DAMAGE TO EARTH STRUCTURES CAUSED BY THE 2004 NIIGATA-KEN CHUETSU EARTHQUAKE

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ABSTRACT: Damage to earth structures in the 2004 Niigata-ken Chuetsu earthquake in Japan is briefly reported. Embankments and retaining walls for railways, roads and building estates suffered serious damage, while river dikes suffered less damage. The former damage was observed at sites where concentration of ground water flow in the subsoil layer may have taken place and/or the fill material may have been partly saturated. The extent of the latter damage was limited, due possibly to less liquefiable conditions of subsoil layers below river dikes in severely-shaken regions. In general, liquefaction of original soil deposits did not occur extensively. On the other hand, liquefaction of backfill soil caused uplift of buried pipes and sewage manholes. Due attentions, such as the use of reinforced soils and countermeasures against liquefaction, are being paid in the reconstruction work of the severely damaged earth structures.

Key Words: the 2004 Niigata-ken Chuetsu earthquake, settlement, embankment, retaining wall, river dike, uplift, buried pipe, sewage manhole, liquefaction, backfill

INTRODUCTION

The Niigata-ken Chuetsu earthquake of October 23, 2004, caused serious damage to a number of earth structures in the central part of Niigata prefecture, Japan. The authors visited the affected area on October 31, November 1 and 6 through 8, 2004, in order to make their investigation. On December 14, 2004, the first author visited some sites where reconstruction work was executed. The visit on November 6 through 8 was made by participating in a damage survey organized by Japan Society of Civil Engineers. This paper reports preliminary results from the investigation, focusing on different performances among several earth structures and their possible causes. Refer to Fig. 1 for the location of sites reported in this paper.

DAMAGE TO RAILWAY AND ROAD EMBANKMENTS

Figure 2 shows collapse of a railway embankment along JR Joetsu line at Hiu, Ojiya city (site 1 in Figure 1). It had been constructed by filling a valley facing the Shinano river. In the earthquake, the fill material, possibly with a part of the original soil deposit, slid extensively to the downstream of the valley. After the earthquake, it was reconstructed by using a reinforced soil retaining wall with a full-height rigid facing as shown in Figure 3b. It employs geogrid as reinforcements, which are placed at a vertical spacing of 30 cm in the backfill. This type of reinforced soil retaining wall was adopted for the reconstruction, since it exhibited an excellent performance during the 1995 Hyogoken-Nanbu earthquake (Tatsuoka et al., 1996). Refer to Figures 4b and 6b for the same type of reinforced soil retaining walls that are under construction.

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In addition, as noted in Figure 3a, a cobble mat was newly placed at the base of the reconstructed embankment below the reinforced soil retaining wall in order to enhance its drainage capability. As a result, steady flow of ground water from the cobble mat could be observed even without any significant precipitation during the survey period. This suggests possible causes for the collapse that concentration of ground water flow in the subsoil layer may have taken place and/or the fill material may have been partly saturated at the time of the earthquake.

Figure 4a shows another collapse of a railway embankment along JR Joetsu line at Aikawa, Kawaguchi-machi (site 2 in Figure 1). It had been also constructed by filling a valley facing the Shinano river, and suffered from a similar type of failure to the one shown in Figure 2. As shown in Figure 4b, its reconstruction after the earthquake was executed by using the reinforced soil retaining wall with a full-height rigid facing. At the same time, reinforcement of the existing original soil deposit below the wall was also executed by anchoring.

Figure 5a shows failure of a gravity type retaining wall along National Highway Route 17 at Kamikatagai, Ojiya city (site 3 in Figure 1). This wall had been constructed in parallel with a railway embankment, which also suffered from sliding failure as shown in Figure 5b. The latter embankment was reconstructed by using the same type of reinforced soil retaining wall as mentioned above (Figure 6b), while the former retaining wall was reconstructed by using another type of reinforced soil retaining wall with segmental facings (Figure 6a).

As shown in Figure 7, road embankments constructed by filling valleys in mountainous areas along National Highway Route 290 (at Kuriyama-zawa, Tochio city; site 4 in Figure 1) suffered from extensive sliding. It should be noted that, as shown in Figure 7a, a reinforced embankment that had been constructed next to the collapsed unreinforced embankment was also damaged in the earthquake. Reportedly, the latter reinforced embankment had been constructed as a part of rehabilitation works for damage caused by previous heavy rainfall.

Figure 8a shows damage to a reinforced soil retaining wall with segmental facings and metal strips as reinforcements at Horinouchi Parking Area of JH Kan-etsu Expressway (site 5 in Figure 1). The facings suffered from overall bulging or overturning, with some of the lower facings tilted locally. Since leaching of ground water from the lower facings was also observed at the time of the survey, it was inferred that the lower part of the backfill material may have been saturated at the time of the earthquake, possibly causing liquefaction-like phenomena and subsequent deformation of the facings. Figure 8b shows temporary rehabilitation work by installing pipes in the backfill, in order to drain ground water from the backfill.

Figure 9a shows damage to an embankment along JH Kan-etsu Expressway at Sakura-machi, Ojiya city (site 6 in Figure 1). The embankment suffered from settlement and lateral spreading, and the latter caused overturning or failure of retaining walls that had supported the lower part of the embankment (Figures 9a and 10a). Lateral spreading took place not only in the embankment but also in the subsoil layers, causing damage to an adjacent regional road as well (Figure 9b). In addition, there were several culvert boxes constructed across the embankment, and the above lateral spreading caused opening of their joints at the centerline of the embankment, as typically shown in Figure 10b.

DAMAGE TO BUILDING ESTATES

Figures 11 through 13 show collapse of embankments for regional road around newly-developed building estates at Taka-machi, Nagaoka city (site 7 in Figure 1). These estates had been constructed by cutting hills and filling valleys. In the earthquake, the filled portions below the regional road as an outer ring road of the estates slid extensively to the downstream of the valleys, causing damage to the neighboring houses on the upstream side as well. At two sites as shown in Figures 12 and 13, gravity type retaining walls that had supported the upper part of the embankments moved along with their subsoil layers and tilted largely.

The fill materials were either clayey gravel (Figures 12 and 13) or volcanic clay (Figure 11). They are with relatively low permeability, and thus their full compaction had possibly been difficult to conduct at the time of the filling work. Since leaching of ground water was observed at the time of the survey, as can be typically seen in Figure 12b, it was inferred that the filled portion at the damaged sites was under loose and wet states at the time of the earthquake. Although the above-mentioned retaining walls had drainage holes at the bottom and non-woven sheets for drainage at the back, their capacities may have been inadequate.

Due attentions, such as the use of proper fill materials, their full compaction and possible combination with the reinforced soil methods, should be paid in the reconstruction work of the severely damaged embankments.

DAMAGE TO RIVER DIKES

Figure 14 shows damage to a dike along the Shinano river at Chiya-gawa, Ojiya city (site 8 in Figure 1). Unlike other river dikes, leaching of ground water from the bottom of the dike as shown in Figure 14b was observed at the time of the survey. This suggests a possible cause for the damage that the fill material may have been partly saturated at the time of the earthquake.

Figure 15a shows a temporarily rehabilitated dike along the Shinano river at Chiya, Ojiya city (site 9 in Figure 1). Reportedly, it suffered from settlement up to 50 cm at the shoulder of the embankment for a length of about 50 m. Since a large-scale sand boil was observed in adjcent ground (Figure 15b), it was inferred that the above damage was caused by liquefaction of subsoil layers below the embankment. It should be noted, however, that liquefiable subsoil layers (i.e, saturated loose sandy deposits) below river dikes exist to a limited extent in the regions that were severely shaken by the earthquake (e.g., along the Shinano and Uono rivers in Ojiya city and Kawaguchi-machi), due to the geologic processes that are specific to the regions. Therefore, the above case as shown in Figure 15 should be regarded as one of the exceptional cases.

Figure 16a shows another temporarily rehabilitated dike along the Shinano river at Namiki-shinden, Nakanoshima-machi (site 10 in Figure 1). Reportedly, it suffered from crest settlement up to 100 cm for a length of about 200 m. Since sand boils were observed in adjacent ground, as typically shown in Figure 16b, this damage can be also attributed to the occurrence of liquefaction in the subsoil layers. It can be seen from Figure 1 that, as compared to the aforementioned two sites (sites 8 and 9), this site is located to the downstream side of the Shinano river with longer epicentral distance. Therefore, this site was possibly subjected to an earthquake motion which was not strong enough to cause complete failure of the dike, although liquefiable subsoil layers may exist more widely than in the severely-shaken regions.

Based on the data reported by MLIT (2004a), progress of temporarily rehabilitation work on damage to river facilities including dikes is summarized in Figure 17 in terms of the number of sites. In ten days after the main shock, temporarily rehabilitation work was completed at about 70, 85 and 75 % of the damaged facilities along the Shinano river, the Uono river, and the other smaller rivers, respectively. In nineteen days after the main shock, it was completed at all the damaged dikes along the Shinano and Uono rivers (MLIT, 2004a). On the other hand, much longer time was required for rehabilitating severely damaged dikes in the other smaller rivers and natural dams that were created by earthquake-induced landslides in mountainous areas. For example, Figure 18 shows rehabilitation work on a severely damaged dike along the Kariyata river at Gohyaku-kari, Nakanosima-machi (site 11 in Figure 1), where cut-off sheet piles had been driven on the river side before executing the partial reconstruction work of the dike.

In general, liquefaction of original soil deposits did not occur extensively, except for the limited number of cases as mentioned above on damaged river dikes. It should be noted that, as typically shown in Figure 19, extensive sand boils on the ground behind a dike along the Shinano river were observed at several sites. However, the surface soil layers had been replaced by borrowed soil after excavating the original deposits to retrieve materials for concrete aggregate. Therefore, these sand boils can be regarded as those caused by liquefaction of backfill soil. As mentioned immediately later, significant damage to underground structures was also caused by liquefaction of backfill soil.

DAMAGE TO BURIED PIPES AND SEWAGE MANHOLES

Figure 20a shows uplift damage to a sewage manhole at Sakura-machi, Ojiya city (site 13 in Figure 1). In the neighboring section, as shown in Figure 20b, settlement of pavement above backfill soil for sewage pipes was observed, while deformation of original soil deposits surrounding the backfill soil was insignificant. Therefore, only the backfill soil should have liquefied during the earthquake and caused the uplift damage to sewage manholes. Based on relevant case histories in the past earthquakes (Koseki et al., 1997; 1998; 2000), it is inferred that the sewage pipes as well were damaged by the liquefaction of backfill soil.

In order to avoid similar damage in the future, the government recommended employing one of the following countermeasures against liquefaction of backfill soil in the reconstruction work of the damaged sewage facilities (MLIT, 2004b).

1. In using sands as the backfill material for sewage pipes, they should be compacted to a value of degree of compaction exceeding 90 %.
2. To maintain high permeability, crashed gravels that have D_{50} not less than 10 mm and D_{10} not less than 1 mm should be used as the backfill material, while compacting them to a value of degree of compaction exceeding 90 %.
3. The backfill material should be solidified by adding cement or other cement-origin hardening additives to have an unconfined compressive strength in the range of 100 to 200 kPa after curing for 28 days in the laboratory. This range corresponds to an in-situ strength of 50 to 100 kPa.

Figure 21 shows complete uplift of buried pipes for providing ground water to thaw snows in winter time and tilting of an uplifted manhole for information cables along National Highway Route 117 at Yachi, Ojiya city (site 14 in Figure 1). They were also caused by the liquefaction of backfill soil. Therefore, in the reconstruction work of not only the sewage facilities but also the other underground structures, due attentions should be paid on countermeasures against the liquefaction of backfill soil.

CONCLUSIONS

The following conclusions can be drawn from the damage survey reported preliminarily in this paper:

1. Embankments and retaining walls for railways, roads and building estates suffered serious damage. Their collapse took place at sites where concentration of ground water flow in the subsoil layer may have taken place and/or the fill material may have been partly saturated.
2. River dikes suffered less damage as compared to the above. The extent of the damage was limited, due possibly to less liquefiable conditions of subsoil layers below river dikes in severely-shaken regions.
3. In general, liquefaction of original soil deposits did not occur extensively. On the other hand, liquefaction of backfill soil caused uplift of buried pipes and sewage manholes.
4. Due attentions, such as the use of reinforced soils and countermeasures against liquefaction, are being paid in the reconstruction work of the severely damaged earth structures.

ACKNOWLEDGEMENTS

The authors express their deep appreciations to Mr. Higashiyama, A. at Fukuda Corporation, Prof. Tatsuoka, F. at Tokyo University of Science, Dr. Tateyama, M. and Dr. Kojima, K. at Railway Technical Research Institute, Mr. Ishihara, M. at Public Works Research Institute, and the members of the geotechnical group for the damage survey organized by Japan Society of Civil Engineers for their help and suggestions in conducting the damage survey.

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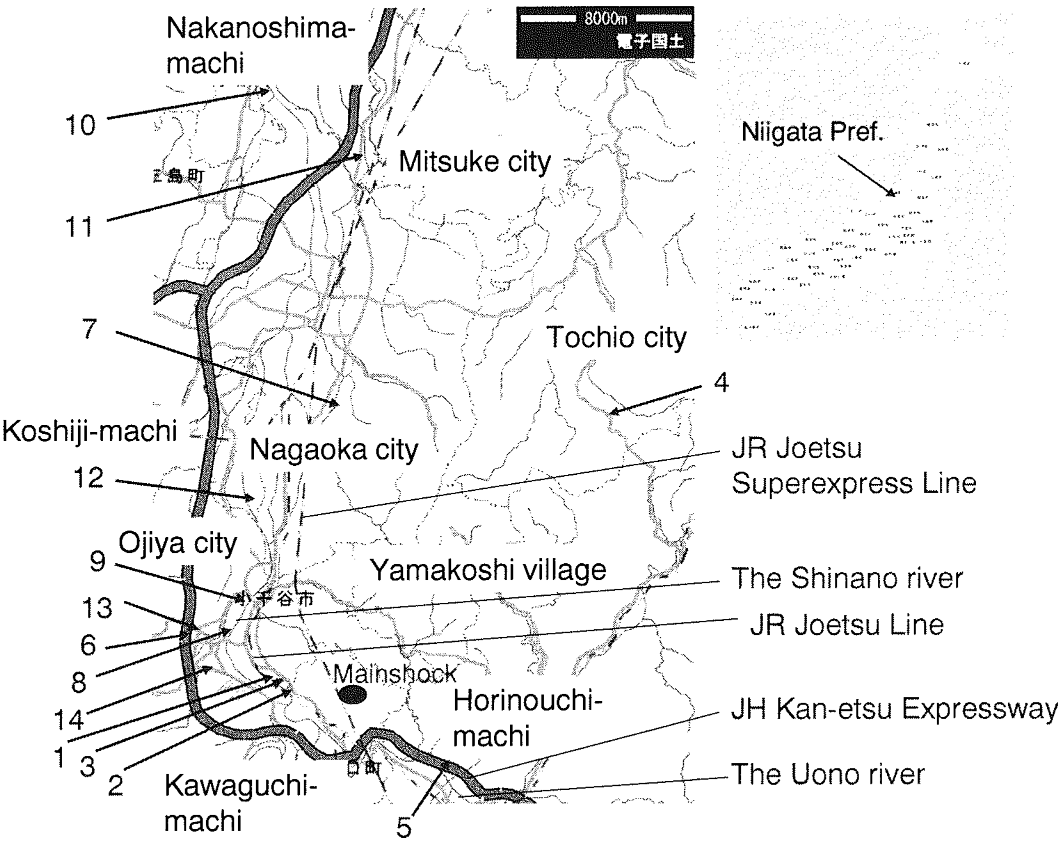

Figure 1 Location of sites reported in this paper

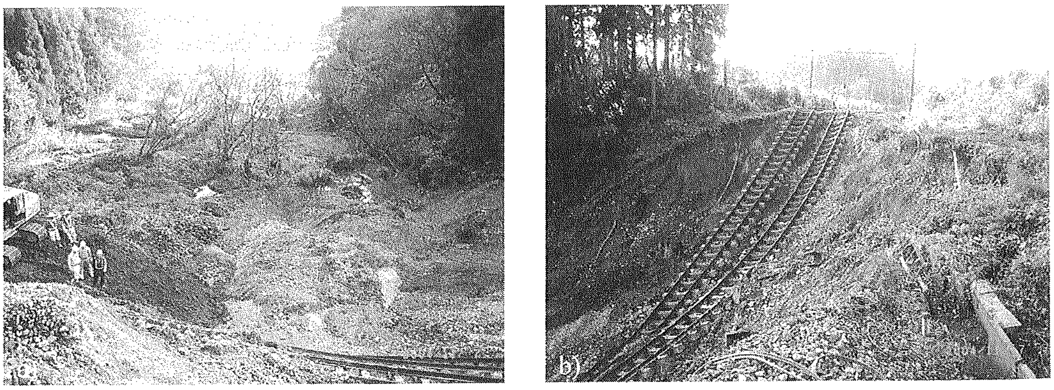

Figure 2. Collapse of an embankment along JR Joetsu line (between Echigo-Kawaguchi and Ojiya stations; at Hiu, Ojiya city; site 1 in Figure 1)

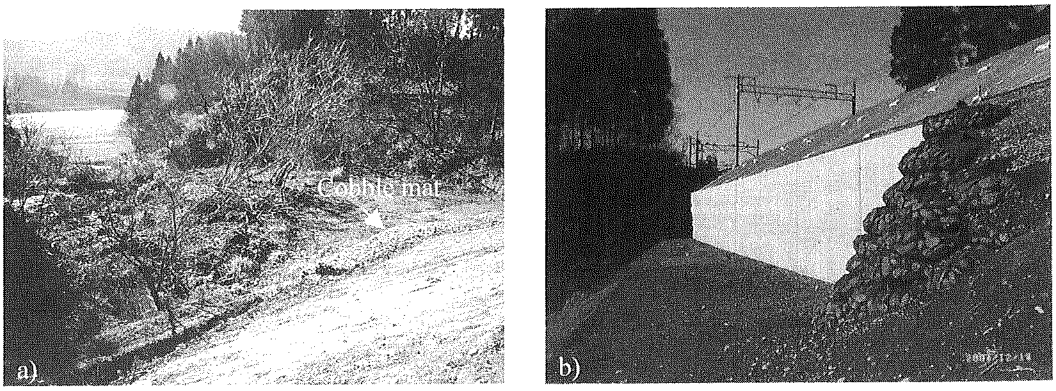

Figure 3. Reconstructed embankment and reinforced soil retaining wall along JR Joetsu line (site 1 in Figure 1)

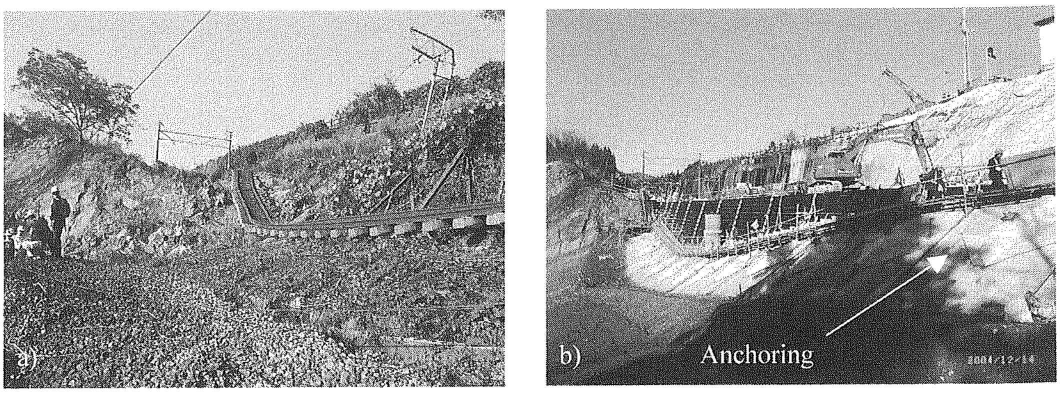

Figure 4. Collapsed embankment along JR Joetsu line and its reconstruction (between Echigo-Kawaguchi and Ojiya stations; at Aikawa, Kawaguchi-machi; site 2 in Figure 1)

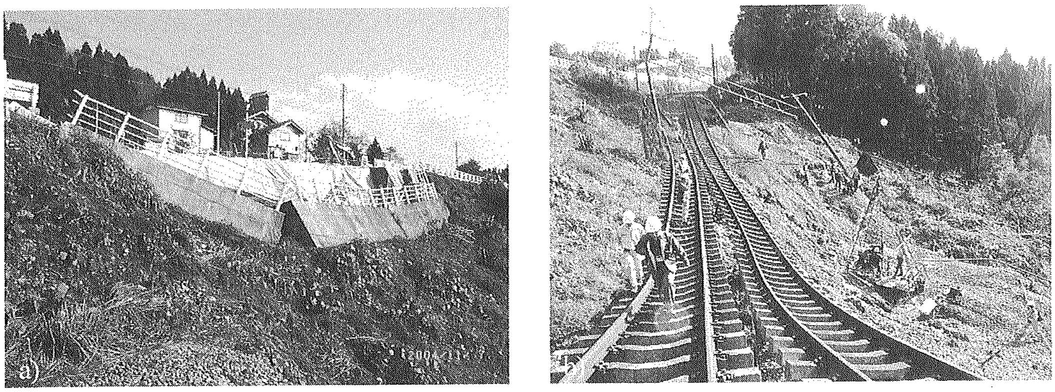

Figure 5. Damage to a retaining wall along National Highway Route 17 and an adjacent embankment along JR Joetsu line (at Kamikatagai, Ojiya city; site 3 in Figure 1)

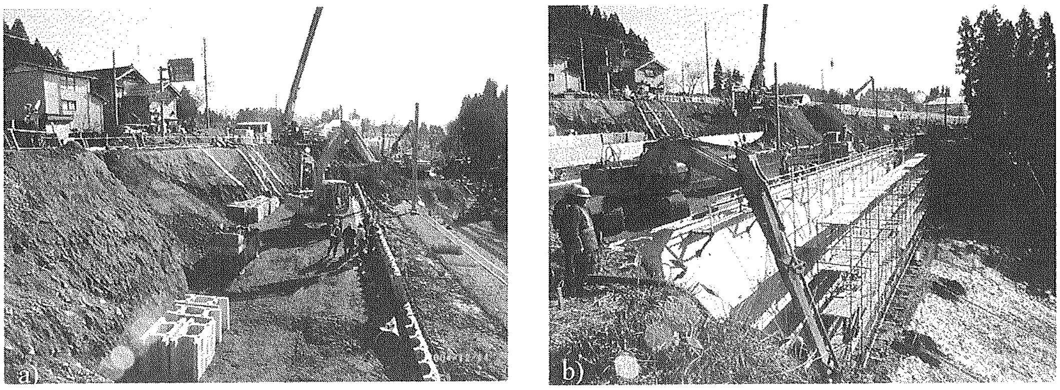

Figure 6. Reconstruction of damaged retaining wall along National Highway Route 17 and the adjacent embankment along JR Joetsu line (site 3 in Figure 1)

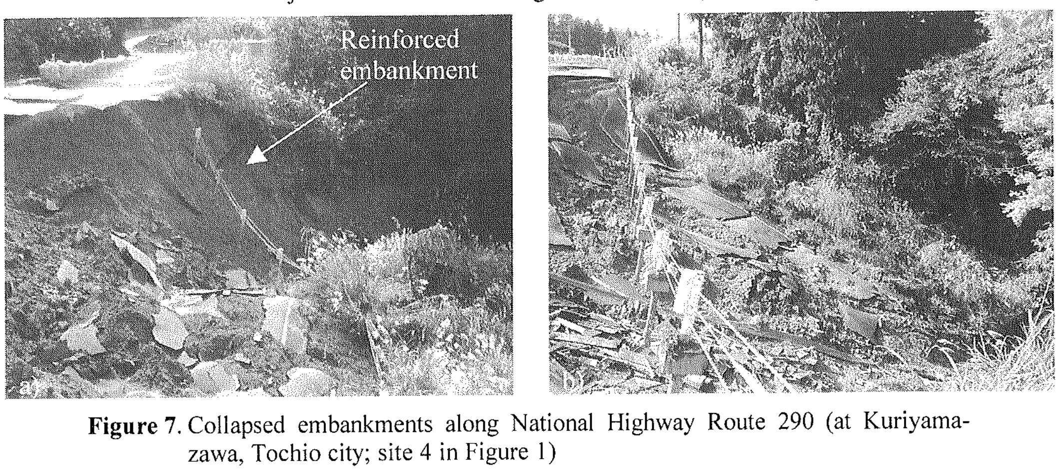

Figure 7. Collapsed embankments along National Highway Route 290 (at Kuriyama-zawa, Tochio city; site 4 in Figure 1)

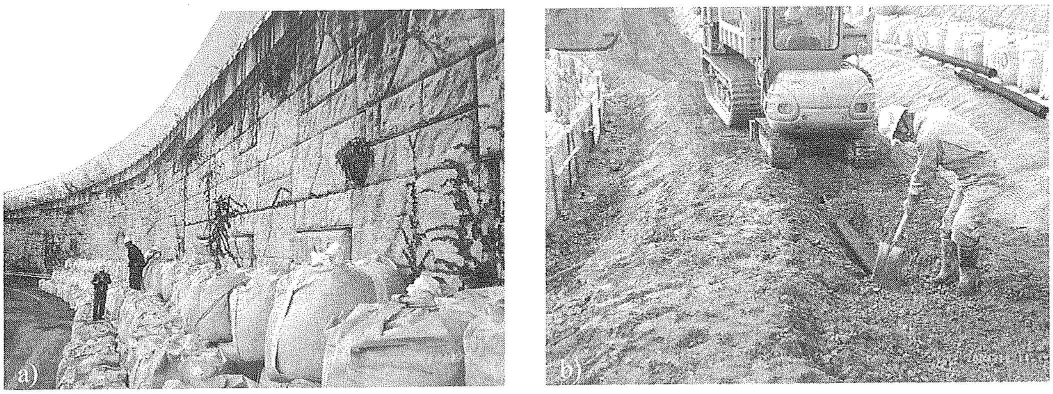

Figure 8. Damage to a retaining wall reinforced with metal strips and its temporary rehabilitation along JH Kan-etsu Expressway (at Horinouchi Parking Area; site 5 in Figure 1)

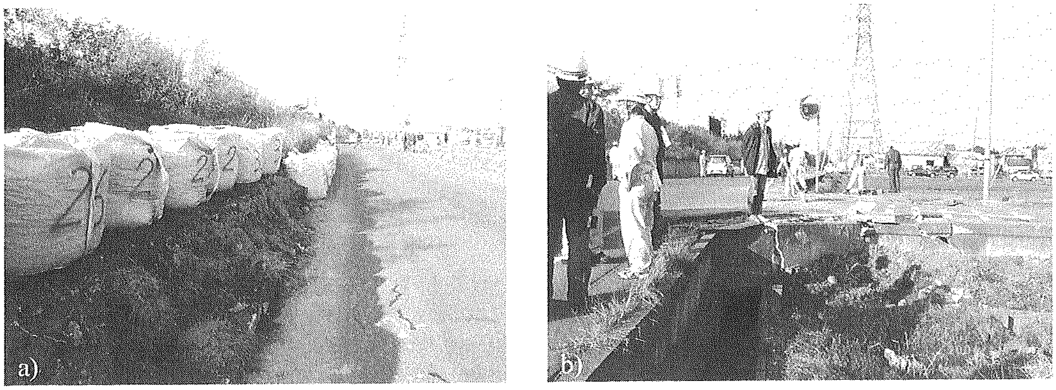

Figure 9. Damage to an embankment along JH Kan-etsu Expressway and an adjacent regional road (at Sakura-machi, Ojiya city; site 6 in Figure 1)

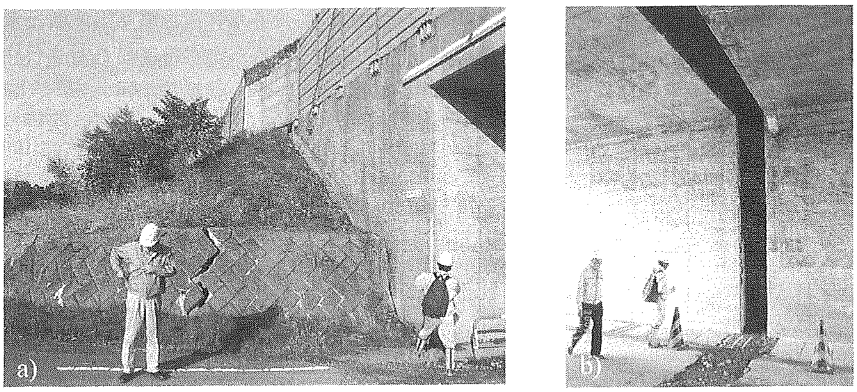

Figure 10. Opening of a joint of culvert box and damage to an adjacent embankment along JH Kan-etsu Expressway (site 6 in Figure 1)

Figure 11. Collapse of an embankment for regional road around newly-developed building estates (at Taka-machi 4-chome, Nagaoka city; site 7 in Figure 1)

Figure 12. Collapse of an embankment for regional road around newly-developed building estates (at Taka-machi 3-chome, Nagaoka city; site 7 in Figure 1)

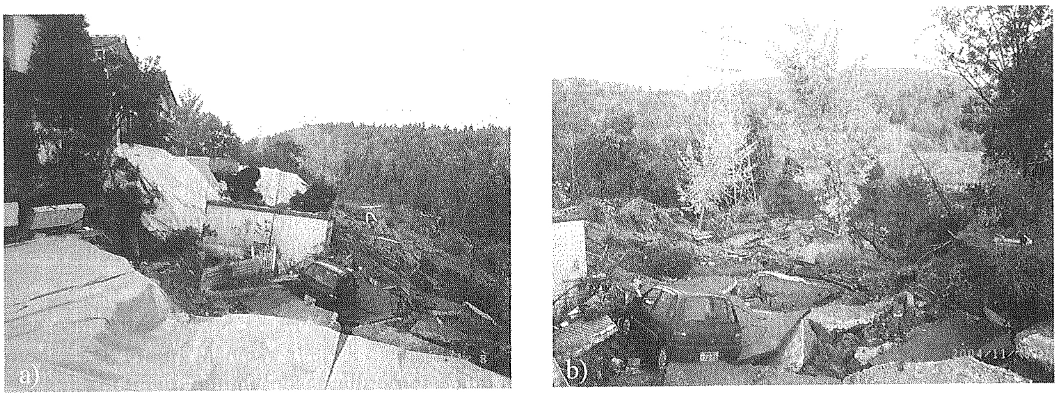

Figure 13. Collapse of an embankment for regional road around newly-developed building estates (at Taka-machi 1-chome, Nagaoka city; site 7 in Figure 1)

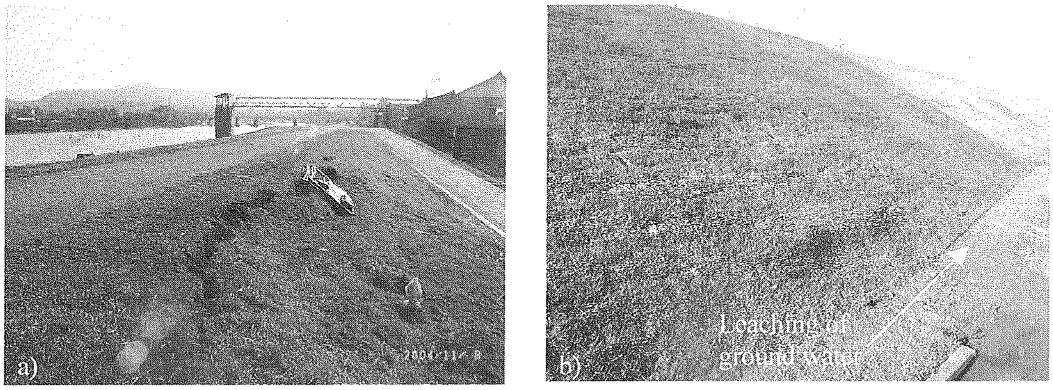

Figure 14. Damage to a dike along the Shinano river (at Chiya-gawa, Ojiya city; site 8 in Figure 1)

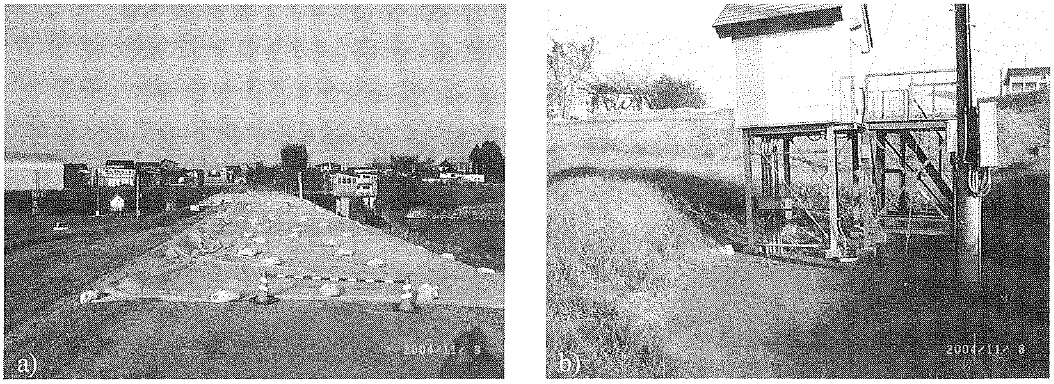

Figure 15. Temporarily rehabilitated dike along the Shinano river and a sand boil on adjacent ground (at Chiya, Ojiya city; site 9 in Figure 1)

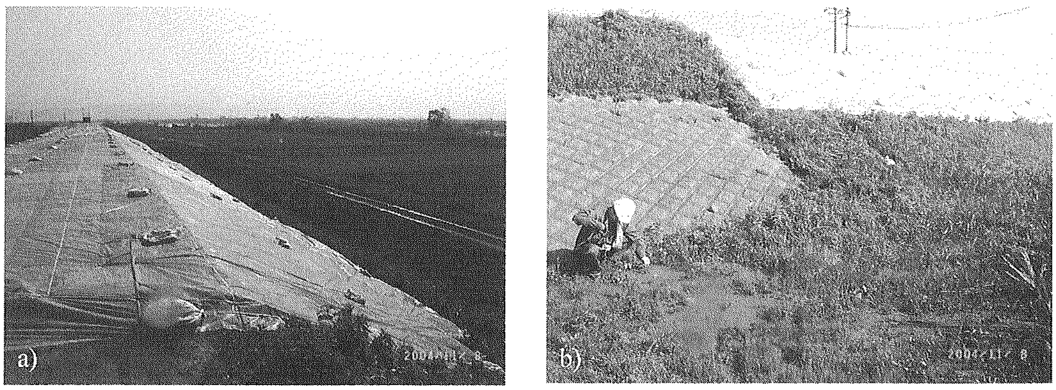

Figure 16. Temporarily rehabilitated dike along the Shinano river and a sand boil on adjacent ground (at Namiki-shinden, Nakanoshima-machi; site 10 in Figure 1)

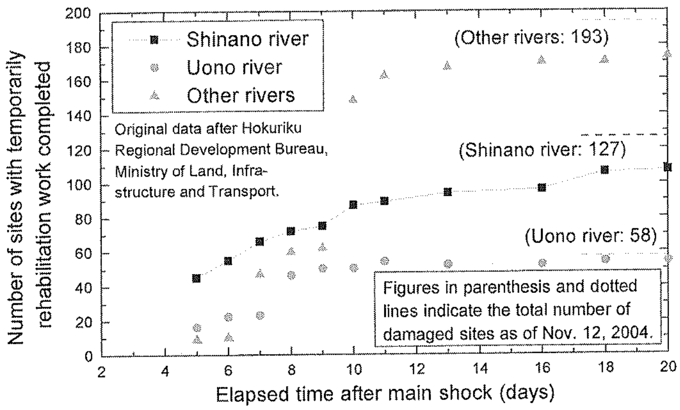

Figure 17. Progress of temporarily rehabilitation work on damaged river facilities including dikes

Figure 18. Rehabilitation work of a dike along the Kariyata river (at Gohyaku-kari, Nakanosima-machi; site 11 in Figure 1)

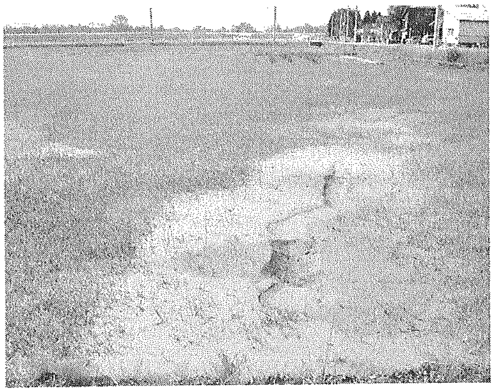

Figure 19. Sand boils on ground behind a dike along the Shinano river (at Iwano, Koshiji-machi; site 12 in Figure 1)

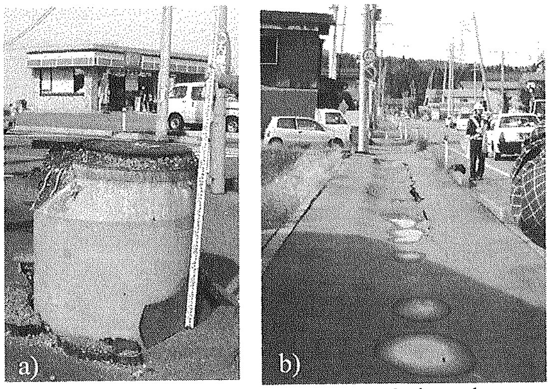

Figure 20. Uplift of sewage manhole and settlement of pavement above backfill soil for sewage pipes (at Sakura-machi, Ojiya city; site 13 in Figure 1)

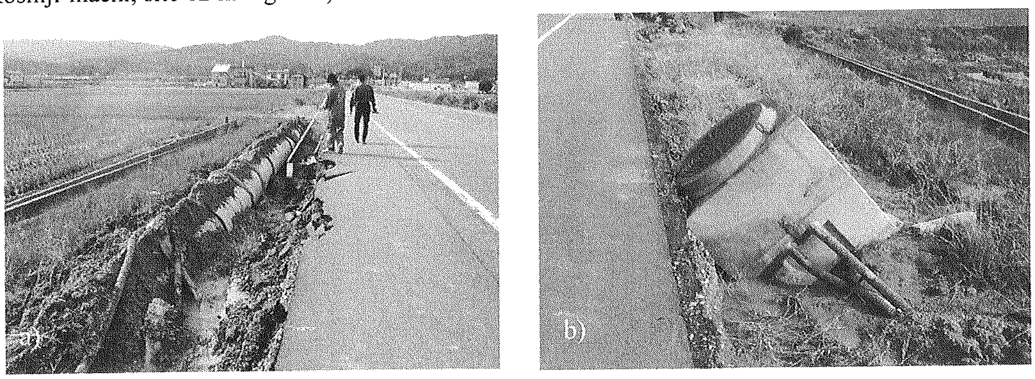

Figure 21. Complete uplift of buried pipes and tilting of an uplifted manhole along National Highway Route 117 (at Yachi, Ojiya city; site 14 in Figure 1)