Investigation on the damage cause of the bridge rubber bearings in the 2011 off the Pacific coast of Tohoku Earthquake

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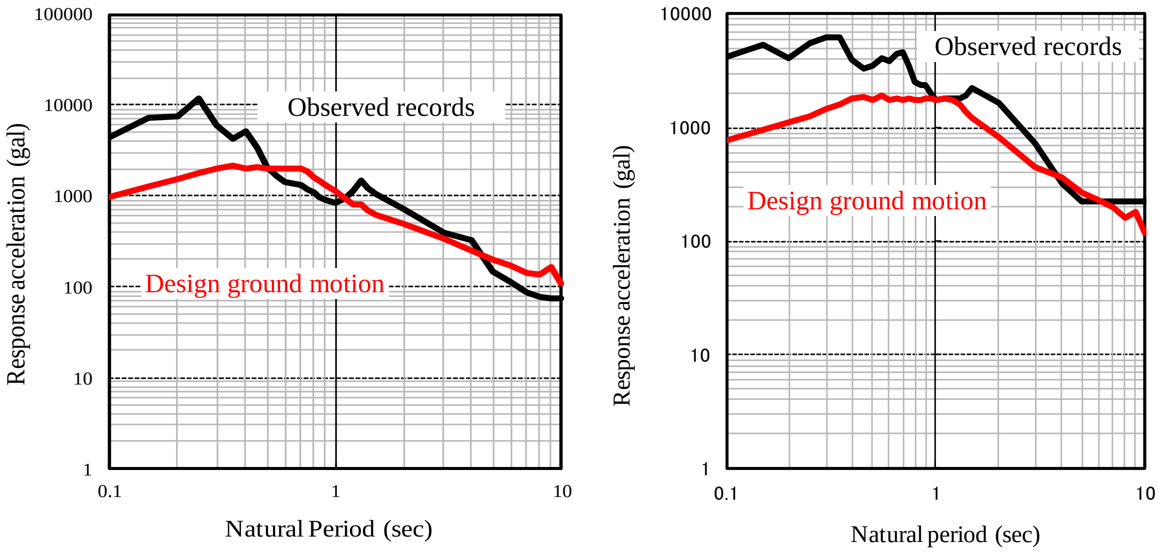
Summary
In the 2011 off the Pacific coast of Tohoku earthquake, the severe damage of the rubber bearings was confirmed for the first time since the rubber isolation bearings were adopted. Specifically, some rubber bearings of the expressway bridges were broken away in the horizontal direction. In this paper, the cause of the observed damages to rubber bearings is investigated. Firstly, examined are the characteristics of the observed ground motions whose maximum ground acceleration is 300 cm/s^2 or more. From the results, the peak displacement response of structures with a natural period ranging from one second to two seconds under the observed ground motions is turned out to be about 1.5 times larger than that of the design ground motion. Finally, dynamic analysis of bridges with rubber bearings is performed to understand how ground motion characteristics and structural properties of the bridges affected the seismic response of the bridges that led to the damage of the rubber bearings.

1. INTRODUCTION

An earthquake with a historic moment magnitude of 9.0 hit the Tohoku region, the northeast part of Japan, triggering tsunami that wiped away cars, ships and buildings all along the east coast. On-site post-earthquake investigation was conducted to assess the damage of several bridges. The investigation is particularly focused on the damage to base-isolated bridges with rubber bearings.

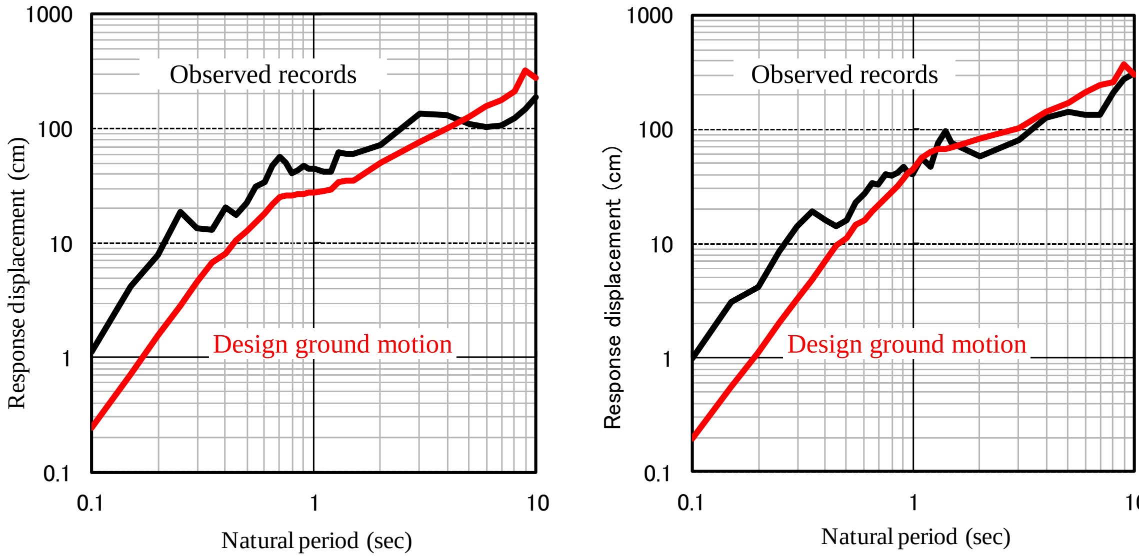
In Japan, the rubber bearings have been widely installed since the 1995 Hyogoken-Nanbu earthquake as either seismic force distribution bearings or base-isolators. By using rubber isolation bearings, the

Photo 1.1. Damage of the bridge rubber bearing
(Photo by East Nippon Expressway Company)



(a) Ground Type I (b) Ground Type II

Figure 2.1. Acceleration response of the observed records



(a) Ground Type I (b) Ground Type II

Figure 2.2. Displacement response of the observed acceleration records

natural period of the bridge becomes longer than the dominant period of the ground motions, resulting in a smaller seismic force on the bridge substructure. In fact, neither the collapse of the bridge piers nor the damage of the rubber bearings has been reported since the 1995 Hyogoken-Nanbu earthquake although magnitude 7 or larger earthquakes occurred several times. However, in the 2011 off the Pacific coast of Tohoku earthquake, severe damage of the rubber bearings was confirmed for the first time since the rubber isolation bearings were adopted as shown in Photo 1.1. Specifically, some rubber bearings of the expressway bridges were broken away in the horizontal direction. In this paper, the cause of the observed damages to rubber bearings is investigated.

2. CHARACTERISTICS OF THE OVSERVED ACCELERATION RECORDS

In Japan, some national institutes have control of the seismometers such as Japan Meteorological

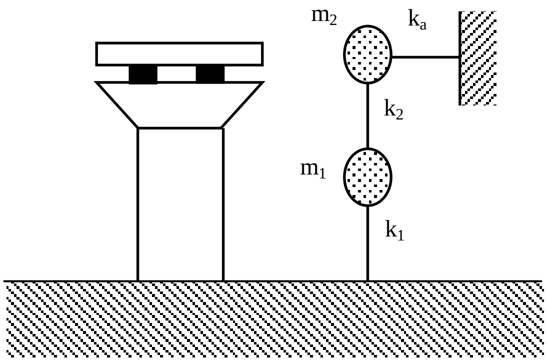


Figure 3.1. Numerical model for trial calculation

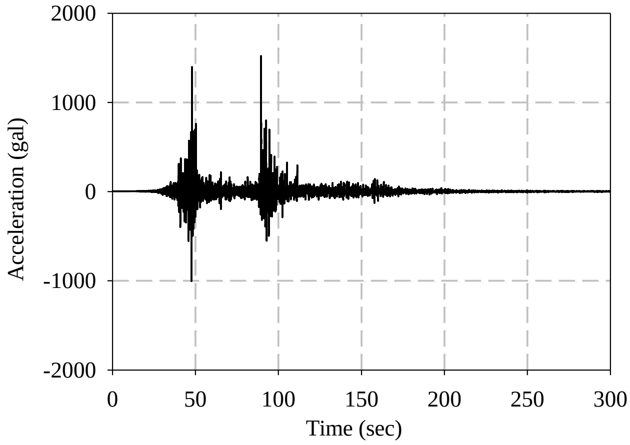


Figure 3.2. Time history of the input acceleraiton

Agency (JMA), National Research Institute for Earth Science and Disaster Prevention (NIED), Ministry of Land, Infrastructure, Transport and Tourism (MILT) and so on. In this study, the observed data by K-NET which is controlled by the NIED are utilized to investigate the characteristics of the acceleration records. There are 80 observation points where the maximum acceleration of the three-direction component synthesis (North-South direction, East-West direction and Vertical direction) exceeds 300 cm/s^2 in the 2011 off the Pacific coast of Tohoku Earthquake.

Response spectra were calculated for the North-South and East-West directions of the 80 observations points, resulting in 160 spectra, where a damping ratio of 0.05 was used.. Grouping the response spectra by ground types based on the three types specified in the Japanese specifications (Japan Road Association, 2002), the maximum acceleration and displacement response values of every natural period among response spectra in each ground type were then found. Such spectra are plotted in Figures 2.1 and 2.2 for ground types I and II, respectively. The response spectrum for the design earthquake is also shown in these figures. It is found that the response acceleration of the 2011 earthquake is much larger than the one of the design wave in the Type I ground, good diluvial ground and rock, when the natural period is lower than 0.7 sec. Moreover, the response acceleration of the 2011 earthquake is larger in the Type II ground, diluval and alluvial ground, when the natural period is around one or two seconds. From Figure 2.2, the displacement response of the 2011 earthquake can become about 1.5 times as large as that of the design earthquake when the natural period is around one or two seconds. The maximum displacement response for the period shorter than two seconds is turned out to be less than one meter.

In general, the ultimate shear strain of natural rubber is about 300% to 400%. Therefore, a rubber bearing with a total rubber thickness of 20 cm can withstand the horizontal displacement of 60 cm, implying that strong ground motion is not a sole cause of the observed damage of rubber bearings and there should be additional condition for the rubber bearing to undergo excessive deformation. One of plausible such conditions is movement restraint of superstructure.

3. TRIAL CALCULATION ABOUT THE DISPLACEMENT OF THE RUBBER BEARING

In the previous chapter, it is pointed out that some sort of the movement restriction of the superstructure may cause the large deformation of the rubber bearing. To examine the effect of the restraint, a simple trail calculation is conducted. Figure 3.1 shows the numerical model used in this study. The pier with natural rubber bearings is modeled as two degrees of freedom system, where

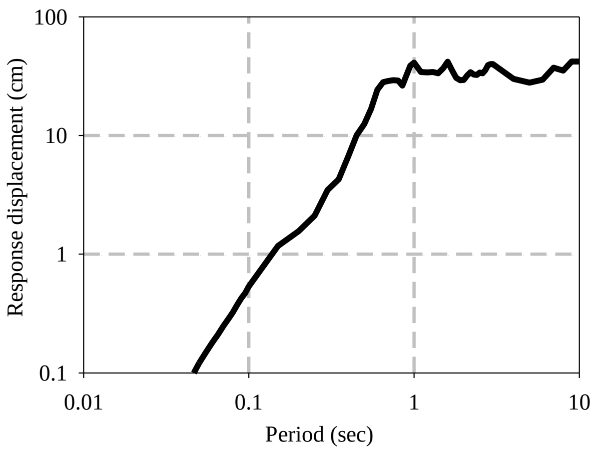


Figure3.3. Response displacemen of the input accleration

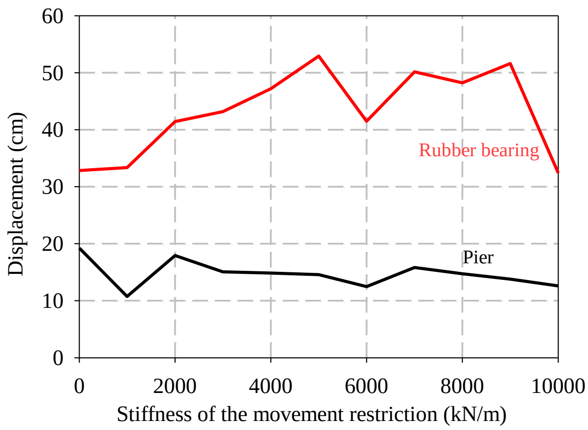


Figure 3.4. Displacement of the pier and the rubber bearing

Table 3.1 Input values of the numerical model

	Value
Mass of pier (m1)	100ton
Mass of superstructure (m2)	20000kN/m
Stiffness of pier (k1)	400ton
Equivalent Stiffness of rubber bearing (k2)	4000kN/m
Movement restriction stiffness of superstructure (k3)	From 0 to 10000 kN/m

Table 3.2 Natural period of the model

Stiffness (k3)	Natural period (1^{st} mode)	Natural period (2nd mode)
0	2.18	0.40
1000	1.91	0.40
5000	1.38	0.40
10000	1.09	0.40

m_1 and m_2 are masses of pier and superstructure, respectively, k_1 and k_2 are pier and bearing stiffnesses, and k_a represents the movement restriction of the superstructure due to the interlocking of the finger joints. Table 3.1 shows the input data of this model. A steel column pier is assumed in this study. The restoring force characteristic of the pier is modeled by the bi-linear model. The second stiffness after yielding is set to be 0.01 times as the initial stiffness. The input ground acceleration is one of the observed acceleration records in Sendai-City as shown in Figure 3.2. Figure 3.3 shows the displacement response spectrum for damping ratio of 0.05. The natural periods of the numerical model without the movement restriction are 2.18 sec for the first mode and 0.40 sec for the second mode.

Figure 3.4 shows the displacement of the pier and the relative displacement between the pier and the superstructure for different degrees of stiffness for the movement restriction. This relative displacement is equal to the displacement of the rubber bearing. Table 3.2 shows the natural period of the numerical model with the movement restriction. It is found that the relative displacement in some cases with the movement restriction becomes much larger than the case without the restriction, whereas the displacement of the pier is not affected significantly by the restriction. Based on this trial calculation, there is a possibility that bearing deformation can become larger than the deformation that causes the ultimate shear strain if the superstructure movement is restrained due to the interlocking of the finger joint or by some other reasons.

4. CONCLUSIONS

In the 2011 off the Pacific coast of Tohoku earthquake, the severe damage of the rubber bearings was confirmed for the first time since the rubber isolation bearings were adopted. First, the 160 ground acceleration records from K-NET are analyzed. The trail seismic response analyses of a base-isolated bridge model are then conducted to investigate the cause of the large deformation of the bridge rubber bearing.

The following remarks can be made as conclusions of this study.

The acceleration response is very large only in the structures with a short natural period smaller than 0.4 seconds in the 2011 off the Pacific coast of Tohoku earthquake.

The displacement response in the 2011 Earthquake is not significantly larger than that of the Japanese design ground motion.

As a result of seismic response analysis of the two DOF system, the deformation of the rubber bearing becomes much larger when the superstructure movement is restricted. It is likely that the movement restriction of the superstructure will cause the large deformation of the bridge rubber bearing.

The earthquake response analyses for the elevated bridge with several-continuous spans will be conducted to examine the effect of the superstructure restriction on the bearing deformation in the future. In addition, the effect of aging of rubber on the seismic performance of an isolated bridge needs to be investigated.

References

Japan Road Association (2002), Specifications for Highway Bridges (Part V seismic design), Maruzen.

Kazuhiko Kawashima (2012), Damage of Bridges due to the 2011 Great East Japan Earthquake, Proceedings of the International Symposium on Engineering Lessons Learned from the 2011 Great East Japan Earthquake, pp.82-101.