DAMAGE MECHANISM OF TAWARAYAMA BRIDGE DUE TO KUMAMOTO EARTHQUAKE

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Abstract

Many bridges were damaged by earthquake in Kumamoto prefecture located southern Japan at 2016. There were damaged even bridges built according to relatively recent seismic standard, and it is important understand the damage mechanism during an earthquake in order to improve seismic technology.

In this paper, we investigated the actual damage of "Tawarayama bridge" which had been seriously damaged. In this bridge, the horizontal displacement was surveyed so that the girder crashed with the abutment, and a large residual displacement was also surveyed in the downward direction. As a damage state of the Tawarayama bridge, it was investigated that the rubber bearing was destroyed, and the superstructure fell on the top of substructure. And, it was investigated scratch due to bolts fractured in upper and lower surface of bearing. In addition, since the displacement of the substructure due to ground displacement was also surveyed, it is supposed that a force on the rubber bearing exceeded the design load when the force transmits from the substructure to the superstructure. Generally, it can be said that were the weakest part of the path through which the force transmitted will be broken. In this bridge, thought the bearings were installed on the same pier, the broken parts were different. It suggests that there were several variations of strength or force unexpected in the design has occurred. To improve the reliability of seismic design, it is important to understand the failure mechanism.

Therefore, we examined the damage mechanism of Tawarayama bridge from investigation result of deformations that occurred in the superstructure, bottom structure and rubber bearing.

Keywords: Rubber bearing, Damage mechanism, 2016 Kumamoto earthquake, Bridge.

1. Introduction

The 2016 Kumamoto earthquake occurred in Kumamoto Prefecture located in the southwestern part of the Japan island (Fig.1, [1]). The earthquake also caused serious damage to road bridges constructed according to seismic design call published in 1996, which is revised based on damage investigation of the 1995 Hyogoken-Nanbu earthquake. In addition to the seismic inertial force, fault displacement and ground displacement ware also surveyed around it, and it is considered that these also affected [2,3].

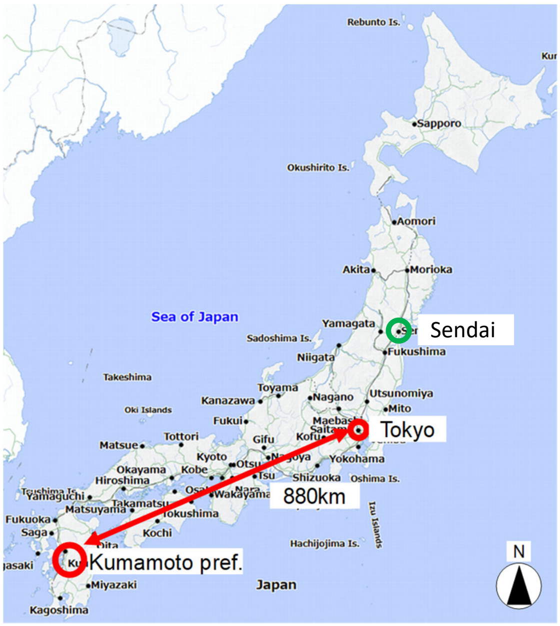


Fig.1 – Location of Kumamoto in Japan

Therefore, in order to improve the reliability of seismic design, it is necessary to estimate the cause of damage of the bridge by the earthquake and propose a design method corresponding to it.

As a method of estimating the cause of damage, it is commonly used an analytical model according to physics model. However, it is some problems that actual seismic force generated in the target bridges cannot be accurately input. Therefore, it is necessary to investigate occurred damage in bridge to estimate the damage mechanism.

In this paper, we focused on the damage of the bearing, main girder and the displacement of the substructure caused by the Kumamoto earthquake on "Tawarayama bridge", estimated damage mechanism based on the actual damage and behavior of the bridge.

2. Outline of Kumamoto earthquake

On April 16, 2016, magnitude 7.3 earthquakes occurred in Kumamoto Prefecture, located in the southwestern part of the Japan. The earthquake caused serious damage not only for houses but also for infrastructure. In addition, large residual displacement was surveyed on the ground surface. Figure 2 shows the distribution of cracks on the ground surface near the target bridge, based on the aerial photo interpretation surveyed by the Geographical Survey Institute [4].

Tawarayama bridge is in the area where the ground surface displacement was surveyed, and it is expected that ground displacement also affected. Fig.3 shows the analysis results of the displacement due to the earthquake observed near Tawarayama Bridge [5].

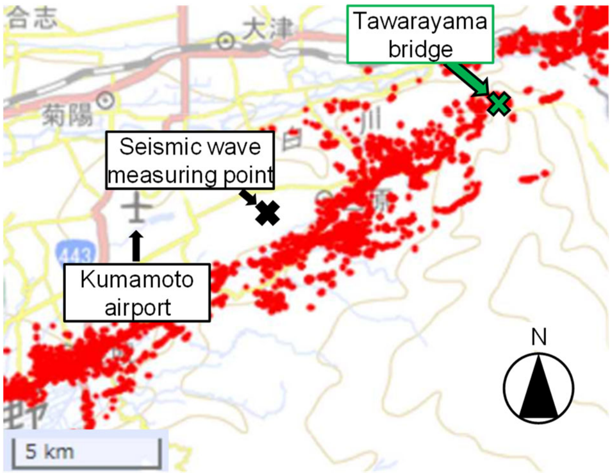


Fig.2 – Ground displacement point by aerial photography (red circle)

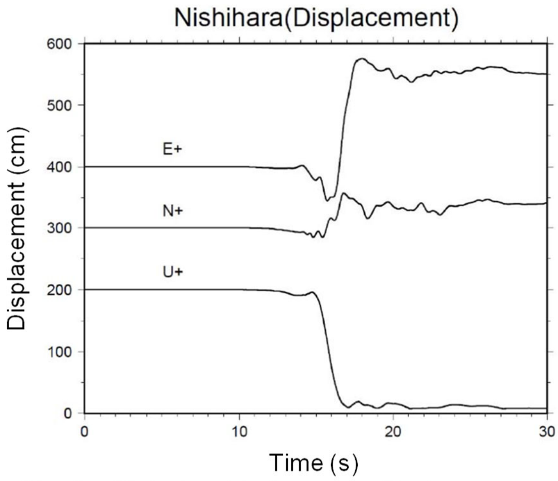


Fig.3 – Relationship between displacement and time at seismic wave measuring point

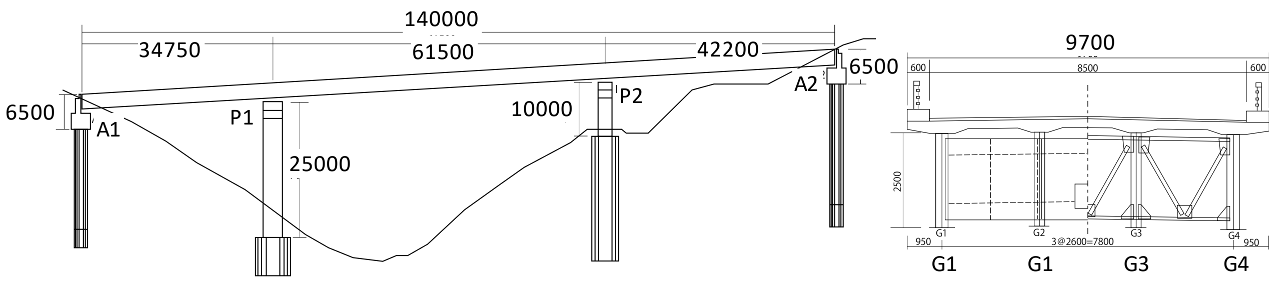


Fig.4 – General plan of Tawarayama bridge

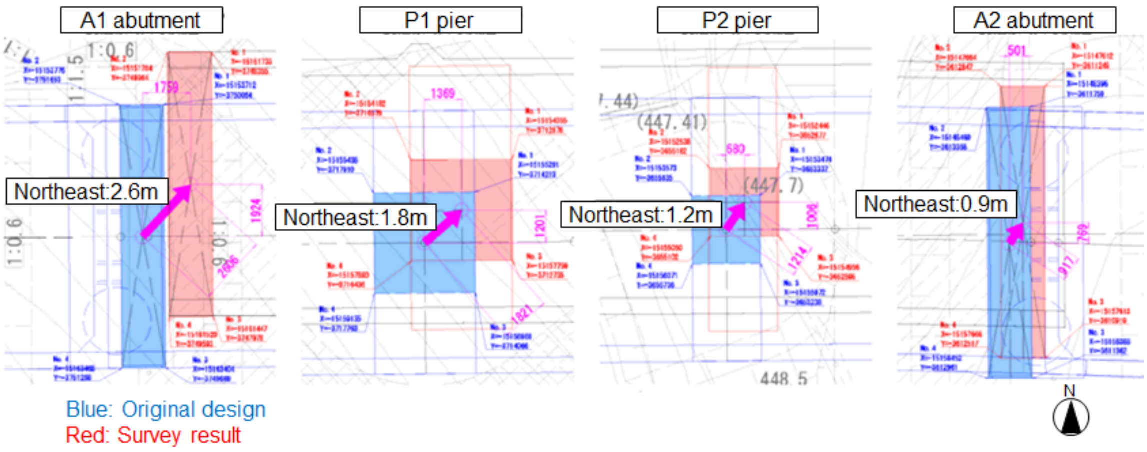


Fig.5 – Survey result of substructure displacement

According to the record, the displacement is large in the northeast and downward directions. It is also estimated that those displacements remained after the earthquake.

3. Specification of Tawarayama bridge

In this study, Tawarayama bridge was investigated whose the function was greatly damaged by the Kumamoto earthquake. Fig.4 shows a general view of the bridge. Tawarayama Bridge was constructed in 2001. This bridge has a continuous non-composite three spans steel girder with bridge length of 140m, rubber bearings, inverted T-type abutment and an overhang type bridge piers and deep foundations. In addition, side block was installed on the bearing on the abutment, and unseating prevention cables connecting the girder and the abutment was installed.

4. Damage outline of Tawarayama bridge

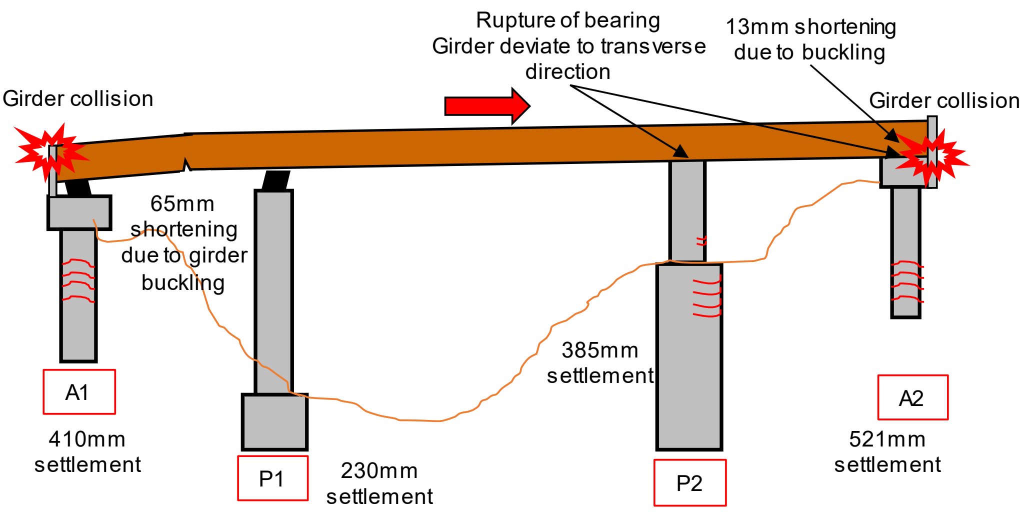


Fig.6 – Outline of Tawarayama bridge damage state

Fig.7 – Buckling of the girder between A1-P1

Fig.8 – Damage overview of the A2 abutment

4.1 Damage state of the super structure and substructure

Tawarayama bridge is located in large ground displacement area. The horizontal and vertical displacement of the abutments and piers were surveyed. Fig.5 shows the displacement of the substructure. The substructures were moved northeastward up to 2.6m. In addition, amount of settlement was different at each location. In addition, the bearing and the superstructure were damaged due to the movement of the substructure. The summary of bridge damage state is shown in Fig.6. The lower part of the main girder between A1 and P1 was buckled as shown in Fig.7. And, the damage of A2 parapet was observed due to the collision of the girder as shown in Fig.8.

4.2 Damage state of the bearing

Names of members of rubber bearing are shown in Fig.9. Fig.10 shows the state of the bearings right after the earthquake. Looking at the A1 bearing, all bearings showed residual deformation to the A1 side, but obvious damage such as rupture of the bearing was not found. Looking at the P1 bearing, there were residual deformation to the northeast direction, but the damage of rubber bearing was not observed same as A1 bearing.

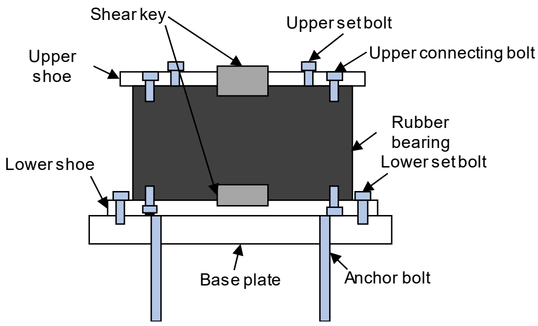


Fig.9 – Members of the rubber bearing

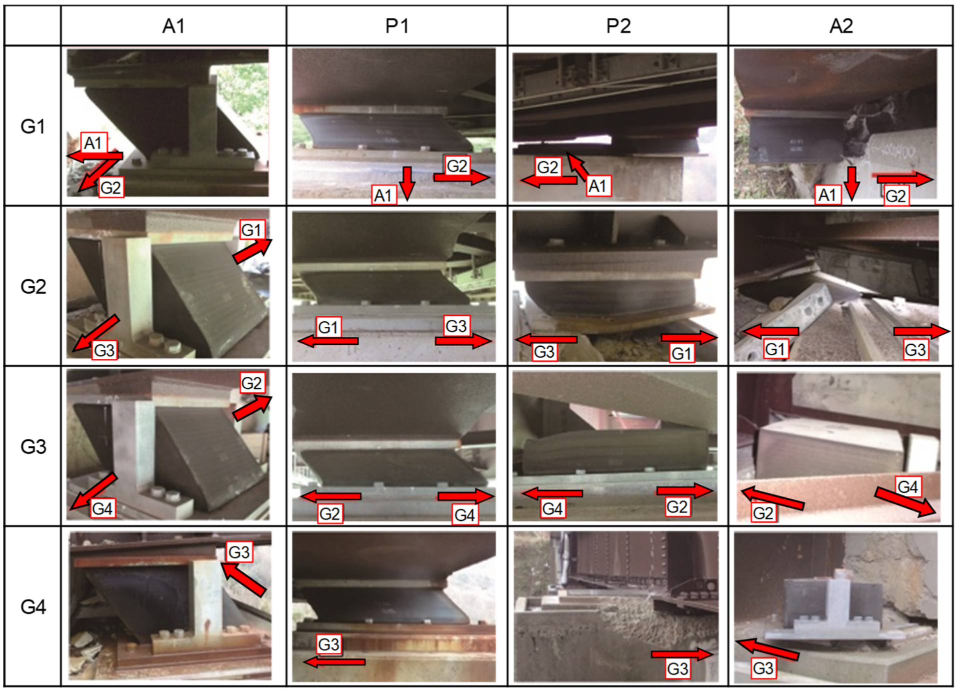


Fig.10 – Overview of the bearing after earthquake

Looking at P2 bearing, the set bolts or connecting bolts to the superstructure or substructure were broken, and girders were separated from the pier. Especially at G1, the bearing fell from the pier. In A2 bearing, the superstructure and substructure were separated due to the damage of bearing connecting bolts same as P2 pier.

The damaged bearings were collected and the damage states at upper and lower side were investigated. An example of overview of the damage is shown in Fig.11. Summary of the investigation results of bearing are shown in Fig.12 and Fig.13. In this paper, we analyzed focusing on damage of P2 bearings.

5. Survey analysis of bearings on P2 pier

(1) G1 and G2 bearings

The bearings of the G1 and G2 moved with the lower shoe plate due to the damage of the lower set bolts. The deformation of bearing was observed at the under part of the rubber and lower shoe plate. It is estimated that the bearing was deformed due to fall on the pedestal when lower set bolts broke. Some of the lower connecting bolts were broken as shown in Fig.13. The lower connecting bolts breaking part is concentrated where the bearing was deformed. Therefore, it is presumed that the lower connecting bolts were broken by the horizontal force after moving with the lower shoe plate.

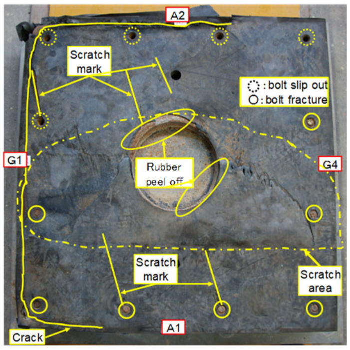


Fig.11 Overview of the P2G3 bearing (upper side)

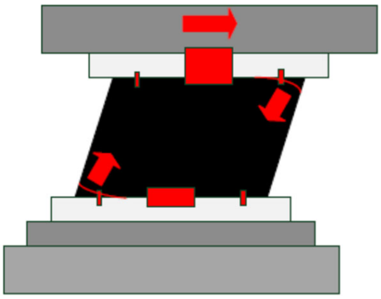
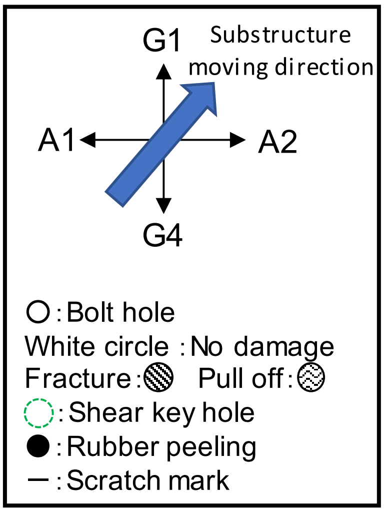


Fig.14 Image of force acted in rubber bearing



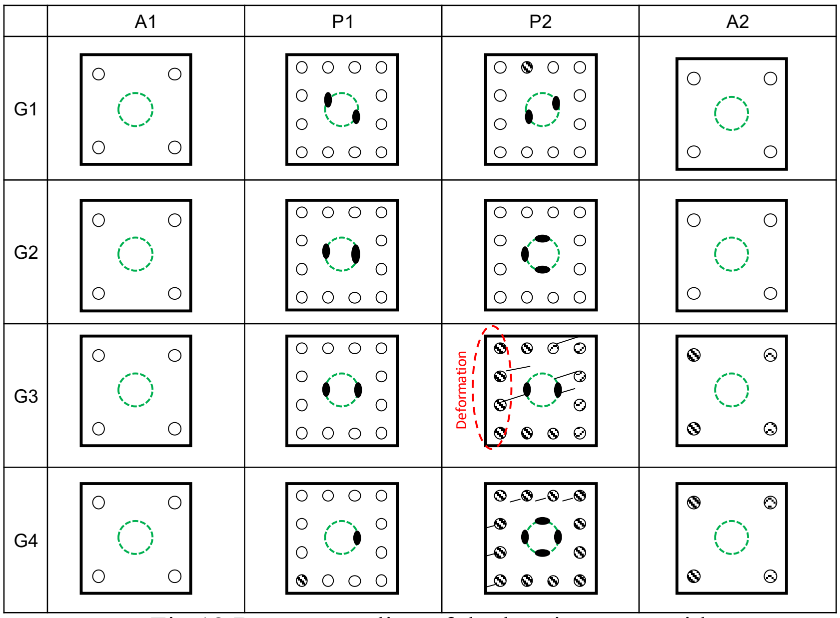


Fig.12 Damage outline of the bearing upper side

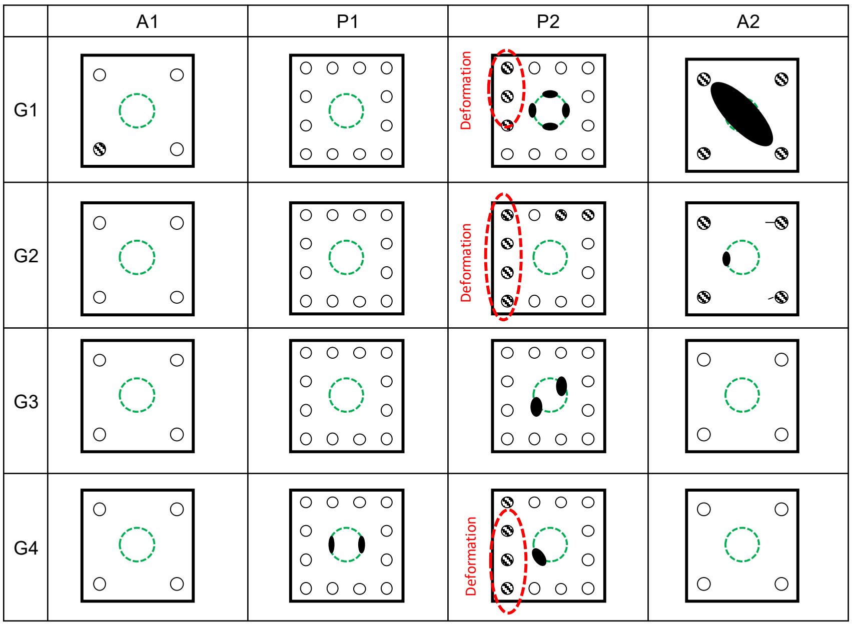


Fig.13 Damage outline of the bearing lower side

(2) G3 and G4 bearing

Looking at the G3 bearing, upper connecting bolts were pulled out or fractured as shown in Fig.13 and G3 bearing was separated from the girder. It is supposed that the upper part of the rubber deformed because the superstructure fell on the bearing.

It is known that a tensile force acts while deforming as shown in Fig.14 when the horizontal force acts on rubber bearing. Shear force acts on one side connecting bolts and tensile force acts on the opposite connecting bolts. Therefore, it is presumed that most connecting bolts fractured due to shear force and the other connecting bolts were pulled off due to tensile force. Also, looking at the upper side of bearing, there are the scratch marks toward one direction, it is presumed that the girder dropped off from the bearing right after connecting bolts fractured.

The G4 bearing dropped from the pier due to upper and lower bolts broke. And rubber bearing deformation was observed. Looking at the damage state of bearing upper side, the scratch marks observed in opposite direction with the G3 bearing. It is considered that the lower set bolts broke and bearing deformed same cause as the G1 and G2 bearing. And scratch marks were made opposite direction with the G3 bearing by later shaking. Finally, it is estimated that the bearings dropped from the pier due to damage to all upper connecting bolts.

6. Estimation of damage mechanism

Fig.15 – Girder collided with A1 abutment

Fig.16 – Girder collided with A2 abutment

At Tawarayama bridge, the damages such as buckling of girder and the damage of abutment were investigated. Based on the results, the damage mechanism is estimated as follow.

(1) Cause of damage of the parapet

It was observed that the girder of A1 and A2 contact with the parapet as shown in Fig.15 and Fig.16. In addition, A2 girder observed displaced to transverse direction. Fig.17 shows damage state of the A2 abutment. Looking at the damage diagram of the parapet, collision marks matched the position of the lower flanges of the girders in the design. In addition, the damage depth of the concrete at the lower part is larger than at the collision point. From this, it is estimated that the bearing was not damaged when girder collided to the parapet, after that, parapet damaged while the girder dropped on the abutment due to the damage of the connecting bolts of bearings.

On the other hand, if the A2 bearings are damaged by the seismic vibration, girder will separate from parapet by the elasticity of the A1 and P1 bearings. However, each end of the girder was contact with the parapet, and in addition, the survey results that the distance between A1 and A2 abutments became shorter suggest that the damage is due to ground displacement.

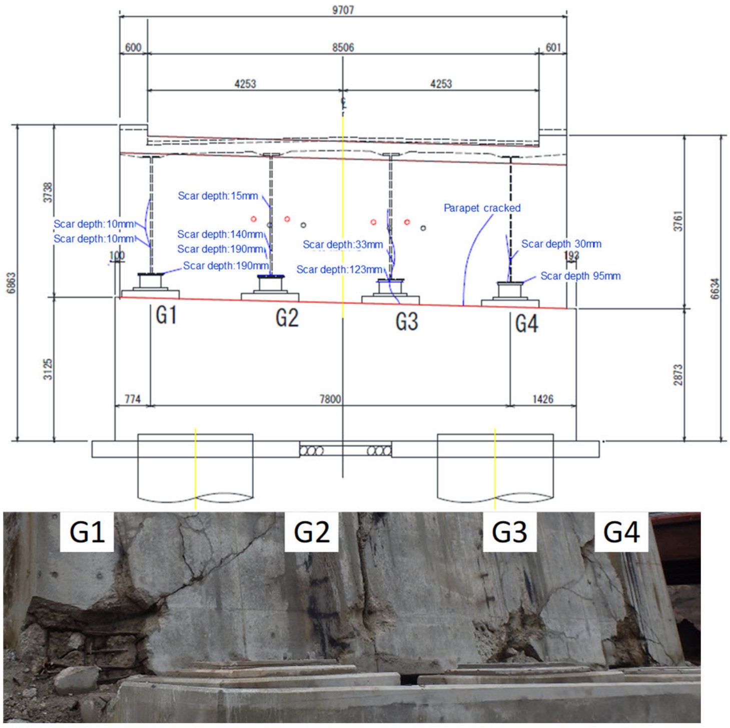


Fig.17 – Damage state of the A2 abutment

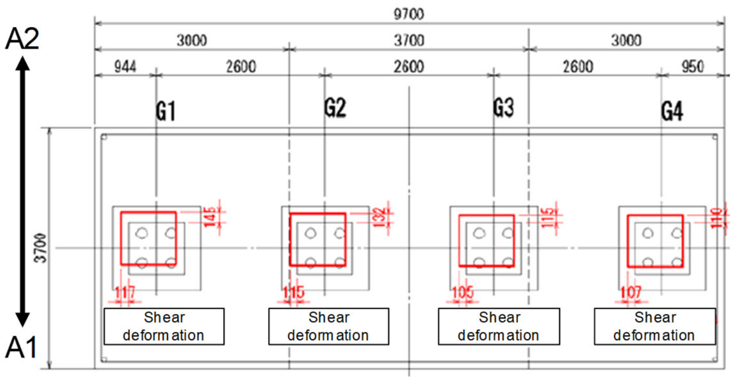


Fig.18 – Position of the upper side of P1 bearing after earthquake

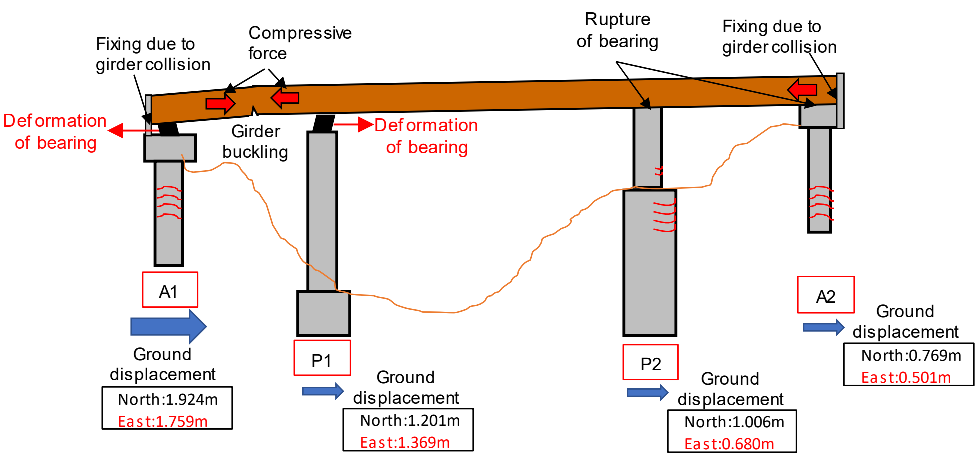


Fig.19 – Image of the girder buckling mechanism

(2) Cause of the buckling of the girder between A1 and P1

In this section, we try to clear the cause of buckling of the girder is whether collision due to seismic vibration, reaction force of bearing or ground displacement. If the girder collides with the parapet due to seismic vibration, the end of the girder is expected to buckle. However, end of the girder at the A1 side did not buckle. Therefore, it is not presumed that the girder buckled by only seismic vibration.

If the reaction forces of the bearings are strong enough to buckle the girder, the bearings are also expected to be damaged. However, obvious damage was not found of the A1 and P1 bearings. Therefore, the acted force is estimated that smaller than the designed external force, and it is not presumed that the girder buckled due to the reaction force of bearing.

It is assumed that the distance between A1 and A2 became shorter and compressive force acted to the girder when the substructure moves by ground displacement. Looking at end of the girder, they are contacting with the parapet. In addition, the direction of deformation of the A1 bearing (see Fig. 15) and the P2 bearing (Fig. 18)were in the direction to compress A1-P1 span. Thus, it is estimated that the compressive force acted the girder between A1 and P1 as shown in Fig.19.

7. Conclusion

This paper estimated the behavior and the damage mechanism of the bridge based on the damage analysis. As a result, the behavior of the bridge was able to estimate based on the damage analysis and result of survey. Especially, in Tawarayama bridge, ground displacement is suggested one of the important factors for damage mechanism of the bridge.

8. Acknowledgements

This study was provided removed rubber bearings 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”.

9. References

[1] The Geospatial Information Authority: (https://www.gsi.go.jp/kihonjohochousa/multilingual.html)

[2] National Research and Development Agency, Public Works Research Institute: Report on Damage to Infrastructure by The 2016 Kumamoto Earthquake, Technical Note of Public Works Research Institute, No.4359 (in Japanese).

[3] Michio Ohsumi, Junichi Hoshikuma: Damage Analysis Based on Damage Mark of Road Bridge Damaged by Kumamoto Earthquake. The 20th Symposium of Seismic design of bridge based on performance. pp.121-128, 2017.

[4] The Geospatial Information Authority: Crack distribution map on the ground surface around “Futagawa fault zone” by aerial photo interpretation, (https://www.gsi.go.jp/BOUSAI/H27-kumamoto-earthquake-index.html#dd).

[5] Tomotaka Iwata: Analysis of the Kumamoto Earthquake record in Mashiki and Nishiharamura-komori, http://sms.dpri.kyoto-u.ac.jp/topics/masiki-nishihara0428ver2.pdf (in Japanese).

