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Dynamic behaviors of an earthquake-damaged viaduct before and after being mended

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ABSTRACT: In Japan, Mizufuka first railway bridge, which is consisted of six single-story Gerber-type RC rigid frame viaducts, was heavily damaged by the Chibaken-Toho-Oki Earthquake having a magnitude of 6.7. The site, where this bridge is located, is steeply varied in the depth of bearing layer, and situated about 80 km away from the epicenter. A major damage to the viaducts was diagonal cracks that occurred in the upper part of the columns. The damaged viaducts were retrofitted by injection of epoxy resin into small cracks and making shear walls between columns transversely. Microtremor and earthquake observation were carried out in the states before and after the mend. The predominant frequency of the mended viaducts is higher than that of the damaged ones, and besides the response of the predominant frequency becomes dull. It is found that the shear strengths of the mended viaducts have increased.

1 INTRODUCTION

On December 17 in 1987, the east parts of the Boso peninsula of Japan were struck by an earthquake. The Japan Meteorological Agency (JMA) named the earthquake the Chibaken-Toho-Oki Earthquake. According to the determination of the JMA the epicenter was located at Lat. 35°21'N, Long. 140°29'E, and its focal depth was 58 km and the magnitude 6.7. Figure 1 shows the location of the epicenter and the distribution of seismic intensity on the JMA scales.

The earthquake caused 2 persons dead, 26 persons severely injured, and a total of 118 persons with minor injury in Chiba Prefecture. The reported number of heavily, moderate and partially damaged wooden houses is 16, 102 and 71,212, respectively (Chibaken 1989).

In order to confirm an effect of retrofitting method for the damaged viaduct (Tanamura 1989, Nishimura 1989) microtremors observation was carried out before and after being mended viaduct. The purpose of this paper is to investigate dynamic properties of the mended and the damaged viaducts by carrying out microtremors and earthquake observations.

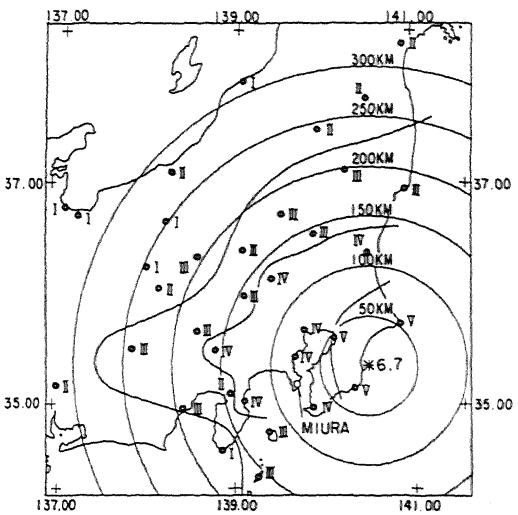


Figure 1. Epicenter and J.M.A. Intensity Distribution (Sasaki 1987).

2 DAMAGE TO BRIDGE

2.1 Outline of bridge and soil condition

The location of the Mizufuka first railway bridge, which was built in 1974 in Miura city, is shown as MIURA in Fig. 1. The

railway bridge is consisted of six single-story Gerber-type RC rigid frame viaducts with one two-span, two three-span and three four-span. Figure 2 shows the plan of the Mizufuka first railway bridge.

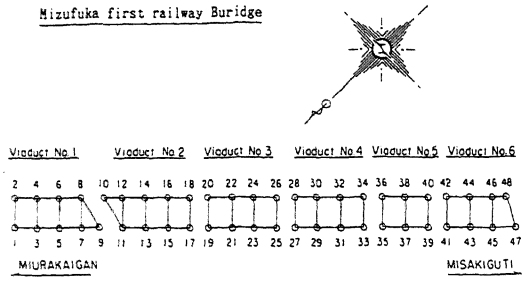


Figure 2. Outline of Mizufuka first railway bridge.

The soil profile along the bridge is shown in Fig. 3; the profile was drawn by based on the ten boring data. The surrounding soil layers consist of alluvial silt and sand and diluvial sand. The depth of the diluvial sand, which is the bearing layer of those viaducts, changes steeply.

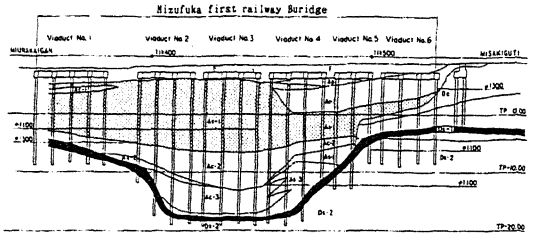


Figure 3. Soil profile along the bridge.

2.2 Damage

Figure 4 shows a distribution of the typical structural damaged viaducts No.2, No.3 and No.4. These three viaducts suffered severe, moderate and slight damage to the upper part of each column. Moreover, categories of three typical damage patterns are classified as shown in Fig. 4. Photographs 1 and 2 show detail of damage to the columns for viaducts No.2 and No.3. The major damage was diagonal cracks in the column of the upper part of viaducts No.2 and No.3. Diagonal cracks in the upper part of columns No.19 and No.22 are very clearly shown in Photos. 1 and 2. Many small cracks occurred in columns.

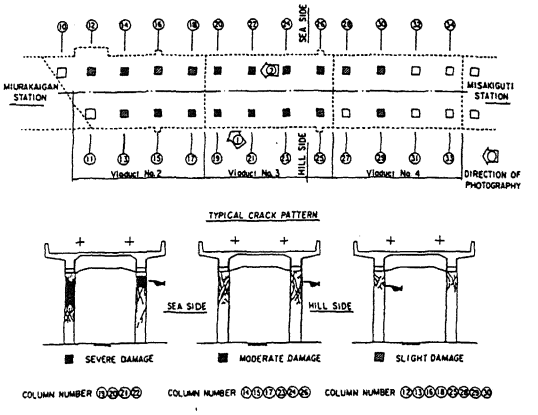
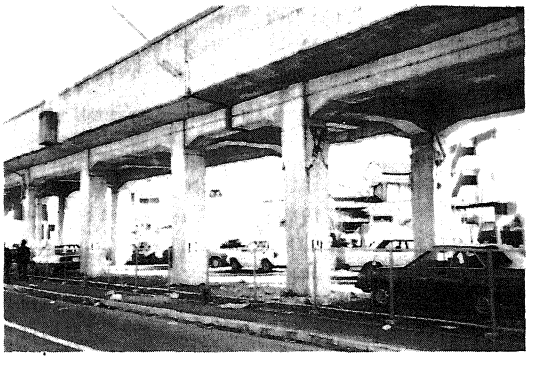
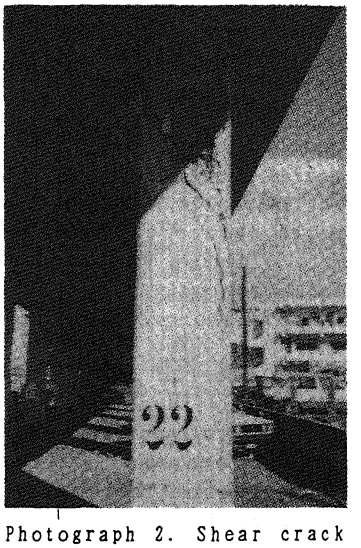


Figure 4. Structural damage distribution of viaducts No.2, No.3 and No.4.



Photograph 1. Side View of damaged viaducts No.2 and No.3.

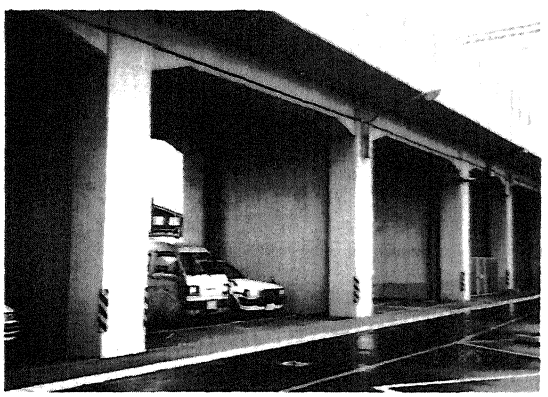


Photograph 2. Shear crack in the column No.22.

2.3 Repairing

It was judged that the viaducts could be repaired and strengthened for re-use. The following procedures were proposed for repairing and strengthening the viaduct.

First of all, Epoxy resin was injected into small cracks in columns. Then, the viaduct was strengthened by newly shear walls. Photograph 3 shows the newly constructed shear walls to the viaduct No.3 of the Mizufuka railway bridge.



Photograph 3. Side View of mended viaduct No.3.

3 OBSERVATIONAL POINTS AND DATA ACQUISITION

3.1 Microtremor

Microtremors were observed on the top of viaduct and the ground under the viaduct. Observation points are 12, indicated as G1 to G6 and B1 to B6 by white and black squares in Fig. 5. Simultaneous observations are made at every 2 point, such as B1 and G1, selected appropriately to examine the amplitudes and phases of microtremors from viaduct to ground over this bridge. Observations were carried out between 12 P.M. and 4 A.M., when the amplitude levels of microtremor in this area most small and predominant noise sources are not found within several hundred meters. The sensing instruments are set 3-components sets of short period velocity seismometers having a natural period of 1.0 sec, damping ratio of 0.64 critical and sensitivity of 3 volts/kines. The output signals from each seismometer are recorded in analog form using magnetic data recorder after being amplified 1000 to 3000 times through amplifiers of DC type. The data on magnetic tape are converted to digital form at sampling interval of 0.01 sec through an A-D converter.

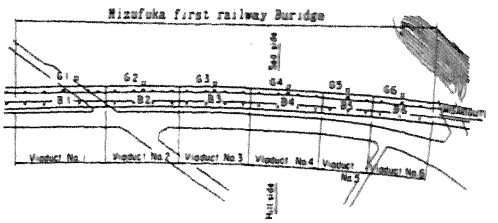


Figure 5. Observation points of microtremor.

3.2 Earthquake

The earthquake observation of the mended viaduct was carried out on and under the viaduct. Two velocity seismometers are installed on the position of the mended viaduct No.3. The observation system use telephone lines for reporting the outbreak of earthquakes and collecting earthquake data.

Earthquake observation began in July 1990 and ended at the end of October 1990. During observation period, six earthquakes have been observed. Table 1 shows the list of observed earthquakes. On October 10 and 14, 1990 two earthquakes with local magnitude of 4.8 and 5.7 on the Richter scale, respectively, were recorded at the viaduct. The event No.5 occurred about 60 km east of the viaduct; and event No.6 occurred 127 km south of the viaduct.

Table 1. List of observed earthquakes.

Event No.	Origin Time	M	Focal Depth (km)	Epicentral Distance (km)	Maximum Amplitude		I*
					Acc(gal)	Vel(kine)	
1	90:07:30	5.5	44	310	9.0	0.19	I
2	90:09:05	4.6	78	67	13.9	0.57	II
3	90:09:14	3.7	56	81	3.5	0.12	I
4	90:09:16	4.2	78	65	12.0	0.35	I
5	90:10:10	4.8	79	60	34.1	1.57	III
6	90:10:14	5.7	25	127	57.9	3.26	III

* : JMA Intensity at Tokyo

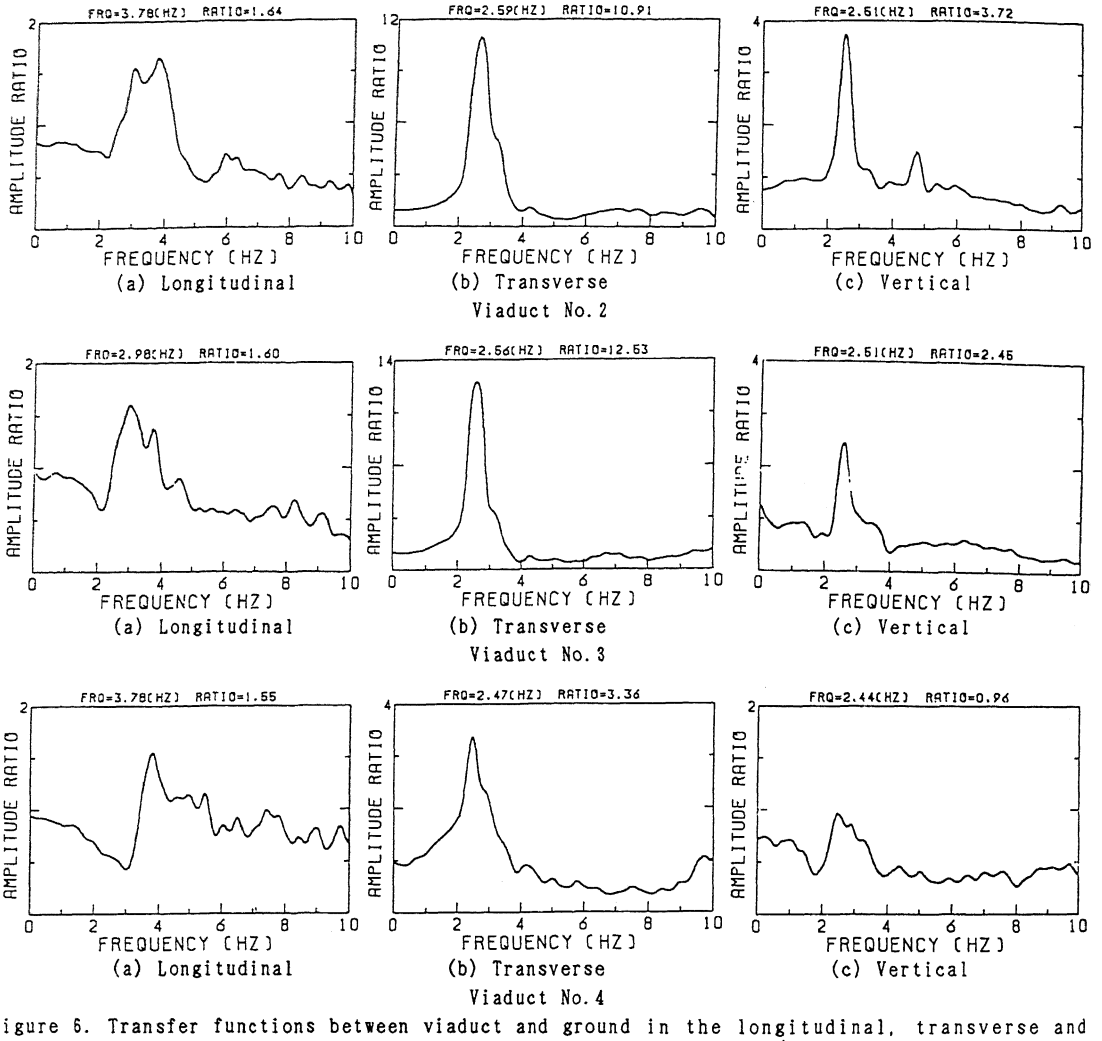


Figure 6. Transfer functions between viaduct and ground in the longitudinal, transverse and vertical directions of damaged viaducts No. 2, No. 3 and No. 4.

4 RESPONSE CHARACTERISTICS

The response characteristics of the damaged and mended viaducts are examined, using the data of simultaneously observed microtremor between on the viaduct and the ground under the viaduct of observational points shown in Fig. 4. The intervals of the analysis are 40.96 sec and the spectra are smoothed by Hanging window.

4.1 Damaged viaduct

Figure 6 shows a transfer function of the velocity time histories between the ground and the viaduct in the longitudinal, transverse and vertical directions to viaducts No. 2, No. 3 and No. 4. It is clearly seen that the predominant frequencies of the transfer functions of the three viaducts in the transverse and vertical directions are approximately 2.5 Hz and that the predominant frequency in the longitudinal direction is approximately 3 Hz. The amplitude ratio of viaducts No. 2 and No. 3 are greater than that of the viaduct No. 4. This is because the upper part of the columns of the viaducts No. 2 and No. 3 are severely damaged than those of the Viaduct No. 4 (see Fig. 4). A common feature of the response of the damaged viaduct in the vertical direction is predominant.

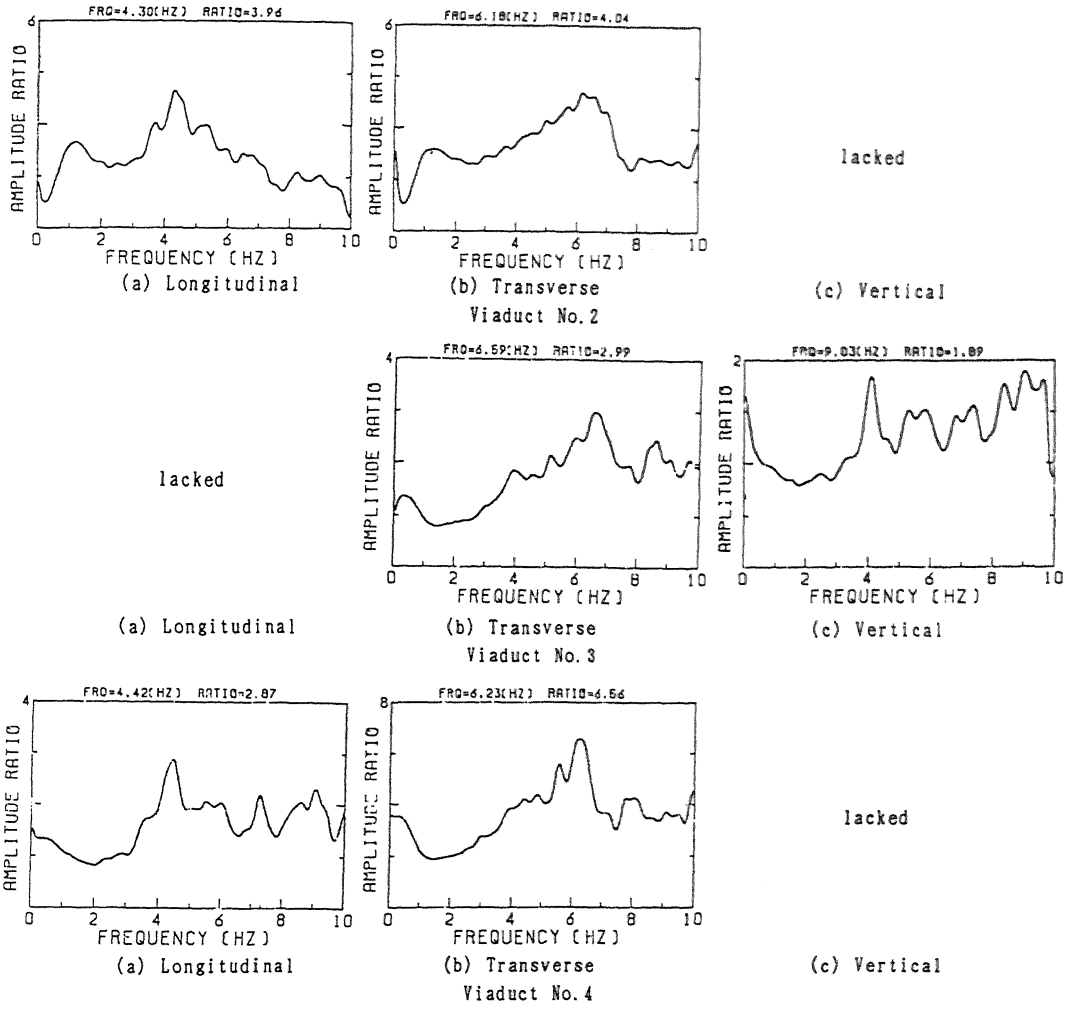


Figure 7. Transfer functions between viaduct and ground in the longitudinal, transverse and vertical directions of mended viaducts No. 2, No. 3 and No. 4.

4.2 Mended viaduct

4.2.1 *Microtremor*

Figure 7 shows transfer functions of the velocity time histories between the ground and the viaduct in the longitudinal, transverse and vertical directions to viaducts No. 2, No. 3 and No. 4. The transfer function of the vertical direction of viaducts No. 2 and No. 4 and the longitudinal of the viaduct No. 3 are lacked. Predominant frequencies of all three directions are not so clear. The predominant frequencies of all three directions are different; 4.0 Hz in longitudinal direction, 6.0 Hz in transverse one and 7.0 Hz in vertical one. The amplitude ratio is not so large compared with the damaged viaducts. Moreover, the amplitude ratio of the transfer function in the vertical direction is unity.

4.2.2 Earthquake

Figure 8 shows the time histories for the two velocities and acceleration time histories in the transverse direction of the mended viaduct No. 3 and the ground under the viaduct recorded event No. 6. The record event shows the peak velocities and acceleration 1.5 times to the ground in the transverse direc-

tion to the viaduct.

Figure 9 shows a mean value of two transfer functions of the velocity time histories between the ground and the viaduct in the transverse direction to the viaduct for the viaduct No.3 derived from the recorded event NO.5 and No.6 earthquakes. It is clearly seen that the predominant frequency of the transverse direction of the mended viaduct No.3 is approximately 6.0 Hz. This predominant frequency obtained from earthquake is in good agreement with that of microtremor.

5 CONCLUSIONS AND REMARKS

In this paper, the dynamic behaviors of the damaged and mended viaduct for the microtremor and earthquakes are compared. The following conclusions may be drawn from the results of this study.

1. It is found that the dynamic response of the damaged viaduct is the same in predominant frequencies of all three directions.
2. The response of the severely damaged viaducts No.2 and No.3 are bigger than that of slightly damaged viaduct No.4.
3. The predominant frequencies of the mended viaduct are different for each direction.
4. The response of the mended viaduct is smaller than that of damaged viaducts.
5. The response characteristics of the mended viaduct obtained from earthquake are coincident well with those in the microtremor.

ACKNOWLEDGMENT

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REFERENCES

Chibaken, 1989. Report of the Chibaken Toho Oki Earthquake 1987.

Nishimura A., N. Matumoto S. Tanaruma & A. Inoue. 1989. Cause of damaged viaduct Part 2(in Japanese). Proceeding of 20th JSCE EES-1989: 17-20

Sasaki Y. 1987, Prompt report of the Chibaken Toho Oki Earthquake of December 17 1987(in Japanese). Dobokugijyutu Shiryou. 30-1: 47-55.

Tanamura, S., S. Nishimura, A. Inoue & Tanshou, H. 1989. Cause of damaged viaduct Part 1 (in Japanese). Proceeding of 20th JSCE EES-1989: 13-16

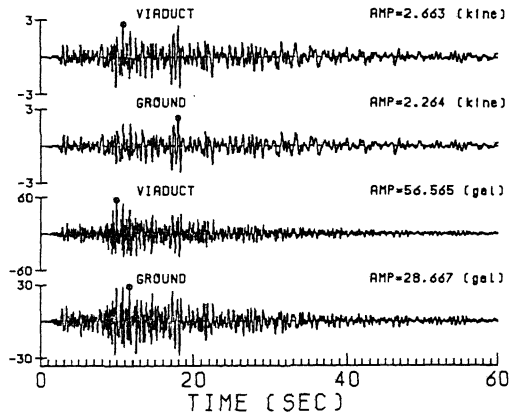

Figure 8. Recorded velocity and Acceleration time histories on the viaduct No.3 and the ground during event No.6 earthquake.

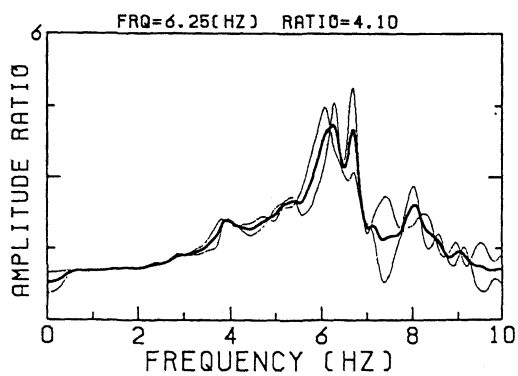

Figure 9. Transfer function between viaduct and ground in the transverse direction of viaduct No.2 due to two earthquakes event No.5 and No.6.