.

Because the flood was much greater than the capacity of a channel section of the river, flood water overflowed at the slightly curved right bank close to 200 m upstream of the Yosasa Bridge, and as they flowed, they washed away the access road. The damage behind the left bank abutment was caused by the suction of the soil resulting from the increased flow.

### 2.2.2 Scouring of an Abutment at Water Colliding Front (Habuto Bridge)

The Habuto Bridge is a simple RCT girder bridge with 4 spans and a total length of 84 m across the Abukuma River (constructed in 1969). The foundations of both abutments and piers are spread foundations. The Abukuma River bends gently towards the right near this bridge.

The flood tilted the abutment on the left bank side that was the outside of this curve to the downstream side and twisted the superstructure. This resulted in cracking, apparently caused by shearing, in two girders on the upstream side.

As Photo 2 shows, on the downstream side of the abutment, the soil behind the abutment washed away with even some soil on the upstream side washed away.

It is assumed that the scouring damage was caused by the direct impact of the flood water on the revetment near the left bank side abutment, and suction of the soil resulting from the vortex which were formed during the flood.

### 2.2.3 Settlement and Tilt of a Pier Caused by Scouring (Kumado Bridge)

The Kumado Bridge is a simple RCT girder bridge with 3 spans and a total length of 30 m across the Kumado River (constructed in 1935). The foundations of both abutments and piers are spread foundations. Like the Habuto Bridge, it is constructed at a point on the Kumado River where the river bends greatly to the right.

Its left bank side abutment was undamaged because it was protected by a concrete revetment and a spur dike, but the pier on the outside of the bend in the river was damaged by scouring.

As shown in Photo 3, the damaged pier settled 2.3 m on the upstream side and tilted by about 20 degrees to the upstream side. This was accompanied by serious deformation of the superstructure and damage such as pulling out of anchor bolts at the bearing, damage to the railings and so on.

In order to clarify the state of streambed near the pier following the flood, the river was partly blocked to alter its flow and a survey was performed, but because of secondary sedimentation, it was not possible to visually confirm the state of scouring.

For this reason, boring explorations were performed at two locations about 4 m upstream from the pier foundation, and although the results for both boring confirmed that there were a clay and a silty layer respectively that were resistant to scouring near the bottom surface of the pier foundations, it was difficult to decisively relate this to the scouring depth.

### 2.2.4 Settlement and Tilt of a Pier by Scouring (Hosokura Bridge)

The Hosokura Bridge is a simple steel I girder bridge with 6 spans and a total length of 123 m across the Abukuma River. It has spread foundations. The river near this bridge is straight, but because the river is wide and there is a curve about 700 m upstream from the bridge, it is hypothesized that the axis of the flooding stream was located near the left bank. In the following explanation, the piers will be called P1 to P5 from the left bank.

As shown in Photo 4, it was confirmed that P1 settled and tilted and that this pulling out anchor bolts at the upstream side bearing supports on P1 and the

downstream side bearing supports on P2. The results of measurements performed at the road surface reveal that the settlement of P1 was 80 cm on the upstream side and 60 cm on the downstream side, and that this caused an angle of tilt of 4.3 degrees in the upstream - downstream direction.

In order to survey the state of scouring near the damaged P1, a radio-controlled boat was used to measure the shape of the streambed. Fig. 2 shows the results of this survey. An attempt was made to also measure the downstream side of the pier during this survey, but it was impossible to do so because the boat came up many times with numerous obstructions on the streambed.

As Fig. 2 clearly shows, the streambed is deep surrounding a location close to the upstream side of the P1, and it was possible to confirm that scouring occurred in this area.

It has been concluded that the damage occurred because near the left bank where the flow rate is high, the P1 has large flow resistance resulting in scouring of the streambed.

## 3. ANALYSIS

Based on the results of the survey described above, it is possible to prepare the following categorization of the highway bridge damage patterns caused by this concentrated intensive rainfall.

a. Washing away access roads behind abutments

b. Washing away abutments

c. Settlement and tilt of abutment foundations as a result of scouring

d. Settlement and tilt of pier foundations as a result of scouring

Table 2 presents the results of categorizing the bridges according to these four damage patterns.

As pointed out based on Table 2, the first characteristic of the bridge damage caused by this intensive rainfall is the fact that the most common form of damage to occur was, as stated above, damage to access roads behind abutments and that the length that was washed away ranged from about 10 m to more than 100 m. These cases of damage were not a result of a structural defect in the damaged abutment nor in the nearby revetments. Because in each case, the capacity of the channel section of the river was smaller than the quantity of flood water, the flood water overflowed the channel, washing away the soil behind the abutment.

When the abutment was subjected to the resistance of the flowing flood waters after the soil behind it had been washed away, it was extremely unstable and,

therefore, susceptible to slippage or overturning. It is not possible to draw a conclusion, but it assumed that the abutment itself was washed away as in damage pattern b.

The second characteristic is that many abutments and piers were damaged by scouring. Damage to seven bridges, that occupy half of all the damaged bridges, is one defined as damage patterns c and d. At 5 of these 7 bridges, the settlement and tilting of the substructure caused severe damage to the superstructure, and the damage was a result of insufficient embedding depth of the foundation or damage to revetments near the abutment in all cases.

The scouring at the bridges occurred near the center of the river where the river is nearly straight, but where the river is curved, the scouring appeared near the outer bank of the curve, indicating that damage is concentrated close to the location of the axis of the stream during flooding.

## 4. CONCLUSION AND FUTURE WORKS

In Japan, the safety of bridges against flood conditions is assessed in advance based on the results of inspections conducted at regular intervals. But in order to provide effective crisis management including guaranteeing evacuation and rescue routes during concentrated intensive rainfall, a careful and rational judgment method on the risk to highway bridges must be provided.

The Public Works Research Institute has developed a scouring monitoring system in order to meet these demands for such technology. It will be possible to use the system to measure scouring of bridge foundations in real time simply by attaching simple measurement devices to existing bridges. A trial system has been fabricated, was installed on an actual bridge, and confirmative testing of the system is now in progress. The survey method using a radio-controlled boat that was mentioned in this paper cannot be used during floods, but it is a technologies that can be used to assess the conditions of streambeds easily and cost-effectively. Beginning with work to bring these technologies to the practical stage, the authors will continue to endeavor to develop disaster prevention technologies for use during floods.

### REFERENCES

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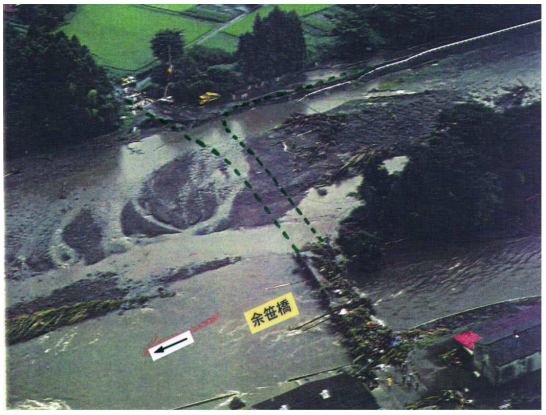


Photo 1 - Yosasa Bridge


Photo 2 - Habuto Bridge


Photo 3 - Kumado Bridge


Photo 4 - Hosokura Bridge

Table 1 - Outline of the Damage

| No. | Bridge | Route Name | Number of spans | Superstructure | Substructure | Foundation | Outline of the Damage |
|---|---|---|---|---|---|---|---|
| 1 | Nozaki | N.H Route4 | 5 | Simple steel box girder | RC wall type | — | ・ Part of the side walk and access road behind the right bank abutment were scoured. |
| 2 | Kumagawa | N.H Route4 | 1 | Simple girder | — | — | ・ Revetments around the right bank abutment were scoured. |
| 3 | Yosasa | N.H Route4 | 6 | Simple girder | Rigid frame type | Spread foundation | ・ The left bank abutment and access road were washed away for about 60m, and one girder supported by this abutment fell down.<br>・ Revetments around the right bank abutment were scoured. |
| 4 | Yosasa | N.H Route294 | 4 | Simple RCT girder | Abutment: semi-gravity type<br>Pier: RC rigid frame type | Spread foundation | ・ The access road behind right bank abutment was washed away for about 60m, and the downstream side backfill of left bank abutment was scoured for about 10 m.<br>・ Part of the railing was damaged by overflow. |
| 5 | Kyowa | Municipal Road | 5 | — | — | — | ・ The access road behind left bank abutment was washed away for about 150m.<br>・ Three of the five girders were washed away. |
| 6 | Terako | Regional Road | 3 | Simple RCT girder | Abutment: gravity type<br>Pier: wall type | — | ・ The access road behind right bank abutment was washed away for about 35m.<br>・ Part of the railing was damaged by overflow. |
| 7 | Kurokawa | Regional Road | 1 | Simple RCT girder | Abutment: gravity type<br>Pier: wall type | Spread foundation | ・ The access road behind right bank abutment was washed away for about 10m.<br>・ Part of the railing was damaged by overflow. |
| 8 | Kurokawa | Prefectural Road | 2 | Simple RCT girder | Abutment: gravity type<br>Pier: wall type | Spread foundation | ・ The right bank abutment and access road were washed away for about 10m, and one girder supported by this abutment was also washed away.<br>・ Part of the railing was damaged by overflow. |
| 9 | Habuto | Principal Regional Road | 4 | Simple RCT girder | Abutment: gravity type<br>Pier: wall type | Spread foundation | ・ The left bank abutment was tilted in the downstream direction with settlement about 1.2m on the downstream side by scouring of backfill on the downstream side.<br>・ The tilt of this abutment caused cracking of the abutment wall and the girder, and damage to the railings. |
| 10 | Kaishin | Prefectural Road | 1 | Simple RCT girder | Abutment: gravity type | Spread foundation | ・ When the road was widened, this bridge was expanded by constructing new abutments on its downstream side. Scouring caused old abutments to settle down about 2 m at both banks resulting in the collapse of the girder.<br>・ Backfill of abutments on the upstream side of the right bank and the downstream side of the left bank was washed away. |
| 11 | Kumado | N.H Route294 | 3 | Simple RCT girder | Abutment: gravity type<br>Pier: wall type | Spread foundation | ・ The pier on left bank side settled by 2.3 m on the upstream side, and its body tilted by 20 degrees under the effects of scouring.<br>・ Settlement and tilt of the pier caused the girder to settle and damaged railings. |
| 12 | Itahagi | Municipal Road | 4 | Simple RC girder | Abutment: gravity type<br>Pier: pile bent type | Spread foundation | ・ Scouring caused settlement of the piers about 10 cm at the center of the river. |
| 13 | Heisei | Municipal Road | 1 | Simple RCT girder or PCT girder | Abutment: reverse T type | — | ・ The access road behind left bank abutment was washed away for about 10 m. |
| 14 | Hosokura | Municipal Road | 6 | Simple Steel I Girder | Pier: wall type | Spread foundation | ・ Scouring caused the pier closest to the left bank to settle about 50 cm, and to tilt in the upstream direction.<br>・ Settlement and tilt of the pier twisted the girder and pulled anchor bolts from the bearing supports. |

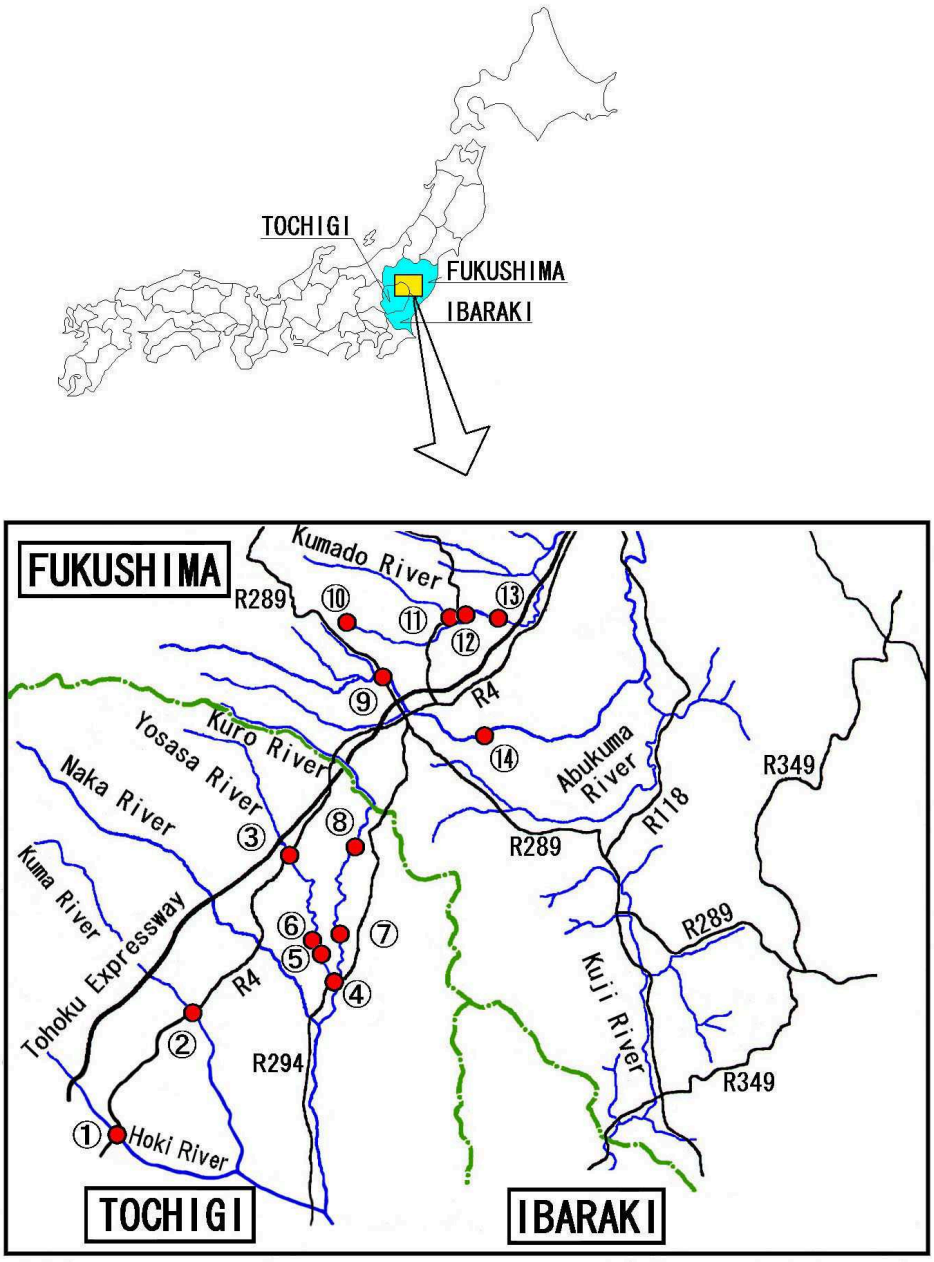
(Note) N.H. = National Highway

Table 2 - Damage Patterns

| No. | Bridge | Route | Damage Pattern | | | | Fatal Deformation of the Superstructure or Bridge Collapse |
|---|---|---|---|---|---|---|---|
| | | | a | b | c | d | |
| 1 | Nozaki | N.H. Route4 | ○ | | | | |
| 2 | Kumagawa | N.H. Route 4 | | | ○ | | |
| 3 | Yosasa | N.H. Route 4 | ○ | ○ | ○ | | ○ (by Pattern b) |
| 4 | Yosasa | N.H. Route 294 | ○ | | | | |
| 5 | Kyowa | Municipal Road | | | | ○ | ○ |
| 6 | Terako | Principal Regional Road | ○ | | | | |
| 7 | Kurokawa | Principal Regional Road | ○ | | | | |
| 8 | Kurokawa | Prefectural Road | ○ | ○ | | | ○ (by Pattern b) |
| 9 | Habuto | Principal Regional Road | ○ | | ○ | | ○ (by Pattern c) |
| 10 | Kaishin | Prefectural Road | ○ | | ○ | | ○ (by Pattern c) |
| 11 | Kumado | N.H. Route 294 | ○ | | | ○ | ○ (by Pattern d) |
| 12 | Itahagi | Municipal Road | | | | ○ | ○ (by Pattern d) |
| 13 | Heisei | Municipal Road | ○ | | | | |
| 14 | Hosokura | Municipal Road | | | | ○ | ○ (by Pattern d) |

(Note) N.H. = National Highway

Damage Patterns
- a: Washing away of access roads behind abutments
- b: Washing away of abutments
- c: Settlement and tilt of abutment foundations as a result of scouring
- d: Settlement and tilt of pier foundations as a results of scouring




(Note) ①-⑭ : see Table 1

Fig.1 - Map of the Disaster Region
(Rivers, Principal Road and Bridge Location)

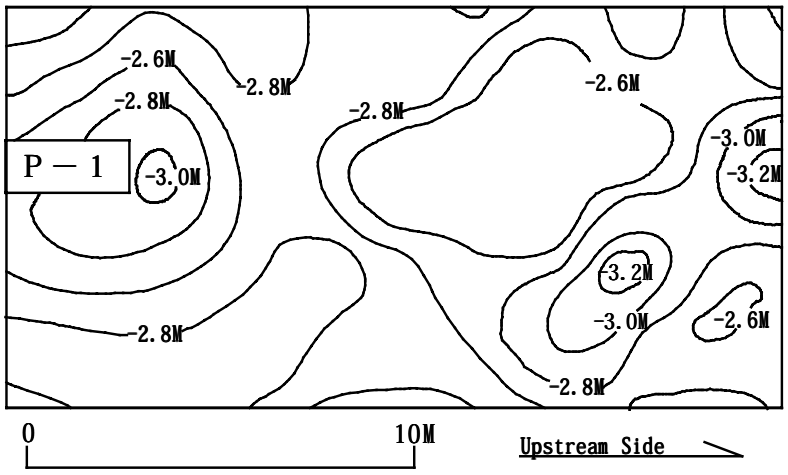



Figure 2. Contour Map of the River Bed
at the Hosokura Bridge