ANALYSES OF DAMAGED BRIDGE BY GROUND DISPLACEMENT DURING NIIGATA-KEN CHUETSU-OKI EARTHQUAKE

Takao Okada[1] and Shigeki Unjoh[2]

Abstract

A 3-span continuous girder bridge supported by rubber bearings to disperse seismic lateral forces was affected by 2007 Niigata-ken Chuetsu-oki earthquake. The bridge pier columns and abutment walls were not damaged. However, all pier and abutment foundations moved with the ground displacement and some cracks were found at the pile heads of both abutments. This paper presents the preliminary damage analyses of the bridge to simulate the effect of the earthquake.

Introduction

The Niigata-ken Chuetsu-oki earthquake occurred on July 16, 2007. The magnitude was 6.8 and the JMA intensity was VI upper. The depth was about 17km. The damage was serious and a number of houses were affected. Nuclear power plant was also affected by the earthquake. In the case of bridge structures, the similar damages were found with those caused by the past earthquakes including damage to bearing supports, parapet walls of abutments, and settlements of backfill soils behind the abutments. Some bridges supported by rubber bearings were affected during the earthquake. The damage of the bridges was not serious but unprecedented. The residual displacement was found at the rubber bearings because of the ground displacement resulting in the movement of substructures.

This paper presents the damage of the bridge and analyses to evaluate the effect of strong ground motion and ground displacement caused by this earthquake.

Overview of the Bridge and the Damages

The bridge analyzed in this study is located as shown in **Fig. 1**. The bridge is about 20km away from the epicenter. The bridge was designed based on the Specifications for highway bridges (March 2002) and was constructed in 2005 to overpass the river as shown in **Fig. 2**. The bridge length is about 150m (47.6m +55m + 45.2m). The superstructure is 3-span continuous curved steel box girder. The substructures are RC columns with a wall type section and supported by the cast-in-place RC pile foundations. The ground consists mainly of soft silt and clay including thin sandy layers causing liquefaction. The ground type for seismic design is classified in TYPE III. The pile lengths are 55 ~ 70 m and the pile diameter is 1.5m. Bearings are rubber bearings to disperse seismic lateral forces in all direction. Two

[1] Researcher, Center for Advanced Engineering Structural Assessment and Research, PWRI
[2] Research Coordinator for Earthquake Disaster Prevention, Research Center for Disaster Risk Management, NILIM

bearings are settled on each pier and abutment. The stoppers are installed at both abutments in transverse direction to bridge axis. Formed cement soil structures were used behind both abutments to decrease the earth pressure to abutments. Box culvert structures are located behind the formed cement soil structures as shown in **Fig. 3**.

During the earthquake, the bridge columns and abutment walls were not damaged, but some movements of foundations of all piers and abutments were found as shown in **Fig. 4**. A2 abutment moved longitudinally by 45cm toward the river. A1 abutment moved transversely by 16cm. The superstructure rotated clockwise. **Fig. 5** shows the residual displacements observed at the rubber bearings. **Fig. 6** shows the joint gap closure between the superstructure and A2 abutment. A1 abutment, P1 column and P2 column settled by 3~4 cm. The backfill soils behind abutments settled by 25 ~ 40 cm as shown in **Fig. 3**. Some cracks at the pile heads of A1 and A2 abutment were found by core drilling investigation.

After the earthquake, the bridge was repaired and retrofitted seismically. The foundation of A2 abutment was retrofitted by adding the number of cast-in-place RC piles. The rubber bearing were restored by jacking up the superstructure and by pushing the superstructure horizontally. The parapet wall of A2 abutment was removed and reconstructed to restore the expansion joints and the design gap between the end of superstructure and abutment.

Dynamic Analysis

Nonlinear dynamic analyses were performed to simulate the dynamic behavior during the earthquake and to figure out the effect of the inertia force caused by the strong ground motion. The analytical model used was a simple beam spring-mass system which was commonly used in the usual seismic design. The superstructure was modeled by the elastic beam elements. The rubber bearings on both abutments and columns were modeled by the linear spring elements. The columns were modeled by elastic beam elements and nonlinear spring elements for plastic hinges. The foundations of each substructure were modeled by the linear spring elements. Equivalent damping ratio used in the analysis was assumed as **Table 1**.

The acceleration strong motion records were obtained by the seismometer of Kashiwazaki interchange which was located nearby the bridge as shown in **Fig. 1**.The accelerations of three directions were used as input ground motion to perform the dynamic analyses. The records were observed in north-south direction and east-west direction. The input accelerations are transformed in the direction of the bridge axis and transverse of the bridge axis. **Fig. 7** shows the input accelerations and the acceleration spectra. The natural period of the bridge is 1.25 seconds. The value of the accelerations is slightly smaller than the standard acceleration for Type II earthquake design ground motion in the range of fundamental natural period of this bridge.

Table 2 shows the comparison of the maximum value obtained through the analysis and the design allowable value of each structural member. The result shows that the piers are within the elastic range and the displacement of rubber bearings are smaller than the design allowable displacement. The analysis estimated that the bridge was not damaged by the inertia force by the earthquake. Since no damage was found to the pier columns and abutment walls, the analytical result accords with the observed situation of the bridge.

Pushover Analysis to Simulate the Bridge Movement

There is a possibility that the movement of foundations were caused by the soft soil and liquefaction-induced ground flow. Thorough the investigation, it was clarified the displacement of each substructure and residual displacement of rubber bearings as shown in **Fig. 4** and **Fig. 5**. To simulate the behavior of the bridge caused by the ground displacement, the pushover analysis considering the observed displacement of each substructure was performed.

The analytical model was the same with the dynamic analysis. The observed displacement of each substructure was input to each footing of substructures to simulate the bridge movement and the residual displacement of rubber bearings. **Fig. 8** and **Table 3** show the comparison of the analytical and the observed displacements. The bridge movement and the residual displacement of the rubber bearings are simulated well. The analytical results of directions of the A1 and P1 movement were slightly different from the observed ones. In this analytical model, the contact of the superstructure with parapets of abutments was not modeled. Therefore it might affect the difference. In fact, the superstructure contacted with both parapets and the superstructure was limited to move and turn around as shown in **Fig. 6**.

Conclusion

This paper presented the preliminaly analyses of the bridge behavior during the 2007 Niigata-ken chuetu-oki earthquake. The following conclusions may be deduced:

1. The damage was not serious but the residual displacements were found at substructures and rubber bearings which were caused by the ground displacement.
2. The dynamic analysis estimated that the bridge was not affected by the strong ground motion. The pushover analysis considering the observed displacement of each substructure simulated the bridge movement and the residual displacement of rubber bearings well.

In future study, it is needed to clarify the reason why the ground displacement occurred. Moreover, it is necessary to consider whether rigid or elastic bearing supports are better on the soft ground conditions including sandy layers causing liquefaction.

Acknowledgments

The authors would like to acknowledge the Hokuriku Regional Development Bureau and the Nagaoka National Highway Office, MILT, for providing the documents and materials on the bridge analyzed. The authors also appreciate East Nippon Highway Company, for providing the ground motion records.

References

Japan Road Association (2003). Specifications for highway bridges. Part V Seismic design, Japan.

Public Works Research Institute (2008). 'Report on Damage to Infrastructures and Buildings by the 2007 Niigata-ken Chuetu-oki Earthquake' Technical Note of Public Works Research Institute, No4086, Japan

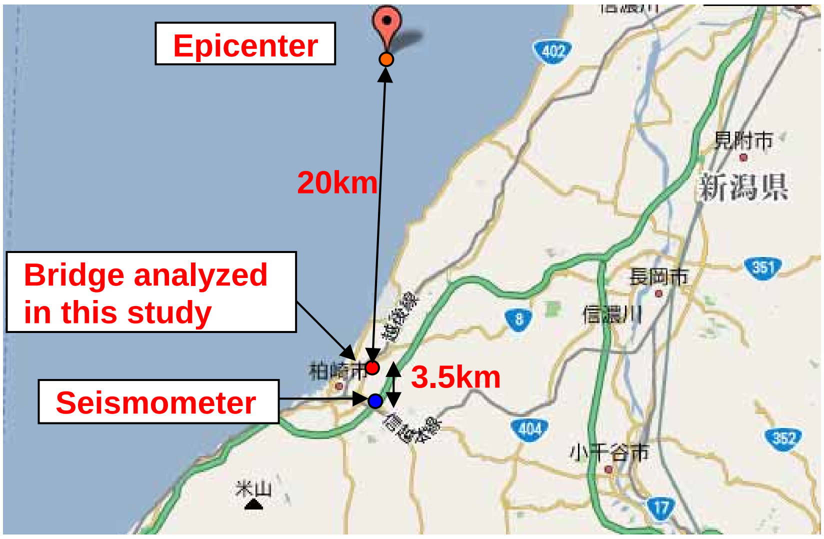

Fig. 1 Location of the bridge analyzed

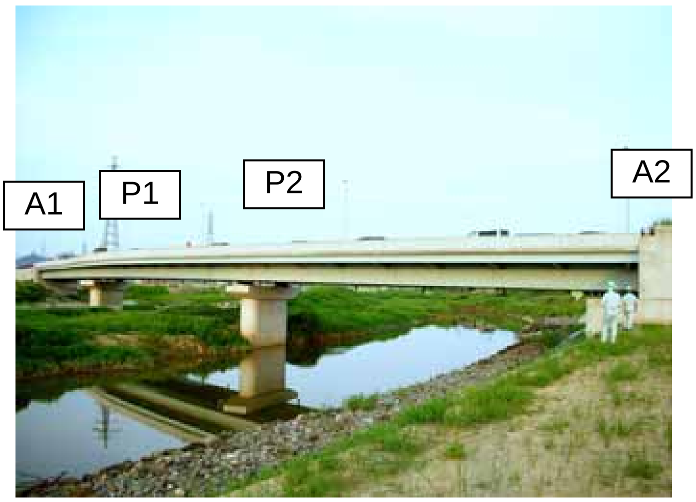

Fig. 2 Overview of the bridge supported by rubber bearings

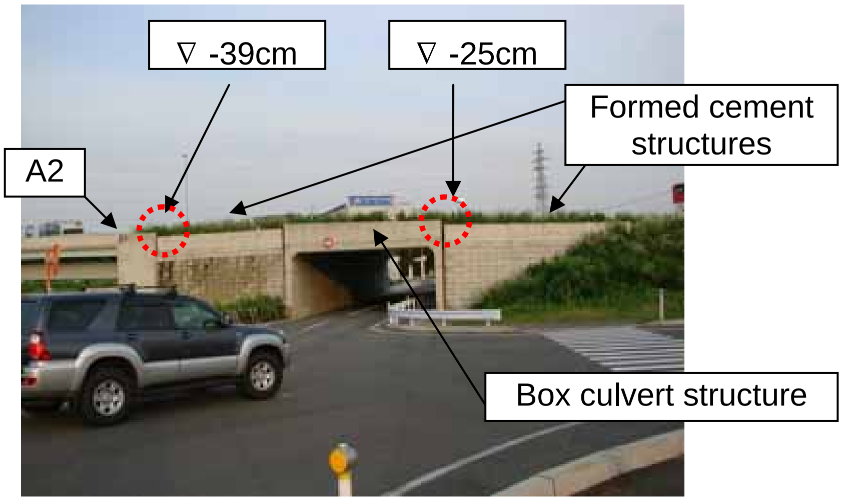

Fig. 3 Box culvert structure nearby A2 abutment

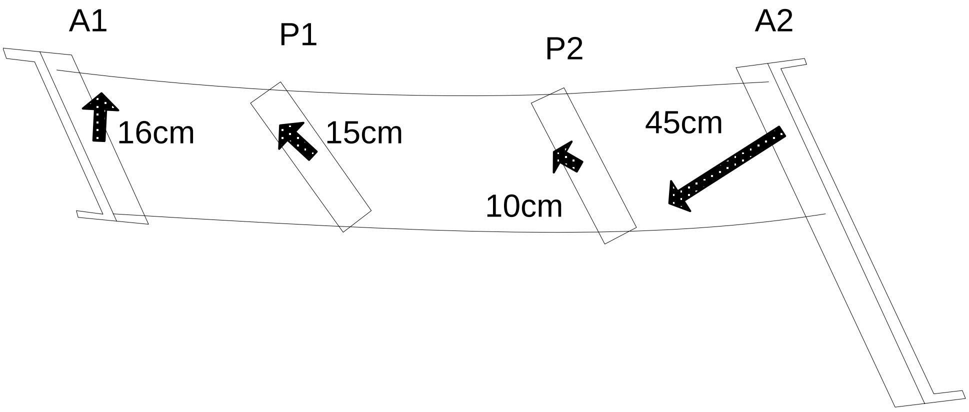

Fig. 4 Horizontal movement of A1, P1, P2 and A2

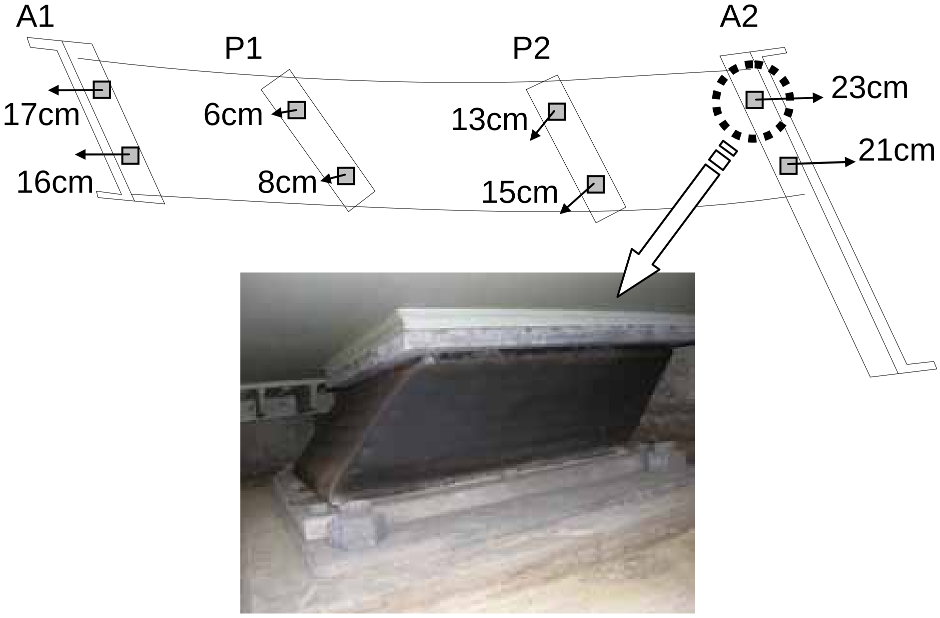

Fig. 5 Residual displacement of rubber bearings

Fig. 6 Clogging of expansion joint

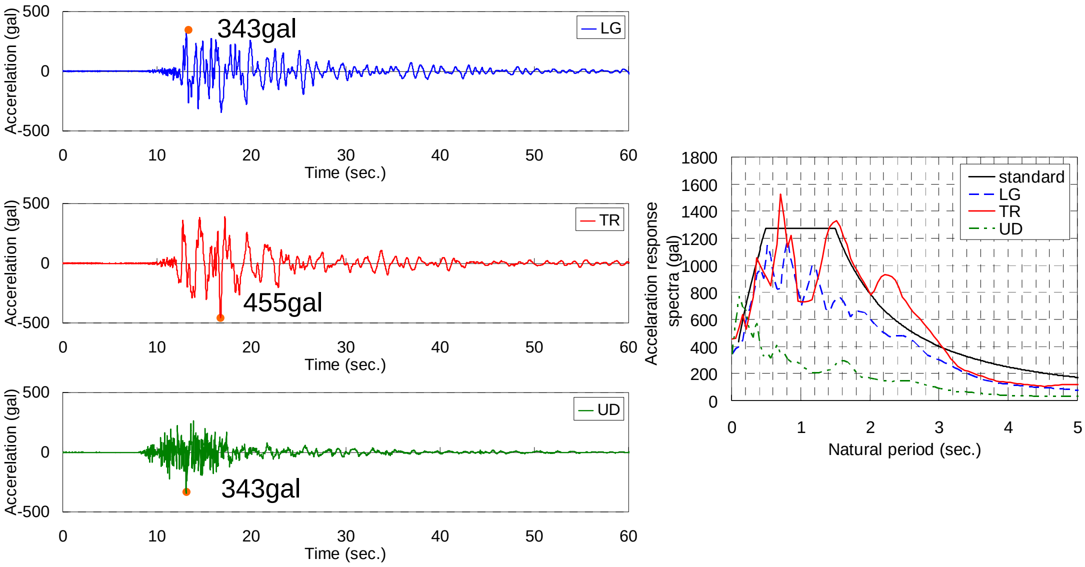

Fig. 7 Input accelerations and acceleration response spectra

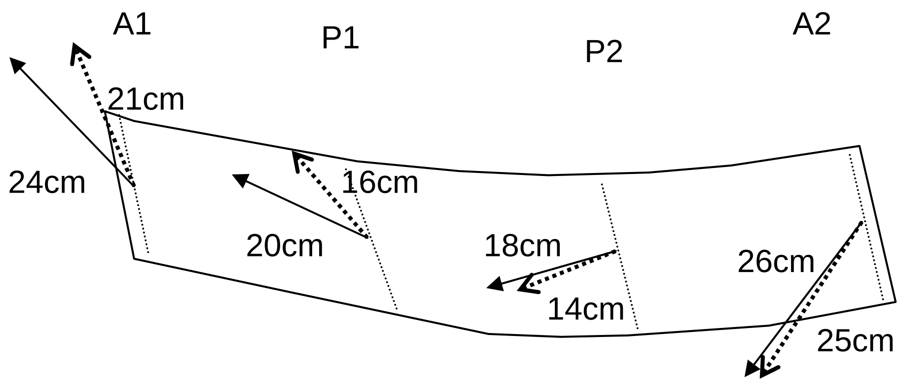

Fig. 8 Comparison of displacement of superstructures
Analysis : ·········> Observed data : ———>

Table 1 Equivalent damping ratio for each structural element

Structural members	Super-structure	RC (except plastic hinge)	Plastic hinge of P1 and P2	Rubber bearing	Foundation
Damping ratio	0.02	0.05	0.02	0.04	0.2

Table 2 Result of dynamic analysis

Rubber bearings			
Displacement		Analysis result (m)	Allowable value (m)
A1	longitudinal axis	0.28	0.58
	transverse axis	-	
P1	longitudinal axis	0.20	0.5
	Transverse axis	0.15	
P2	longitudinal axis	0.20	0.48
	transverse axis	0.17	
A2	longitudinal axis	0.30	0.51
	transverse axis	-	
Piers			
Ductility of plastic hinge		Analysis result	Allowable value (μa)
P1	longitudinal axis	0.81	4.3
	transverse axis	0.26	3.3
P2	longitudinal axis	0.84	4.2
	transverse axis	0.24	3.2
Shear stress		Analysis result (kN)	Allowable value (kN)
P1	longitudinal axis	7845	203044
	transverse axis	7854	27488
P2	longitudinal axis	8075	20344
	transverse axis	7137	27488

Table 3 Comparison of the residual displacement of rubber bearings

Residual displacement of rubber bearings		Analysis result (mm)		Observed value (mm)	
		G1	G2	G1	G2
A1	longitudinal axis	150	150	170	160
	transverse axis	-	-	0	0
P1	longitudinal axis	7	21	60	80
	Transverse axis	-5	-16	-10	-20
P2	longitudinal axis	11	36	80	110
	transverse axis	-64	-76	-100	-100
A2	longitudinal axis	-246	-247	-230	-210
	transverse axis	-	-	10	10