17th World Conference on Earthquake Engineering, 17WCEE

Sendai, Japan - September 13th to 18th 2020

DAMAGE MECHANISM OF OHKIRIHATA BRIDGE DUE TO KUMAMOTO EARTHQUAKE

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Abstract

In 2016 Kumamoto Earthquake occurred in Japan, many road bridges were severely damaged under the earthquake ground motion and the ground deformation. Many bridges lost the function. It is presumed that the damage was severe because these combined action due to this earthquake exceeded the design assumption, so future seismic design has to presume the possibility of the action different from the design force.

To prevent the failure of the bridge function due to the action exceeding the assumption, it is important to verify the mechanism of the bridge and to reflect in the design standard based on knowledge obtained from the investigated data.

This study aim to clarify the behavior of the bridge during the earthquake. Firstly, the force acting to the bearing supports was estimated by the damage trace, and the failure mechanism of the bearing support was estimated. Secondly, the behavior of the bridge was verified based on the post-earthquake investigated data of bridge and the results of the test of the bearing supports.

Keywords: 2016 Kumamoto Earthquake, Bridge, Bearing support, Damage Trace

1. Introduction

On April 16, 2016, the magnitude 7.3 earthquake occurred at Kumamoto prefecture in Japan (The 2016 Kumamoto Earthquake). Many bridges were damaged such as the collapse due to the earthquake, and lost the bridge function [1]. The failure of bridge function affects the emergency transport. In order to prevent this damage, it is important to verify the bridge damage mechanism, and reflect the obtained knowledge in the bridge seismic design.

There are some methods to estimate of the bridge behavior by the earthquake. One of the estimation methods, there is the approach method from the dynamic analysis. This method can evaluate the time history of the bridge behavior, the stress of member etc. by assumed the bridge structural condition and the action such as the earthquake wave at the site. So that, this method has been used by many researches [2, 3]. But the property of the earthquake movement and the character of the bridge such as member stiffness have to assume, thus the result of the dynamic analysis may be different from real behavior. Other method, there is the approach method estimating from the damage trace. This method can clarify the bridge behavior and the acted state of the damage point because of stack of facts gotten from the damage trace and damage state of damaged member [4-6].

The author's group investigated the bridges damaged in the 2016 Kumamoto Earthquake, and recorded the damage state of the bearing support, the abutment and the pier, etc. In addition, we got some bearing supports used for the damaged-bridge, thus can investigate the damage state of bearing supports, and can evaluate the bridge state based on these information.

This study estimated the bridge behavior based on the damage traces and the damage state of the bearing supports. In this paper, we estimated the bridge behavior of Ohkirihata Bridge based on the damage traces and the damage state of the rubber bearing supports.

2. Damage investigation on Ohkirihata Bridge

Ohkirihata Bridge which is located in Kumamoto prefectural Route 28 (Fig. 1) is a curved 5-span continuous steel bridge. This bridge was designed based on Design Specification for Highway Bridge 1996, and constructed in 2001. The bridge general view is shown in Fig. 2.

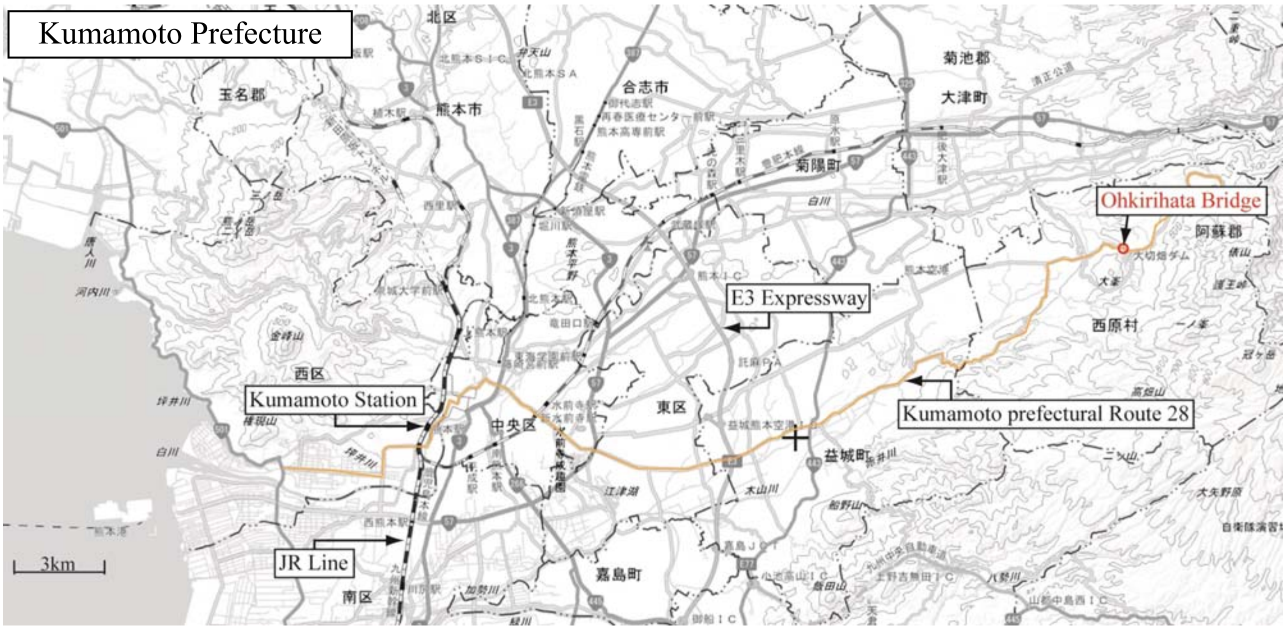
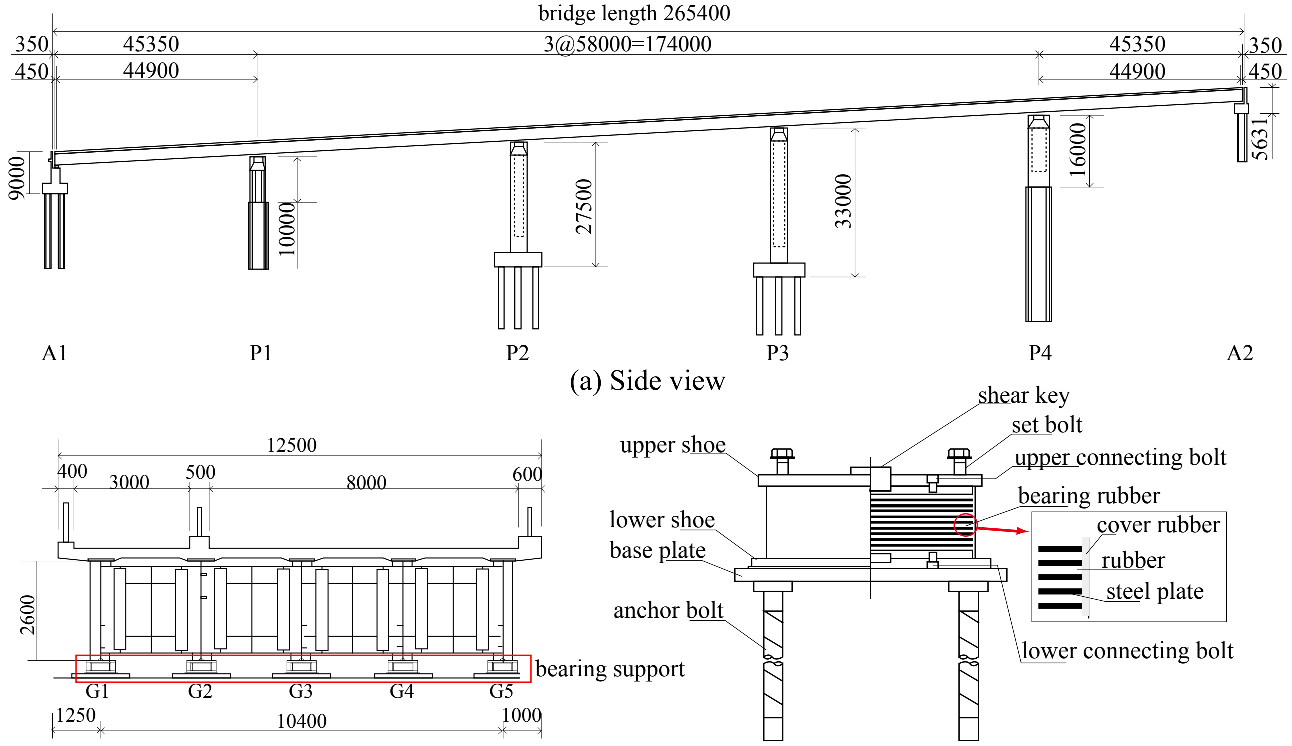


Fig. 1 – Location of Ohkirihata Bridge



(a) Side view

(b) Section view (c) Bearing support

Fig. 2 – General view on Ohkirihata Bridge

In Ohkirihata Bridge, the pavement in back of the A1 abutment was raised, and the expansion joint was broken due to the earthquake as shown in Photo 1. At the A1 abutment parapet, the collided mark was found as shown in Photo 1. Most bearing supports were broken, and the superstructure was moved to the A2 abutment and the G1 girder side. Side blocks which are installed to prevent the lateral displacement at the A1 and A2 abutment were broken. The concrete crack was generated at the abutments and piers, but it did not reached to the catastrophic damage such as collapse.

Photo 1 –Damage state at A1 abutment

3. Damage state and behavior of bearing supports

This study targeted the bearing support installed at the P1 pier, and investigated the behavior of bearing support estimated by the damage state. The main girder at the P1 pier moved to the A2 abutment side about 550mm ~ 700mm and the G1 girder side about 800mm as shown in Fig. 3. Furthermore, all bearing supports at the P1 pier were broken and main girders fell from the bearing support.

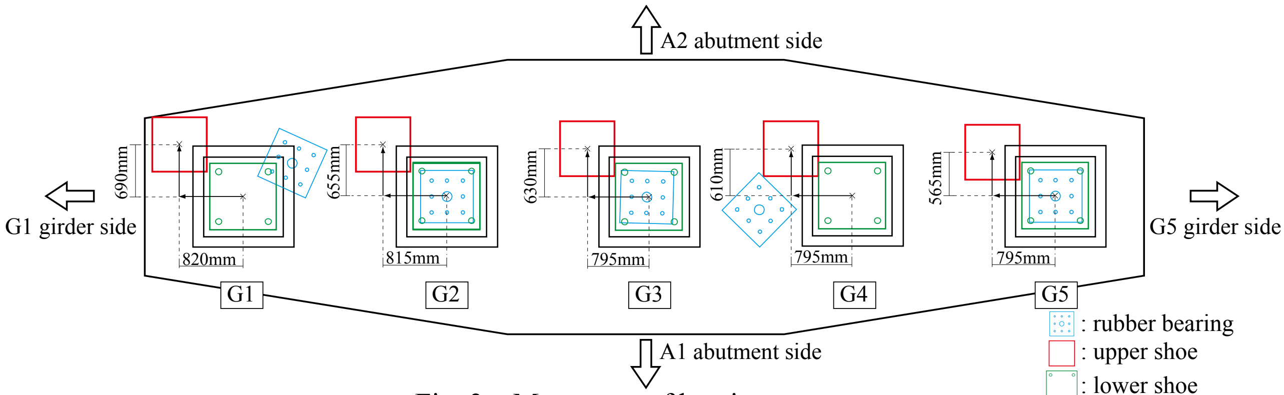


Fig. 3 – Movement of bearing supports

3.1 G1 Bearing support

Photo 2 shows the damage state of the bearing support installed at the G1 girder right after the earthquake. The upper and lower connecting bolts of the bearing support at G1 girder were damaged as shown in Photo 2(a) and (b). The rubber bearing moved to the A2 abutment and the G5 girder side and was turned over. The removed bearing shows in Photo 3. The upper shoe at the A1G5 corner was deformed as shown in Photo 3(a), because the main girder fell on the removed upper shoe on the pedestal as shown in Photo 2(c).

The top surface of the rubber bearing is shown in Photo 3(b). The upper connecting bolts at the G1 girder side (a-c) were slipped out, and other upper connecting bolts (d-h) were occurred the broken-out, it looks like the section appearing in the shear failure, and the hole which installs the shear key (named shear-key-hole) on the rubber bearing at the G1 girder side was deformed. According to the loading test of bearing support conducted by authors [7], it is found that the connecting bolt (p) in Fig. 4 was generated the tensile force and the shear-key-hole was deformed. From this knowledge, it is presumed that the upper connecting bolts at the G1 girder side were slipped out because the rubber bearing was excessively deformed to the G1 girder side, and the other upper connecting bolts were broken, because the shear key carried the shear force was come off the rubber bearing or the upper shoe.

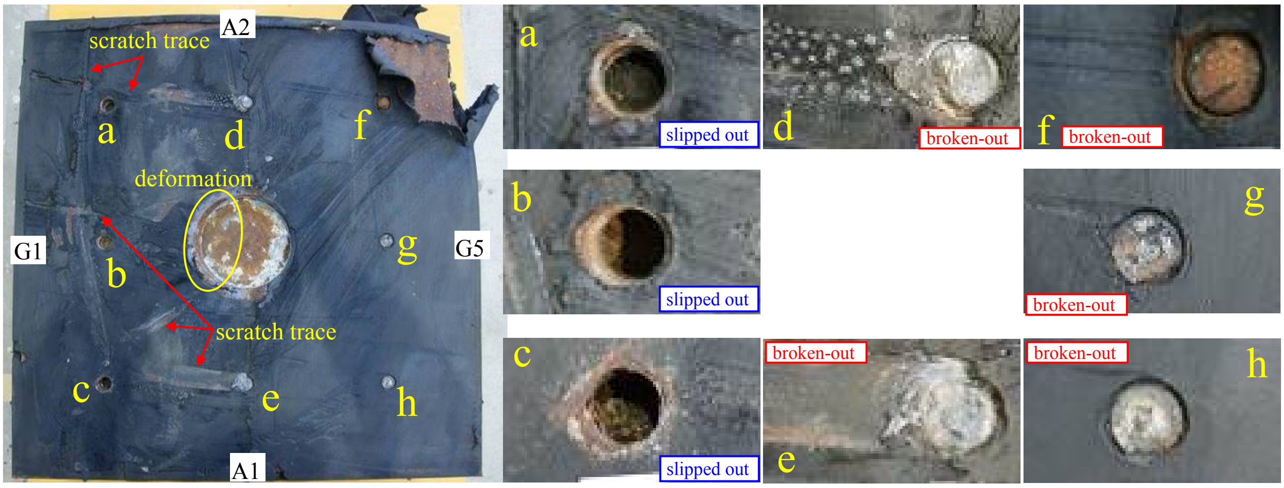
The bottom surface of the rubber bearing is shown in Photo 3(c). The all lower connecting bolts were broken at the rubber bearing surface. Looking at the broken-bolt marks, there are the gap and the burr. According to the loading test of connecting bolts conducted by authors [8], it is confirmed that the gap and the burr are generated in the direction of the force when the connecting bolt was broken by the external shear force as shown in Fig. 5. From this knowledge, it is presumed that the lower connecting bolts were deformed in the direction of the arrow shown in Photo 3(c), and were broken at the rubber bearing surface. Looking at the lower shoe in Photo 4, there are scratch traces by the broken-out-bolt beside the bolt hole. And thus, it is presumed that lower connecting bolts were broken because the bearing support was excessive rotated around the shear-key-hole. In addition, the direction of the scratch trace was matched with the rotated direction found from the broken-out section of the connection bolt described above.

(a) Failure of rubber bearing (b) Turnover of rubber bearing (c) Falling of main girder

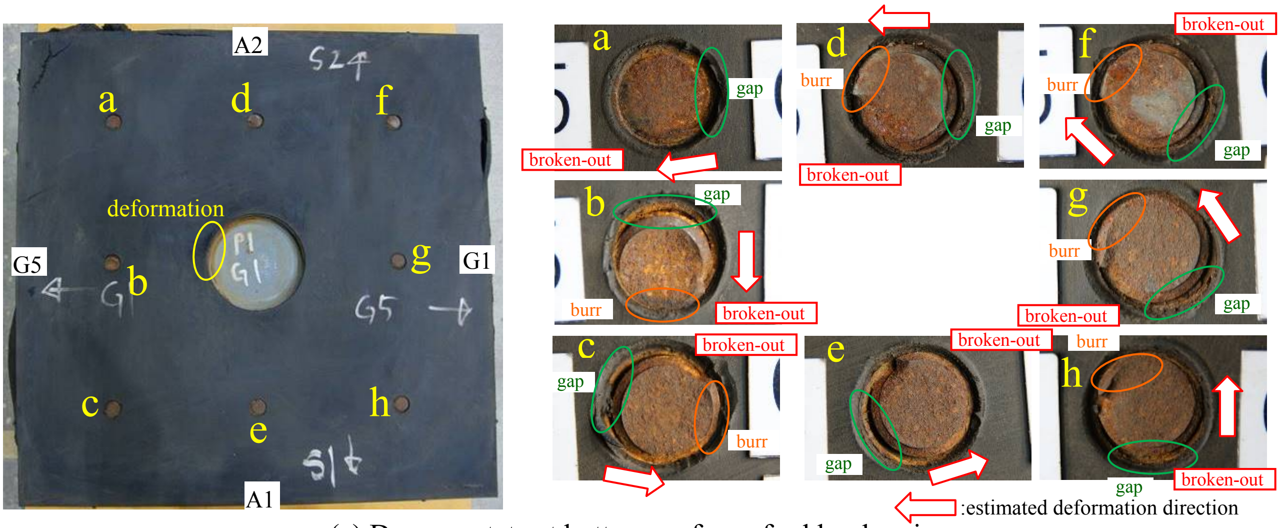
Photo 2 – Damage state (G1 bearing support)

note: the upper shoe were just put on the rubber bearings

(a) Damage state at side of upper shoe and rubber bearing



(b) Damage state at top surface of rubber bearing



(c) Damage state at bottom surface of rubber bearing

Photo 3 – Removed bearing support (G1)

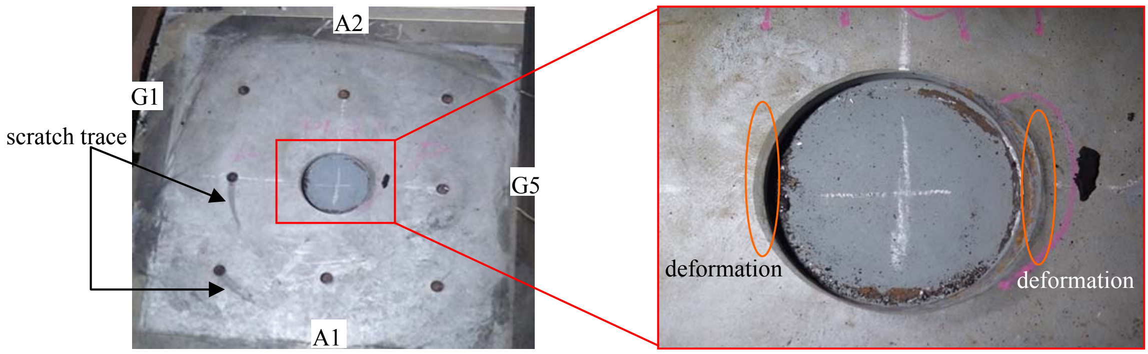


Photo 4 – Damage state of lower shoe

From these analyses, it is estimated that the bearing support installed at the G1 girder was broken by the behavior of the deformation to the G1 girder side and the rotation around the shear-key-hole. Next, we presume which one was damaged first. If the upper connecting bolt was broken before the failure of the lower connecting bolt, the rotation force did not generate at the rubber bearing. Therefore, it is not presumed that the upper connecting bolt was broken before the failure of the lower connecting bolt. On the other hand, in case of the lower connecting bolt was broken before the failure of the upper connecting bolt, the external force from the upper shoe can be transmitted to the lower shoe if the lower shear key was not removed. So the bearing support may be deformed such as Fig. 4.

Therefore, it can be estimated that the lower connecting bolts were broken by the rotation of the bearing support before the failure of the upper connecting bolt, next the upper connecting bolts were broken by the deformation of the bearing support to the G1 girder side as shown in Fig. 6. Looking at the lower shoe in Photo 4, the shear-key-hole at the G5 girder side was deformed too, and thus it is estimated that the bearing support was deformed to the G5 girder side.

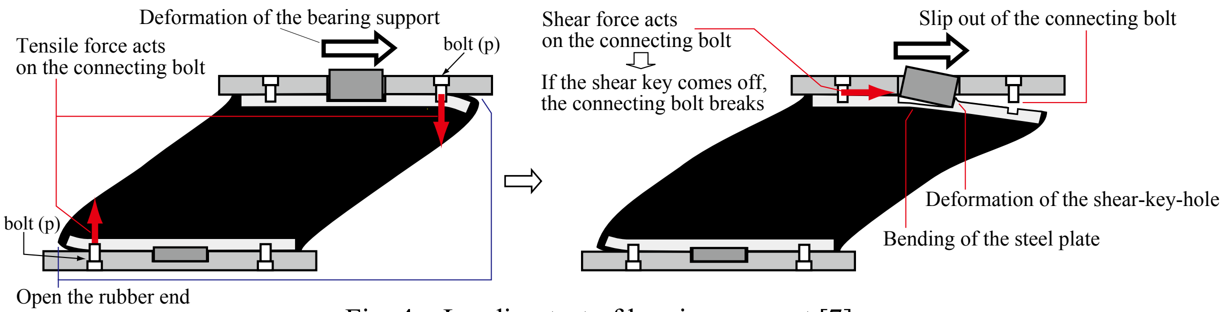


Fig. 4 – Loading test of bearing support [7]

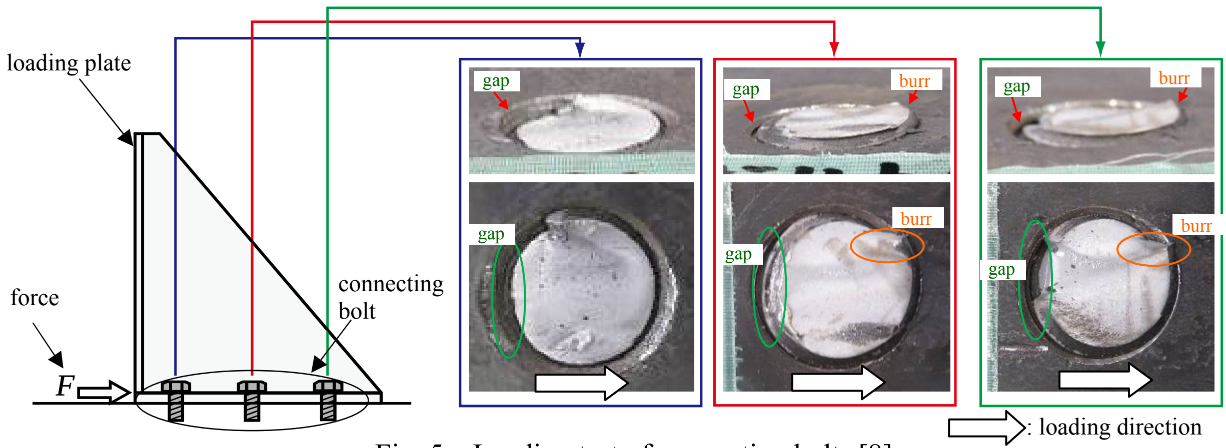


Fig. 5 – Loading test of connecting bolts [8]

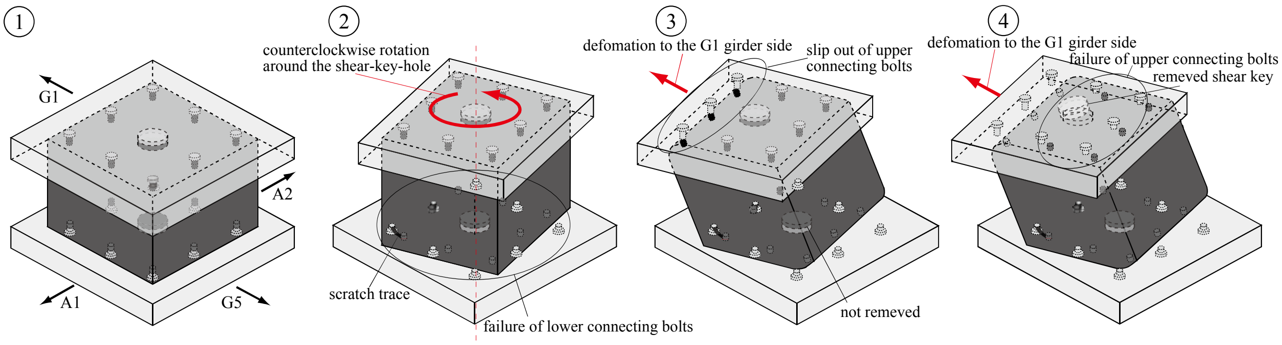


Fig. 6 – Estimated behavior of G1 bearing support

3.2 G2 Bearing Support

Photo 5 shows the damage state of the bearing support installed at the G2 girder right after the earthquake. The upper connecting bolts of the G2 bearing support were broken, and the lateral bracing fell down on the bearing support. The removed bearing is shown in Photo 6. At the side of the bearing support shown in Photo 6(a), the upper shoe at the A1G5 corner was deformed, because the main girder fell down on the G1 girder side pedestal as shown in Photo 5. The cover rubber at the G1 girder side was damaged, it is presumed that the cover rubber was shaved by the lower flange when the girder fell from the bearing support. At the top surface of the rubber bearing, upper connecting bolts at the A1 abutment side (c,e,h in Photo 6(b)) were slipped out, and the other upper connecting bolts were broken at the rubber bearing surface. And the shear-key-hole at the A1 abutment side was deformed. At the bottom surface of the bearing support, there were not damage trace and the lower connecting bolts were not damaged. Referring to the past knowledge [7], it is estimated that the upper shoe of the G2 bearing support was moved to the A1 abutment side, and upper connecting bolts were broken by the excessive deformation of the rubber bearing as shown in Fig. 7.

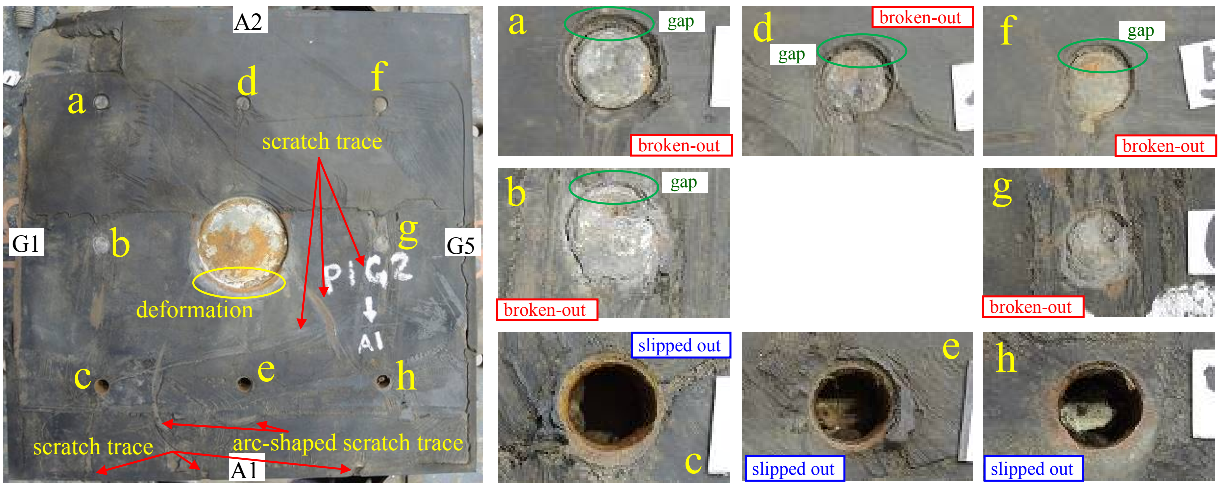
Looking at the Photo 6(b), there was the arc-shaped scratch trace at the A1 abutment side, and was almost matched with the shape of the shear key. Furthermore, there were scratch traces at the end of the A1 abutment side, and the interval of damage traces were almost matched with the interval of the upper connecting bolts. Therefore, it is presumed that the main girder might be moved to the A1 abutment side at least until the position of the arc-shaped damage trace.

Photo 5 – Damage state (G2 bearing support)

A1 side G1 side A2 side G5 side

note: the upper shoe were just put on the rubber bearings

(a) Damage state at side of upper shoe and rubber bearing



(b) Damage state at top surface of rubber bearing

Photo 6 – Removed bearing support (G2)

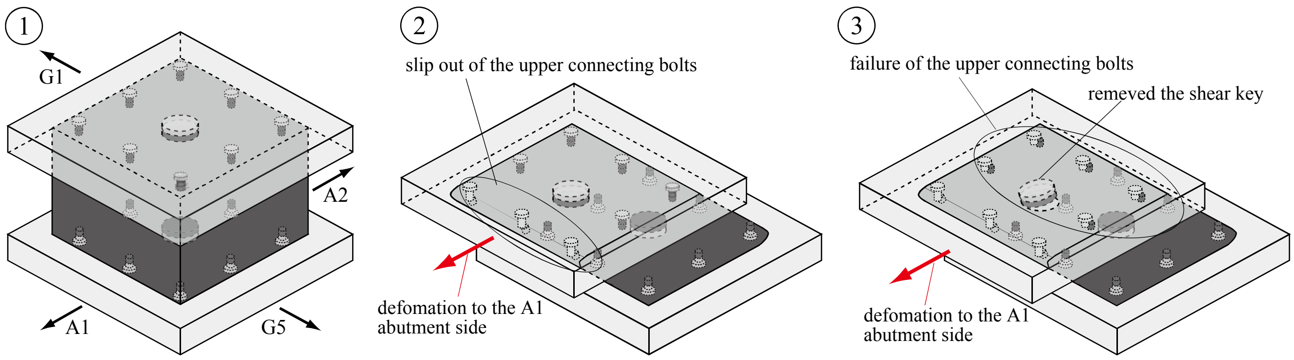
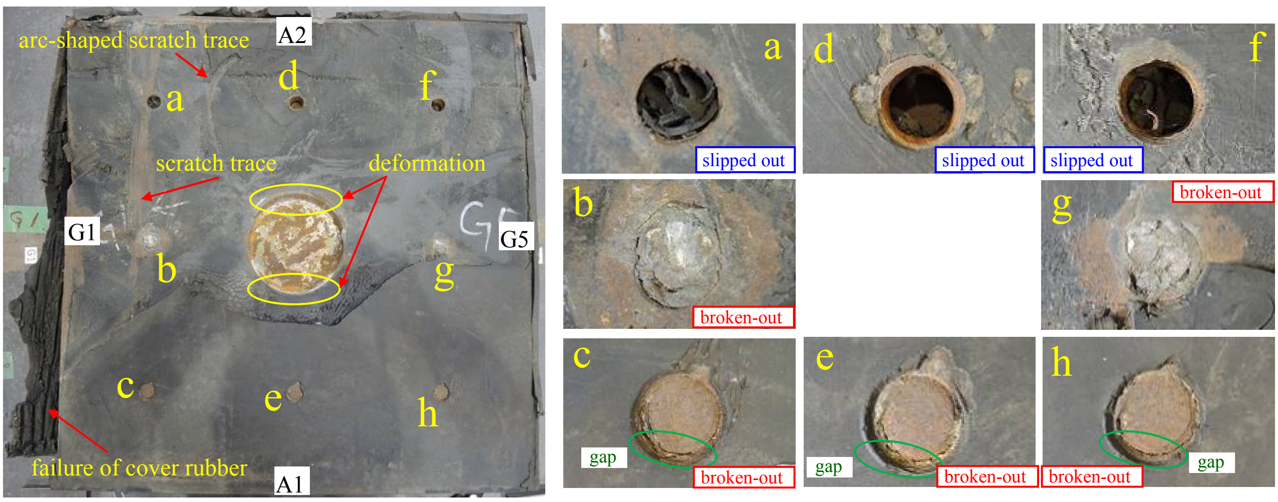


Fig. 7 – Estimated behavior of G2 bearing support

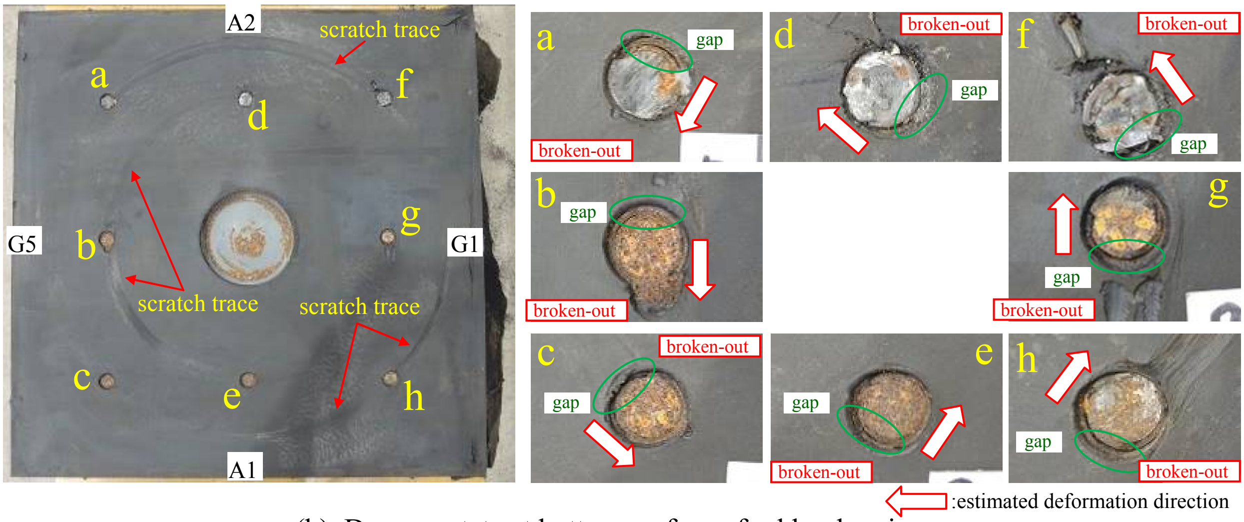
3.3 G3 Bearing Support

Photo 7 shows the damage state of the bearing support installed at the G3 girder right after the earthquake. The upper and lower connecting bolts of the G3 bearing support were damaged, and the rubber bearing at the G5 girder side was raised by the collision with the inspection walk. The removed bearing support is shown in Photo 8. At the top surface of the rubber bearing, upper connecting bolts at the A2 abutment side (a,d,f in Photo 8(a)) were slipped out, and other connecting bolts were broken at the rubber bearing surface. In addition, the shear-key-hole at the A2 abutment side was deformed. Referring to the past knowledge [7], it is presumed that the bearing support was excessively deformed to the A2 abutment side. At the bottom surface of the rubber bearing, all lower connecting bolts were broken and there were scratch traces like drawing a circle. Referring to the past knowledge [8], it is presumed that the G3 bearing support was rotated counterclockwise around the shear-key-hole.

Photo 7 – Damage state (G3 bearing support)



(a) Damage state at top surface of rubber bearing
Photo 8 – Removed bearing support (G3)



(b) Damage state at bottom surface of rubber bearing
Photo 8 – Removed bearing support (G3)

Based on these analyses, the behavior of the G3 bearing support was estimated the behavior like the G1 bearing support. Also, there was the arc-shaped scratch trace on the top surface of the rubber bearing as shown in Photo 10(a). This scratch trace was almost matched with the shape of the shear key, and thus it is presumed that the G3 girder was moved at least to the A2 abutment side and to the G1 girder side.

3.4 G4 Bearing Support

Photo 9 shows the damage state of the bearing support installed at the G4 girder right after the earthquake. The upper and lower connecting bolts of the G4 bearing support were damaged, and the rubber bearing was ruptured. In addition, the rubber bearing moved to the A1 abutment and the G1 girder side as shown in Fig. 3, and the main girder fell down on the moved-rubber-bearing. The removed bearing support shows in Photo 10. At the top surface of the rubber bearing, there were gaps and burrs at the upper connecting bolt as shown in Photo 10(a). Referring to the past knowledge [8], it is presumed that the upper connecting bolts were deformed in the direction of the arrow shown in Photo 10(a). That is, it is presumed that the bearing support was rotated around the shear-key-hole. At the bottom surface of the rubber bearing, the lower connecting bolts at the A2 side (a,d,f,g in Photo 10(b)) were slipped out and other connecting bolts were broken at the rubber bearing surface. In addition, the shear-key-hole at the A2 abutment side was deformed. Referring to the past knowledge [7], it is presumed that the bearing support was deformed to the A1 abutment side.

Based on these analyses, the upper shoe of the G4 bearing support is estimated rotated around the shear-key-hole, and was deformed to the A1 side as shown in Fig. 8. Incidentally, the relative direction of rotation is matched with the rotation of the bearing support at the G1 and G3 girder.

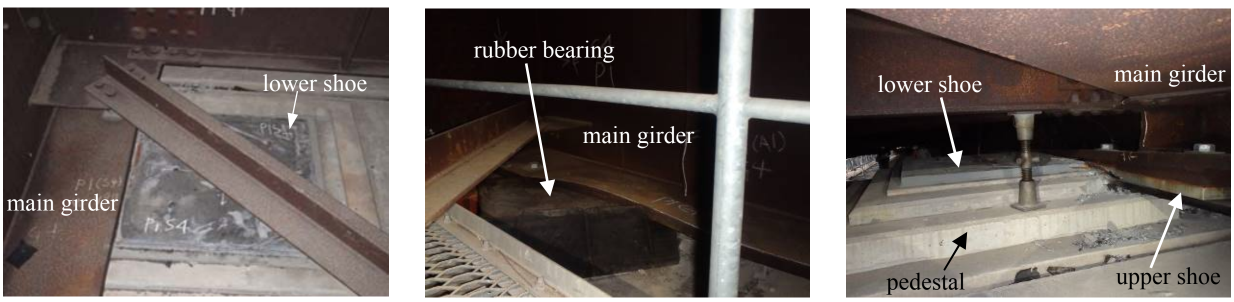
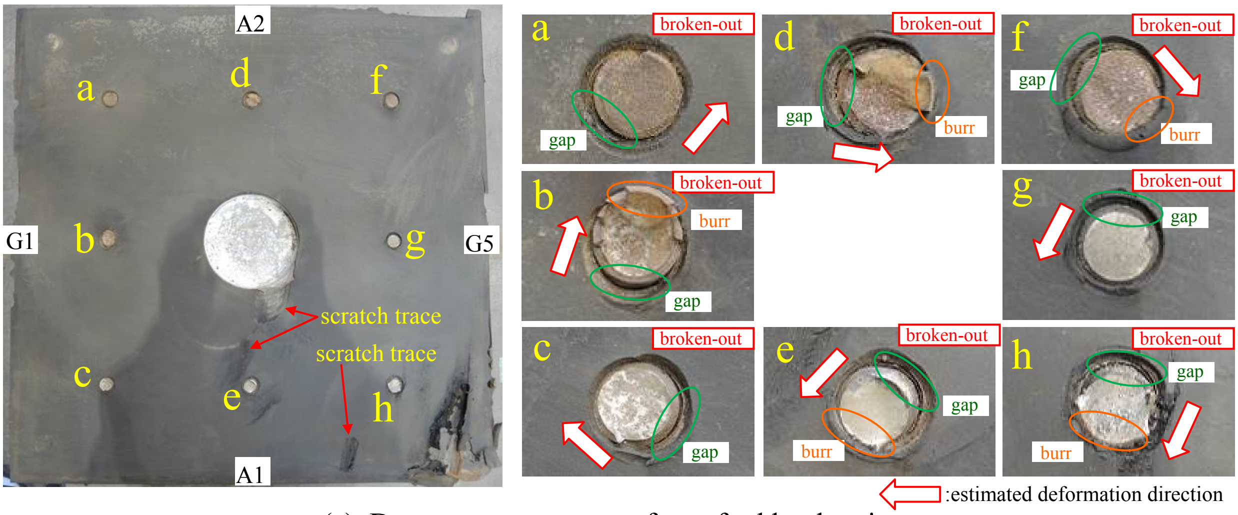
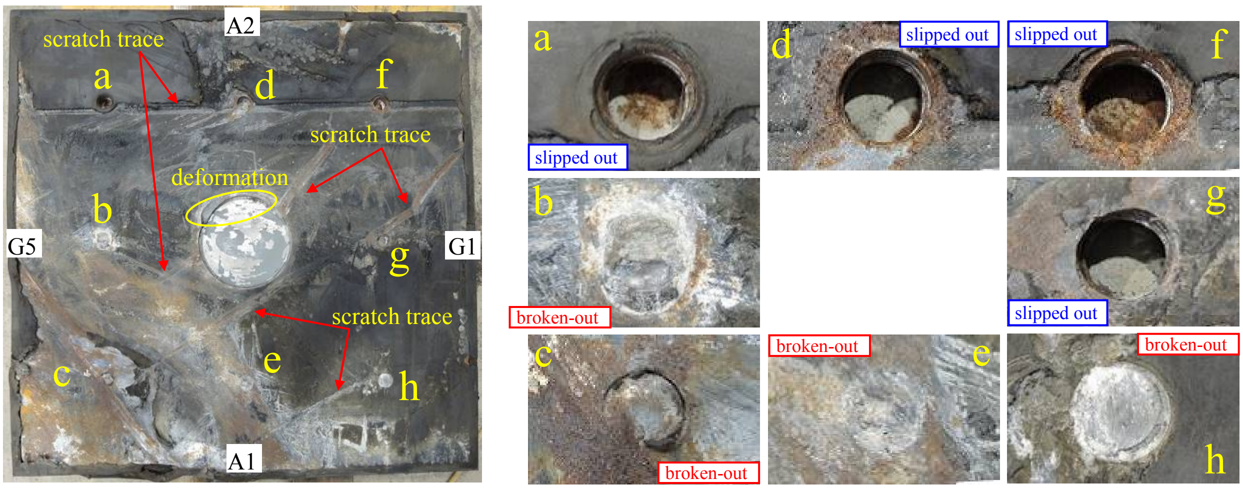


Photo 9 – Damage state (G4 bearing support)



(a) Damage state at top surface of rubber bearing



(b) Damage state at bottom surface of rubber bearing

Photo 10 – Removed bearing support (G4)

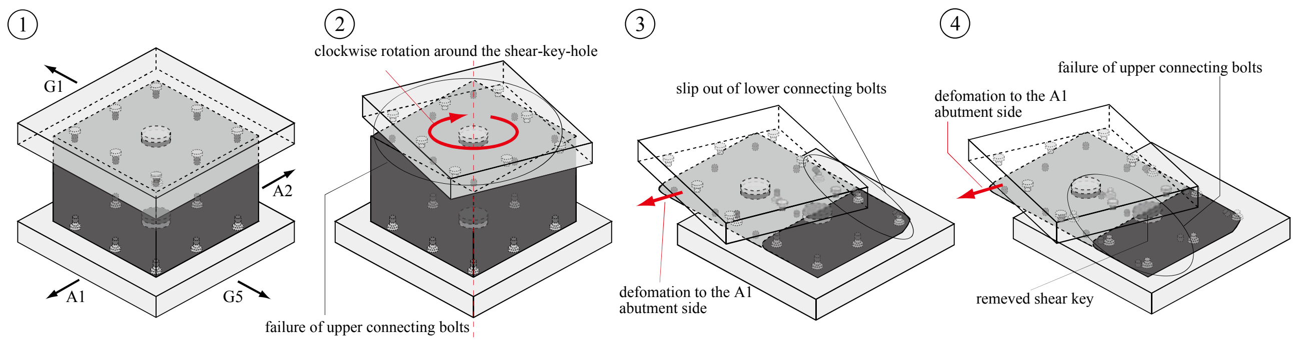


Fig. 8 – Estimated behavior of G4 bearing support

3.5 G5 Bearing Support

Photo 11 shows the damage state of the bearing support installed at the G5 girder right after the earthquake. The upper connecting bolts of the G5 bearing support were damaged. The cover rubber at the G1 girder side was damaged, it is presumed that the cover rubber was shaved by the lower flange when the girder fell from the bearing support. The removed bearing support is shown in Photo 12. At the top surface of the rubber

Photo 11 – Damage condition (G5 bearing support)

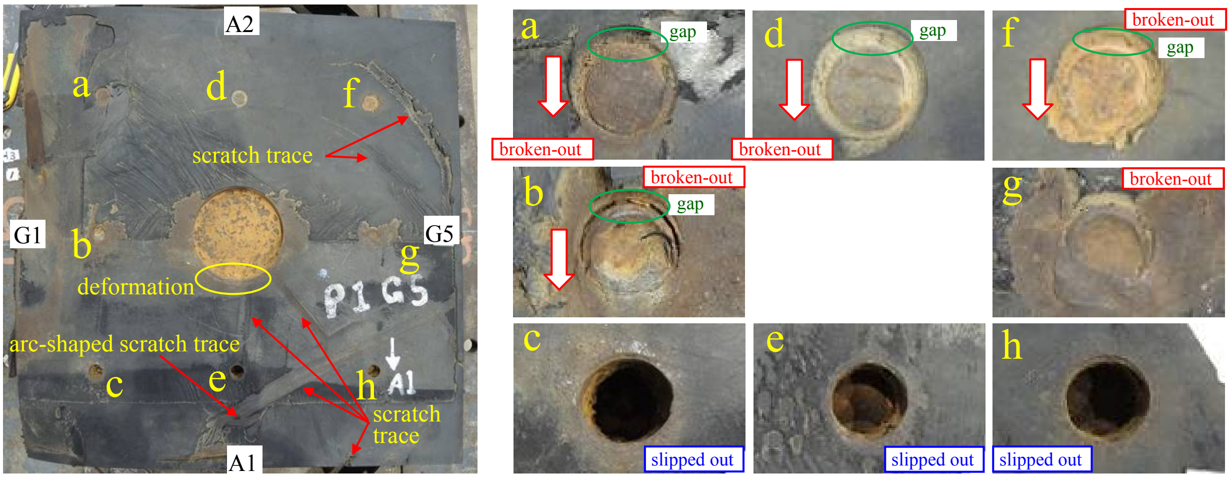


Photo 12 – Removed bearing support (upper surface of rubber bearing) (G5)

bearing, upper connecting bolts at the A1 abutment side (c,e,h in Photo 12) were slipped out and the other connecting bolts were broken at the rubber bearing surface. And the shear-key-hole at the A1 abutment side was deformed.

Referring to the past knowledge [7], it is estimated that the upper shoe of the G5 bearing support was deformed to the A1 abutment side. There was the arc-shaped scratch trace as shown in Photo 12. This scratch trace was almost matched with the shape of the shear key, and thus it is presumed that the shear key at least moved to the position of the arc-shaped scratch trace.

5. Conclusion

This paper estimated the behavior and the damage reason of the bearing support based on the damage trace and the damage state of the bearing support. As a result, the behavior of the bearing support was able to estimate based on the damage trace and the damage state of the bearing support. In the future, we will analyze the bearing supports installed at other positions, and estimate the behavior of the bridge based on the damage trace and the damage state of the bearing supports, etc.

Acknowledgements

This study was provided removed-bearing supports and investigation data from Kumamoto Reconstruction Project Office on Ministry of Land, Infrastructure, Transport and Tourism Kyushu Regional Development Bureau. The authors wish to extend sincere appreciation for Kumamoto Reconstruction Project Office.

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