DAMAGE TO EARTH STRUCTURES FOR NATIONAL HIGHWAYS 
BY THE 2004 NIIGATA-KEN CHUETSU EARTHQUAKE

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ABSTRACT

Damage to earth structures for national highways by the 2004 Niigata-ken Chuetsu earthquake is reported. After overviewing damage to roads, several case histories on severe damage and rehabilitation work for national highways are documented. Immediately after the mainshock, national highways and prefectural roads were closed at 101 sites. Among them, main national highway routes Nos. 8, 17 and 116 were closed at 17 sites, while all of them could be re-opened within ten days after the mainshock. On the other hand, national highway route No. 291 that runs through mountainous areas suffered from extensive damage at two sites, where alternative routes had to be constructed. The national highway route No. 291 suffered also from damage to embankments constructed on valley and/or landslide areas and damage to cantilever and gravity type retaining walls constructed in gorge area. The damage to the national highway route No. 17 included collapse of a gravity type retaining wall constructed on uncemented debris or weathered terrace deposits and collapse of a segmental retaining wall supporting a cut slope. The national highway route No. 8 suffered from embankment failures due possibly to liquefaction of a loose sand subsoil layer and/or concentration of longitudinal or transverse ground water flow.

Key words: earth structure, earthquake damage, liquefaction, national highway, rehabilitation work, the 2004 Niigata-ken Chuetsu earthquake (IGC: E8)

INTRODUCTION

At 17:56 on Oct. 23, 2004, the mainshock of the Niigata-ken Chuetsu earthquake with a magnitude specified by the Japan Meteorological Agency, $M_{JMA}$, of 6.8 hit the central part of Niigata prefecture, Japan. It was followed by three major aftershocks with $M_{JMA}$ equal to or larger than 6.0 that occurred within one hour after the mainshock. In addition, several other subsequent aftershocks continued for about two weeks (JMA, 2004).

By this earthquake, many types of infrastructures failed completely or were damaged severely, in particular natural slopes and earth structures. It was because the strong earthquake occurred in mountainous areas and a strong rainstorm by Typhoon No. 23 hit the affected region immediately before the earthquake (Tatsuoka et al., 2006). The daily precipitation due to this typhoon recorded on Oct. 20 (i.e., three days prior to the mainshock) at Nagaoka City that is located in the affected region was as heavy as 100 mm (JMA, 2004).

In this report, after overviewing the damage to roads caused by this earthquake, several case histories on severe damage to earth structures for national highways are documented, focusing on the details of the damage, ground conditions and rehabilitation works.

OVERVIEW OF DAMAGE TO ROADS

Table 1 summarizes the number of sites where the traffic was suspended completely along national highways and prefectural roads (MLIT, 2005). Immediately after the mainshock, these roads were closed at 101 sites. Among them, national highway routes Nos. 8, 17 and 116 that had been operated directly by Ministry of Land, Infrastructure and Transport (MLIT) were closed at 17 sites as shown in Fig. 1, while all of them could be re-opened after competing temporary rehabilitation works within ten days after the mainshock.

In the affected region, there also existed Kan-etsu and Hokuriku Expressways operated by Japan Highway

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739

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Table 1. Number of sites with traffic suspension along national highways and prefectural roads (MLIT, 2005)

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NH: national highway

Fig. 1. Location of sites where traffic was suspended immediately after the mainshock along national highway routes Nos. 8, 17 and 116

Corporation (currently East Nippon Expressway Company Limited). Although part of these expressways was closed for inspection immediately after the mainshock, they could be re-opened to emergency traffic such as ambulances, fire trucks and police cars within 19 hours after the mainshock (JSCE, 2006).

Herein, case histories on severe damage to earth structures along national highway routes Nos. 291, 17 and 8 that were rehabilitated by MLIT are reported. It should be noted that, although the national highway route No. 291 had been operated by the office of Niigata Prefecture before the earthquake, its damage was so extensive that a part of this route was rehabilitated by MLIT for a length of 10 km on behalf of the original operator.

NATIONAL HIGHWAY ROUTE NO. 291

Location of sites with major damage to national highway route No. 291 in Yamakoshi district (currently part of Ojiya City) is indicated in Fig. 2. Refer to Fig. 1 for its general location within the affected region. This route runs through mountainous areas that were damaged se-
verely by the earthquake.

As shown in Photo 1, several slopes and road embankments facing Kamisawa River at Takezawa (site SE-1 in Fig. 2) failed extensively. For rehabilitation work, it was decided not to reconstruct this part of road for a length of about 1 km, but to excavate a new tunnel as an alternative route in the mountains located on the other side of the river. Such decisions were made based on topographic maps and digital cross-sections that were prepared in two weeks after the earthquake by using aerial photo and laser surveys combined with the global positioning system.

Since the above tunnel excavation requires more than one year (tentatively scheduled until autumn of 2006), a local road was employed as a temporary detour. Still, it took about eight months to make the through traffic possible, because part of the local road had to be reinforced and reconstructed. It should be also noted that, due to heavy snow fall, execution of such rehabilitation works had to be paused during the winter season from January to April.

In addition, at Higashi-takezawa (near the site BR-3 in Fig. 2), a huge slope failure created a natural dam along Imo River (Tatsuoka et al., 2006), which caused submergence of Shin-egaj bridge at site BR-3 located in the

![Photo 1](https://example.com/photo1.jpg)

**Photo 1.** Slope failures at Takezawa along national highway route No. 291 (site SE-1)**
Photo 2. Embankment failure at Kajigane along national highway route No. 291 (site SE-3): a) aerial view and b) collapsed soils

Photo 3. Embankment failure at Kajigane along national highway route No. 291 (refer to Photo 2a) for the direction to which each photo was taken

Photo 4. Aerial view of landslides at Kajigane along national highway route No. 291 (site SE-2)

temporary reservoir. The slope failure was so extensive that re-routing of the national highway at this site had to be implemented for its rehabilitation work.

In the followings, other case histories on severe damage to embankments and retaining walls are reported. All of them were rehabilitated by reconstructing the existing route.

**Damage to Embankments Constructed on Valley and/or Landslide Areas**

At Kajigane in Yamakoshi district (site SE-3 in Fig. 2), as typically shown in Photos 2 and 3, several road embankments that had been constructed by filling valleys
Photo 5. Collapse of a) cantilever retaining wall (site RW-1), b) gravity (leaning type) retaining wall (site RW-2) at Minami-nigoro along national highway route No. 291 and c) reconstructed segmental retaining wall

suffered flow-type failure. Since the collapsed soils flowed down by several tens of meters on a rather gentle slope (Photo 2(b)), they seem to have been under a state of high water contents at the time of the earthquake. The excessive water was provided possibly by the heavy rainfall due to Typhoon No. 23, or by the collapse of carp ponds located on the mountain side of the embankment.

Fig. 4. Original and rehabilitated cross-sections of failed retaining walls at Minami-nigoro along national highway route No. 291: a) cantilever retaining wall (site RW-1) and b) gravity (leaning type) retaining wall (site RW-2)

Photo 6. Damage to segmental retaining wall at Minami-nigoro (site RW-1) along national highway route No. 291

In the latter case, the carp pond may have failed during the mainshock, causing permeation of split water into the embankment body, and the embankment may have failed during one of the three major aftershocks as described in INTRODUCTION. A typical cross-section of failed embankments is shown in Fig. 3(a) with estimated ground profile. In this case, the embankment was reconstructed by using geogrid-reinforced soils near its bottom.

In addition, as shown in Photo 4, a lot of landslides were induced at Kajigane by the earthquake. Some road embankments were involved in such landslide and failed, as typically shown in Fig. 3(b) (site SE-2 in Fig. 2). In
order to stabilize the landslide, they were reconstructed by adding berms as counterweights on the valley side, while ensuring the drainage capacities, as typically shown in Fig. 3(c).

Due to these embankment and slope failures, no traffic access to Kajigane was possible after the earthquake. Thus, the equipment for their temporary rehabilitation works had to be brought by helicopters.

It should be noted that, during the above reconstruction works, a special care was taken not to introduce alien plants but to restore the domestic vegetation. Due attentions were also paid to achieve “sceneic byway” routes, for example, by making a round cut during cut slope works, while referring to the pioneer works executed in the United States (NCBO, 2006).

**Damage to Retaining Walls Constructed in Gorge Area**

At Minami-nigoro in Ojiya City (sites RW-1 and 2 in Fig. 2), as shown in Photo 5, cantilever and gravity type retaining walls that had been constructed to support road
shoulders facing a gorge of Asahi River collapsed or tilted extensively. The possible causes for these failures are large earthquake loads exerted on the wall and the backfill soil, submergence of the backfill due to previous heavy rainfall, and/or insufficient bearing capacity of the retaining walls constructed on sloped ground. In order to improve the drainage capacities from the backfill, these walls were reconstructed by using segmental retaining walls, as typically shown in Fig. 4 and Photo 5(c).

As shown in Photo 6, a segmental retaining wall that had been constructed to protect cut slopes on the mountain side was also damaged to a limited extent. It was rehabilitated by minor restoration works of the segmental blocks (Fig. 4(b)), after confirming that there occurs no landslide movement involving the cut slopes.

At a neighboring section (site BR-1 in Fig. 2), as shown in Photo 7, an abutment wall of Nishiki-goi bridge suffered severe cracking. In this case, it is estimated that landslide-induced movement of the retained ground caused such damage. This bridge will be re-built completely.

In the reconstruction works for the above cases, a careful judgment was required whether the landslide movement would restart again or not by possible heavy rainfalls in the future. It was, therefore, required to establish rational procedures to evaluate properly the potential of re-triggering such landslide movement. This issue still requires future studies.

NATIONAL HIGHWAY ROUTE NO. 17

National highway route No. 17 connects major cities and towns in the affected region from north to south, such as Nagaoka, Ojiya and Kawaguchi. Therefore, in order to restore the traffic capacities between them, it had to be re-opened as soon as possible.
Fig. 6. Cross-section of geogrid-reinforced soil retaining wall at Tenno (site R17-6) along national highway route No. 17 as rehabilitation work for damaged gravity type retaining wall.

At Wanatsu tunnel (site R17-2 in Fig. 1) with a total length of 300 m, part of the concrete linings was cracked severely and some of them fell down from the tunnel crown as shown in Photo 8. The fallen concretes amounted up to about 50 tons. This damage caused traffic suspension for nine days until Nov. 2 when temporary rehabilitation work as shown in Photo 9 and Fig. 5 by installing inner steel supports with shotcretes for a length of 120 m was completed. Permanent rehabilitation work of the damaged concrete lining was completed on Dec. 26, 2004. Extensive efforts were dedicated to execute the rehabilitation works as soon as possible, since the daily traffic through the tunnel before the earthquake was as large as 17,000 vehicles with no nearby detour route available.

Herein, other case histories on severe damage to retaining walls and cut slopes are reported.

Damage to Retaining Wall Constructed on Uncemented Debris or Weathered Terrace Deposits

At Tenno in Kawaguchi Town (site R17-6 in Fig. 1), a gravity type retaining wall collapsed completely, as shown in Photo 10. This wall had been constructed to support the road embankment in parallel with a railway embankment for JR Joetsu line, which also suffered from sliding failure as shown in Photo 10(a). The gas and water pipes and information cables that had been buried in the road embankment were also damaged. These embankments had been filled on uncemented debris or weathered terrace deposits. They were underlain by alternative layers of tertiary sand, silt and mud stones of Kawaguchi group.

The damaged road embankment was reconstructed by using a geogrid-reinforced soil retaining wall with panel type facings as shown in Fig. 6 and Photo 11(b). At the adjacent site, the railway embankment was reconstructed by using a combination of another type of geogrid-reinforced soil retaining walls with full-height rigid facings and rock bolts as shown in Fig. 7 (Morishima et al., 2005).

It should be noted that, during the reconstruction works of the damaged road which was completed on Dec. 29, 2004, a temporary 2-lane detour road was employed as shown in Photo 11(a). After obtaining special permissions of the land owners, this detour road was constructed along a route that includes private properties and completed on Oct. 31. Before its completion, as shown in Photo 10(a), an emergency 1-lane detour route at the side of the collapsed embankment had to be used for about a week.

Damage to Retaining Wall Supporting Cut Slope

At Ushigashima in Kawaguchi Town (site R17-5 in
Fig. 8. a) Estimated profile of back slope and b) cross-section of rehabilitation work at Ushigashima (site R17-5) along national highway route No. 17 along section A-A shown in Photo 12(a)

Photo 12. Damage to retaining wall and its back slope at Ushigashima (site R17-5) along national highway route No. 17: a) aerial view and b) collapsed retaining wall

Fig. 13. Temporary rehabilitation works at Ushigashima (site R17-5) along national highway route No. 17 by using a) sheet piles and b) large sand bags

Fig. 1), a segmental retaining wall supporting a cut slope collapsed 24 m in length, which was accompanied by surface landslide of its back slope as shown in Photo 12. Reportedly, the collapse of the retaining wall was triggered by one of the aftershocks, and not by the mainshock. As shown in Fig. 8(a), the back slope had a dip slope structure, consisting of alternative layers of tertiary sand and mudstones of Kawaguchi group, which had been weathered in particular near the surface to larger extents. In addition, due to the preceding heavy rainfall, the ground water table within the slope had been higher than usual.

As for temporary rehabilitation work, the following measures were taken, while continuously monitoring possible landslide movements by using nine extensometers for a period of 35 days starting from Oct. 25.

a) Steel sheet piles were installed in front of the slope in order to prevent the collapsed soils from flowing out over the road (Photo 13(a)).

b) Large sand bags were placed at the foot of tilted retaining walls in order to resist against their overturning movements (Photo 13(b)).

c) Differential settlements and large cracks on the road surface were smoothened.

d) Earth removal works were executed on cracked slopes where leaching of ground water was observed.

e) Cracked slopes were covered with plastic sheets in order to avoid permeation of rain water.
As shown in Fig. 8(b), after removing the surface soils affected by the landslide, the cut slope was reconstructed with shotcrete crib work. At the upper part of the slope, horizontal bore holes were excavated for drainage, and ground anchoring was executed to resist against the landslide.

**NATIONAL HIGHWAY ROUTE NO. 8**

National highway route No. 8 is another main route, which is located in the north of the affected region and apart from the epicenter of the mainshock, connecting major cities such as Mitsuke, Nagaoka and Kashiwazaki (Fig. 1). The daily traffic through this route before the earthquake amounted up to 46,000 vehicles in Nagaoka City.

Although the general level of the ground motion along this route was smaller than those at the aforementioned sites along national highway route Nos. 291 and 17, severe damage to earth structures also occurred, as reported herein.

**Damage to Embankment with Possible Concentration of Longitudinal or Transverse Ground Water Flow**

At Miyamoto in Nagaoka City (site R8-4 in Fig. 1), an embankment failed as shown in Photo 14. The embankment deformation and the road surface settlement accumulated during several large aftershocks.

At the adjacent section, a geogrid-reinforced embankment with an additional berm was also damaged by excessive deformation (Photo 15(a)). Similarly, cantilever type retaining walls using precast L-shaped reinforced concrete that were located on the other side of the road were also damaged by outward displacements at the base of the wall (Photo 15(b)).

A typical soil profile with SPT-N values at this site is shown in Fig. 9. No liqueifiable loose clean sandy soil layer existed in the subsoil, while the loose silty fine sand layer at a depth of about 2 to 4 m from the ground surface may have liquefied during the earthquake. It should be noted that the site was located at the edge of hilly region and thus adjacent to a cut slope section. In fact, during temporary rehabilitation works by removing collapsed retaining walls located at the foot of the embankment and by placing large sand bags instead, it was observed that the ground water table was very high. Therefore, concentration of longitudinal or transverse ground water flow into soft clayey subsoil layers which was magnified by the preceding heavy rainfall may have affected the above failure as well.

Before reconstructing the embankment and retaining walls as permanent rehabilitation work, as shown in Fig. 10, the subsoil layers were improved by gravel compaction piles with a diameter of 0.7 m, a length of 7 m and a horizontal spacing of 1.4 m. This method was
selected in order to enhance drainage capacity of ground water and to provide shear resistance against sliding failure along the estimated circular failure plane.

**Damage to Embankment with Liquefiable Layer in the Subsoil**

At Mitsuke-Ohashi bridge in Nagaoka City (site R8-1 in Fig. 1), one of the approaching embankments failed as shown in Photo 16. The cross-section of the damaged embankment with estimated soil profile is shown in Fig. 11. In this case, a loose sand layer with SPT-N value of 8 existed immediately below the ground water table, which is estimated to have liquefied during the earthquake. It was underlain by alternative sand and clay layers, and this sand layer may have liquefied as well.

Before reconstructing the embankment aspermanent rehabilitation work, the subsoil layers were improved by installing in-situ cement-mixed piles by the jet grouting method with a diameter of 1.1 m, a length of 9 m and a horizontal spacing of 1.5 m.

In addition, at this site, a box culvert constructed in the approaching embankment suffered from uneven settlement of about 30 to 50 cm and opening of the construction joint at the center line of the culvert by about 20 cm as shown in Photo 17(a). This uneven settlement was also caused by liquefaction of subsoil layers, as can be seen from extensive sand boiling in front of the culvert as shown in Photo 17(b). It should be noted, however, that the liquefiable subsoil layer with this case may not be original but artificial, which corresponds to the backfilled
extensive damage at two sites at Takezawa and Higashitakezawa, where alternative routes had to be constructed as rehabilitation work.

In addition to the above, the national highway route in the mountainous areas suffered from damage to embankments constructed on valley and/or landslide areas. They were typically reconstructed by using geogrid-reinforced soils, adding berms as counterweights and/or ensuring drainage capacities. This route suffered also from damage to cantilever and gravity type retaining walls constructed in gorge area. They were reconstructed by using segmental retaining walls with improved drainage capacities.

The damage to the main national highway routes included complete collapse of a gravity type retaining wall constructed on uncemented debris or weathered terrace deposits. It was reconstructed by using a geogrid-reinforced soil retaining wall. A segmental retaining wall supporting a cut slope collapsed with surface landslide of its back slope. After removing the surface soils affected by the landslide, it was reconstructed with shotcrete crib work that was combined with drainage work and ground anchoring at its upper part.

In regions located apart from the epicenter of the mainshock, two embankments were severely damaged due possibly to liquefaction of a loose sand subsoil layer and/or concentration of longitudinal or transverse ground water flow. They were reconstructed after improving the subsoil layers by gravel compaction piles or in-situ cement-mixed piles.

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REFERENCES