Performance of highway bridges under Chuetsu Earthquake, Japan

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ABSTRACT: This paper reports on the 3-day reconnaissance visit to the damaged sites of Magnitude 6.9 Chuetsu Earthquake in Niigata, Japan. The damage characteristics of about thirty highway bridges visited is described in detail. The damages to bridges were not extensive and less severe than witnessed in the Hyogo-ken Nanbu Earthquake of 1995. The main reason is that there are not many bridges in the areas that experienced high intensity earthquake ground motions. It was observed that bridges, which have been seismically retrofitted, performed satisfactorily without sustaining severe damage. It is vital that bridges designed to older design specifications should be retrofitted as soon as practicable. There was not enough evidence to confirm that bridges designed and constructed to the current specifications have performed well under the near field strong earthquake.

1 INTRODUCTION

On 23 October 2004 at 17:56 (local time), an earthquake of intensity 7 in JMA (Japan Meteorological Agency) scale of 7 (Richter scale of magnitude 6.9) with a focal depth of about 13km struck the central (Chuetsu) region of Niigata Prefecture. Niigata is located in the north west of Honshu, the largest island of Japan (Figure 1). The main earthquake hit Kawaguchi, a town located in the central part of Niigata, some 200km northwest of Tokyo. The initial earthquake caused noticeable shaking across almost half of Honshu Island. Figure 2 shows the strong motion record observed by Niigata Prefecture at Kawaguchi (This record is provided by JMA).

Figure 1. Location of Niigata

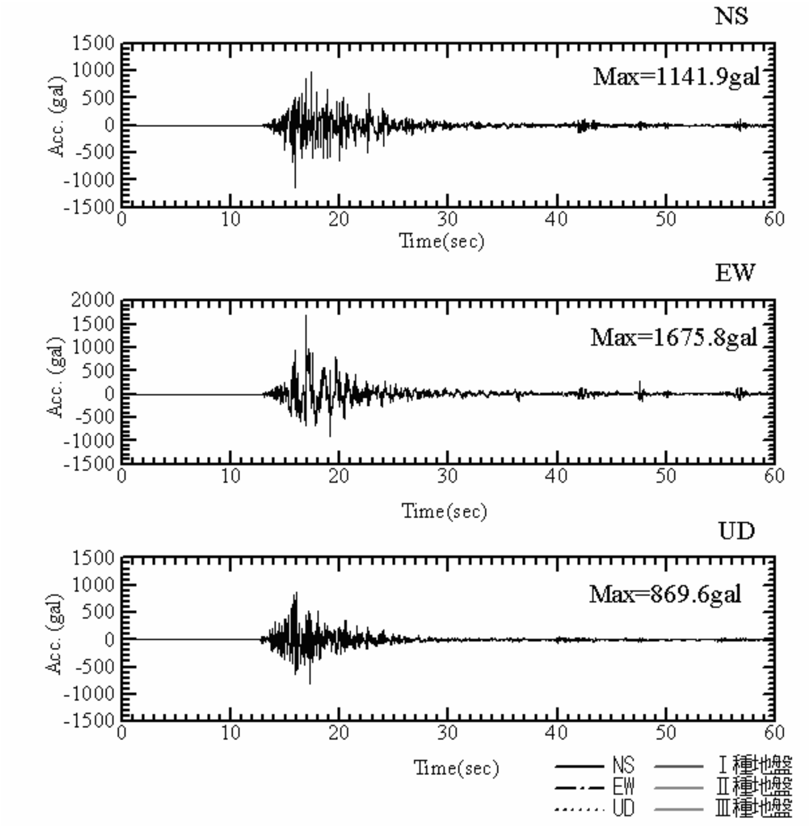

Figure 2. Strong motion record at Kawaguchi station (With kind permission from JMA)

Within the next hour, two more earthquakes measuring JMA intensity of upper 6 (6+) hit the towns, Ojiya and Tokamachi in the central region of Niigata Prefecture. Intervening and subsequent earthquakes of lesser intensity also occurred in the region. During the first 66 hours since the first earthquake, 15 more earthquakes of JMA intensities of lower 5 (5-) or higher were recorded in the central region of Niigata.

The earthquakes damaged many public buildings and households, bridges and roads, and cut off gas, water and electricity supplies in many parts of Niigata prefecture. The first earthquake derailed the bullet train that was running on the Joetsu Shinkansen Line linking Tokyo and Niigata. This was the first time a bullet train derailed in its 40 years of service. No-one was injured due to the derailment. The cause for the derailment of eight of the ten cars is still a subject under investigation and scrutiny.

Based on the information released by Niigata Prefectural Emergency Task Force Headquarters (as of 18 November 2004), 40 were killed and 2,858 were injured; 2,030 houses were destroyed, 4,431 were severely damaged, and 41,896 were partially damaged; 10,451 public buildings were damaged; 229 number of river banks were damaged; and 442 landslides occurred.

This paper is based on the 3-day reconnaissance visit to damaged sites between 1 and 3 November 2004 carried out by the Earthquake Engineering Research Team of Public Works Research Institute. Over 30 bridges were inspected during the visit. The following sections describe the damage characteristics, their severity, temporary and permanent repairs carried out followed by lessons learnt from the Chuetsu Earthquake.

2 DAMAGES TO BRIDGES

The damages to bridges were not extensive and less severe than witnessed in the Hyogo-ken Nanbu Earthquake (1995), Japan. The main reason is that there are not many bridges in the areas that experienced high intensity earthquake ground motions.

The other reason is that many of the bridges designed prior to 1980 have already been retrofitted after 1996, based on the experience from many catastrophic failures of civil structures in the Hyogo-ken Nanbu Earthquake. This was especially evident in one of the bridge sites on National Highway No. 8 in Ojiya, where there are twin bridges over a railway line (Figure 3). The older of the twin bridges already had its pier columns retrofitted with steel jackets and had no damages due to the earthquake. However, the other bridge designed to pre-1980 specifications did not receive any retrofit and had damage to the pier columns. The damage was in the form of cover spalling and buckling of longitudinal reinforcement (Figure 4), which has been temporarily repaired with carbon FRP wraps as an emergency measure to allow traffic.

Figure 3. Twin bridges on National Highway No. 8 over the railway in Ojiya

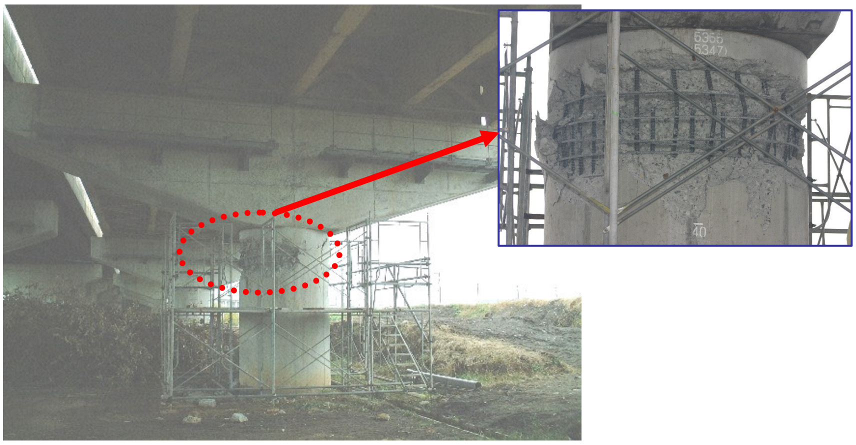

Figure 4. One of the damaged pier columns of the railway overbridge in Ojiya

The commonly observed damage characteristics were settlement of bridge approaches, and slumping of soil behind bridge abutments resulting in damage to bearings and/or abutment back walls. In some bridges, damage has occurred in pier columns. In some instances excessive movements have caused damage to joints. There was no collapse of a bridge, loss of spans, or complete failure of a support found in these earthquake struck areas.

2.1 *Approach road settlement*

Most of the damage in many of these bridge sites was triggered by settlement of soil. This is mainly caused by the loosening of soil due to the typhoon that struck these areas a few days prior to the earthquake. Soil settlement is a disruptive damage as a number of approach roads of bridges have settled and required immediate resurfacing/repair for emergency and relief traffic to pass. Figures 5 and 6 show some of the approach road settlement.

Figure 5. Approach road settlement at Hurumiya Bridge

Figure 6. Approach road settlement at Koshino Bridge

2.2 *Damage to abutments due to soil slumping*

Slumping of soil has caused damage to bridge abutments. In some cases the abutment has rotated damaging the bearings, back walls and wing walls.

The bearings were damaged at the abutments of Miyanaka Bridge over the river Shinano, the longest river in Japan (367km long). The holding down bolts yielded and motar pads cracked and spalled as shown in Figure 7. The damage was extensive that temporary supports had to be installed for emergency and relief traffic (Figure 8).

Figure7. Damage to bearings of Miyanaka Bridge

Figure 8. Temporary support at one of the damaged bearings, Miyanaka Bridge

Damage to the abutment back walls from the impact of supersı the form of cracking and spalling of concrete. Wanazu, Imok 9(a), (b) and (c) respectively) are a few examples where damage to back walls has occurred under longitudinal response.

The abutments of Yamabe Bridge, located at the foot of a sloping terrain, have rotated considerably and pulled off the piles as shown in Figure 10. Soil has slumped more than a metre at this bridge site as shown in Figure 11.

(a) Wanazu Bridge

(b) Imokawa Bridge

(c) Horinouchi Bridge

Figure 9. Damages to abutment backwalls

Figure 10. Pile pull-off, Yamabe Bridge

Figure 11. Soil slumping at Yamabe bridge site

2.3 *Damages due to excessive longitudinal displacement*

Another feature that has caused damage in bridges was excessive longitudinal displacement. In addition to the damage to bearings and back walls, bridge joints have been damaged due to excessive longitudinal movement. Figure 12 shows a damaged joint on Uonuma Bridge.

Figure 12. One of the damaged joints on Uonuma Bridge

2.4 *Damage to columns*

Damage to pier columns was not extensive as in Hyogo-ken Nanbu Earthquake. The damage included flexural and shear failure of columns. One of the main causes for the failure was premature curtailment of longitudinal reinforcement as was in many failed pier columns of Hyogo-ken Nanbu Earthquake, designed to pre-1980 specifications

Both pier columns of Uonogawa Bullet Train Bridge sustained flexural plastic hinges at their mid-height as seen in Figure 13. Part of the longitudinal reinforcement was cut-off at mid-height resulting in inadequate flexural strength in these columns.

Figure 13. Flexural hinges developed at mid height of pier columns, Uonogawa Bullet Train Bridge

Ojiya Bridge over the river Shinano received damage to its shortest pier column. The cover concrete has spalled and longitudinal reinforcement buckled at the top of the column as shown in Figure 14. The column was later wrapped with carbon FRP sheets as a temporary repair for emergency and relief traffic (Figure 15).

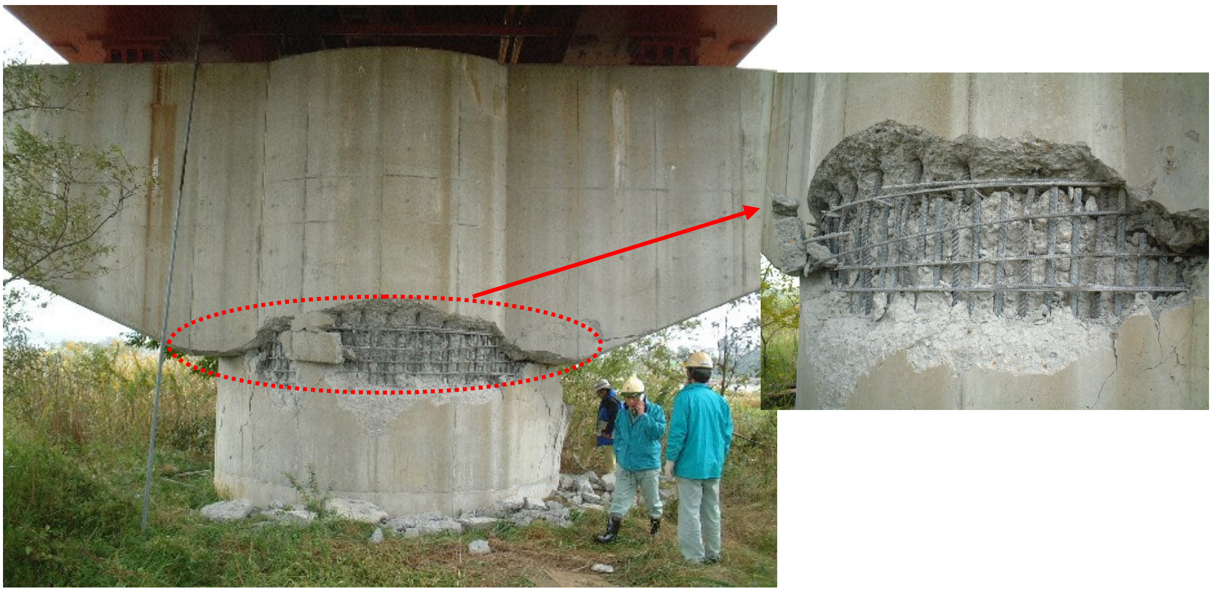

Figure 14. Damaged pier column, Ojiya Bridge (Photo courtesy of H. Nishida, PWRI)

Figure 15. Column repaired with carbon FRP sheets, Ojiya Bridge
(Photo courtesy of H. Nishida, PWRI)

One of the wall piers of Yamabe Bridge developed flexural plastic hinges at the section of abrupt change in stiffness (Figure 16) under transverse response. This was further exacerbated by the sloping terrain and condition of the site soil.

Figure 16. Damaged wall pier, Yamabe Bridge

The old Uragara Bridge, a 3-span continuous reinforced concrete bridge, received damage to its pier columns. Shear cracks developed in the top part of the pier columns as shown in Figure 17.

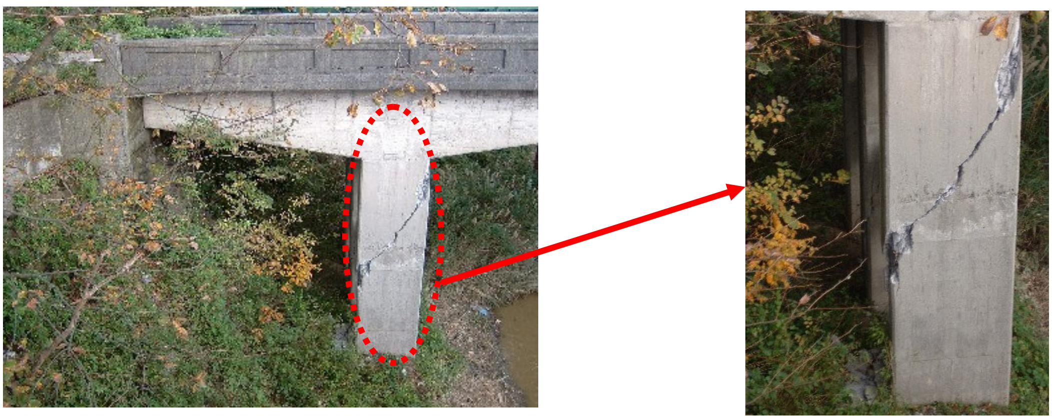

Figure 17. Shear cracks in one of the pier columns, old Uragara Bridge

2.5 *Damages due to liquefaction*

There was no major damage due to liquefaction was observed unlike in the previous large earthquake 40 years ago in Niigata Prefecture, where three bridges collapsed primarily due to liquefaction of sandy soils around the estuary of the River Shinano.

Liquefaction of soil was observed at the site of Katada Viaduct, where the bullet train derailed. Figure 18 shows the site where liquefaction has taken place and a part of the Katada Viaduct with derailed bullet train. No visible damage was observed at the footings of the viaduct. Development of Plastic hinges were observed at the top of the columns in some of the piers.

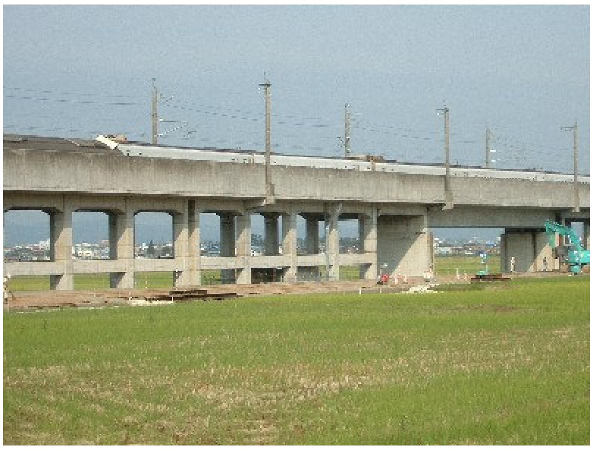

Figure 18. Katada Viaduct with derailed bullet train

3 **REPAIRS**

Both permanent and temporary repairs were done to bridges and approaches to send emergency and relief traffic immediately after the earthquake. A number of bridge approaches received resurfacing within a few days. Some of the damaged columns of bridge piers were temporarily wrapped with carbon FRP to prevent further damage due to after shocks.

4 **LESSONS LEARNT**

The 3-day reconnaissance visit to over thirty bridge sites in the earthquake-hit areas highlighted certain key features: (a) bridges that received seismic retrofit have performed satisfactorily without sustaining either any or major damage; (b) bridges designed based on older design specifications (especially the pre-1980 structures) should be retrofitted as necessary on a priority basis; and (c) there was not enough evidence to confirm that bridges designed and constructed to the current design specifications have performed well under near field strong earthquakes. This is because there are not many bridges constructed after 1996 in the high intensity earthquake hit areas.

5 **ACKNOWLEDGMENT**

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