DAMAGE TO ROAD FILL BY THE 2007 NOTO-HANTO EARTHQUAKE

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ABSTRACT :

The 2007 Noto Peninsula Earthquake caused considerable damage to embankments of mountainside roads, and suspended the road traffic function for a long period. In this paper, after over viewing damage to road embankments by this earthquake, the results of ground surveys and case analyses of embankments damaged and undamaged by the Noto Peninsula are documented. Relatively large embankments were collapsed in 11 sites along the Noto Toll Road by this earthquake. From the results of the surveys, it was found that seepage water inside embankments might cause the embankment failures. It was also clarified that terrain and geological factors that affected the stability of road embankments during an earthquake.

KEYWORDS: earthquake damage, road embankment, the 2007 Noto-Hanto Earthquake

1. INTRODUCTION

On March 25, 2007, the Noto-Hanto Earthquake with a magnitude 6.9 occurred with its epicenter off the west coast of the Noto Peninsula Japan. This earthquake caused considerable damage to embankments of mountainside roads, and suspended the road traffic function for a long period. In this paper, after over viewing damage to road embankments by this earthquake, the results of field and ground surveys of embankments damaged and non-damaged by the Noto-Hanto Earthquake conducted to examine factors that affected the seismic performances of the mountainside road embankments are documented.

2. OVERVIEW OF DAMAGE TO ROAD

The Noto-Hanto earthquake damaged road facilities in 80 places that required some kind of traffic restriction. The breakdown of the 80 places is: 53 places on a toll road (Noto Toll Road), one place on an ordinary national highway (Noetsu motor road), 9 places on a subsidiary national highway, and 17 places on a prefectural highway. Figure 1 shows the locations of the damaged sites.

The majority of the damage to the road facilities was the failure of embankments constructed by filling valley, and failures due to the liquefaction of the foundation ground were rarely observed. Relatively large embankments were collapsed in 11 places along the Noto Toll Road, and in two places along national highway route 249. The embankment failure near the Bessho Dake Service Area located at the 17.7 km point along Noto Toll Road are shown in Photos 1.

The types of damage to the embankments were flow type failures to high embankments constructed on catchment areas such as swamps and valleys. Differential settlements at the approach to structures such as culverts and abutments were observed. The differential settlements were also observed at the boundary between cut slope and embankment. Failure to an entire embankment due to liquefied foundation ground was rarely observed. These damage patterns had been also observed as characteristic damage patterns of mountainside embankments in past earthquakes (Koseki et al. 2006).

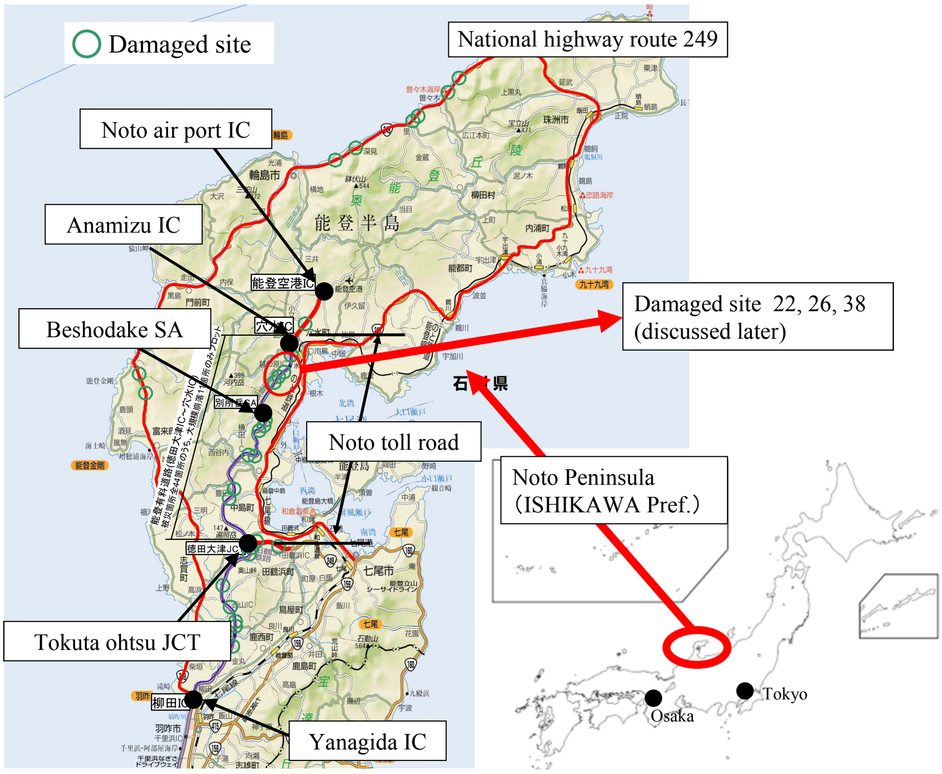


Figure 1 Locations of damaged sites along the Noto Toll Road and national highway route 249

(a) Close view (b) Aerial view

Photos 1 Embankment failure near the Bessho Dake SA along the Noto Toll Road

In this paper, the damage level of the embankments was categorized into three levels according to the definition established by Ishikawa prefecture (Committee for the Study of Recovery Methods for the Noto Toll Road (2008)). First, A. Failure means complete failure of embankments. Second, B. Settlement/crack indicates deformation and cracks in the road surface that reached the subgrade, and C. Crack means deformation and cracks in the road surface that did not reach the subgrade. These definitions will be used to describe the damage levels of the Noto Toll Road hereafter.

Traffic was completely closed between the Yanagida Interchange (IC) and the Anamizu IC on the Noto Toll Road immediately after the earthquake. The Committee for the Study of Recovery Methods for the Noto Toll Road, chaired by Prof. Kawamura of the Kanazawa Institute of Technology, was established after the earthquake, and the committee examined emergency recovery methods, and recovery methods for all of the damaged places.

Two lanes (one running in each direction) on the Noto Toll Road were opened temporarily at 15:00 on March

29 after the completion of emergency rehabilitation work between the Yanagida IC and the Tokudaotsu IC, and a detour was routed between the Tokudaotsu IC and the Anamizu IC. The section between the Tokudaotsu IC and the Yokota IC was opened on April 20, and the section between the Yokota IC and the Anamizu IC was opened on April 27. The entire length of the Noto Toll Road was recovered sequentially, and it was reopened on November 30 without any detours.

On the other hand, as for the ordinary national highway, the subsidiary national highway and the prefectural highway, all the highways were recovered except for a place damaged by falling rocks around Sosogi, Machino, Wajima city on national highway route 249, and these damaged sites were also reopened in one way alternating traffic between 5:00 and 20:00 since July 7th.

3. FIELD SURVEY

3.1 Survey Method

We conducted field surveys of the damage to road facilities on the Noto Toll Road three days after the earthquake and six weeks after the earthquake. The first survey was carried out between March 28 and March 30, and the second one was between May 8 and May 11. In the second survey, damaged and undamaged embankments in the section between the Tokudaotsu IC and Anamizu IC along the Noto Toll Road were examined in detail. The breakdown of the second field survey is summarized in Table 1. During the field survey, following points were carefully investigated at the damaged and undamaged sites.

1) Supply of water and moistness of the slope behind embankments (Existence of swamps, ponds, and marshes)
2) Moistness at the surface of embankment slopes and slope toes, existence of spring water, and soundness of drainage facilities
3) Subsided road surfaces, cracks, bulges, deformations such as cracks on the slopes and swelling, repair history, and existence of past disasters.

3.2 Tendency of Damage to Road Embankments Based on The Field Survey

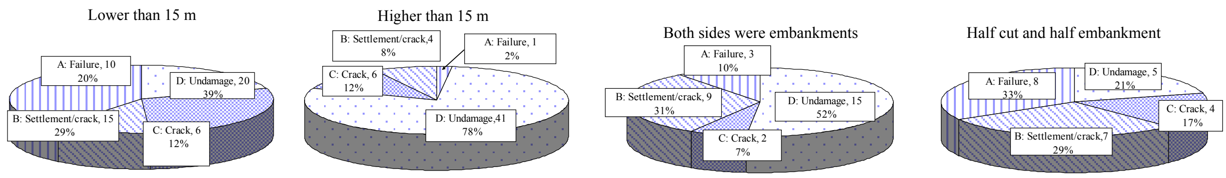
The results of the field surveys, which were conducted on the embankments between the Tokudaotsu IC and Anamizu IC on the Noto Toll Road, will be summarized hereafter. There were 103 embankments between the Tokudaotsu IC and Anamizu IC, of which 51 embankments were higher than 15 meters. We conducted detailed field surveys on these 52 embankments.

Table 1 Total number of surveyed fills at the second field survey

Damage levels		Total number of fills	Number of surveyed
Damage	A. Failure	11	11
	B. Settlement/Crack	19	19
	C. Crack	12	8
D. undamage		61 (31 fills were higher than 15m)	14 (all the surveyed fills were highter than 15m)
Total		103	52

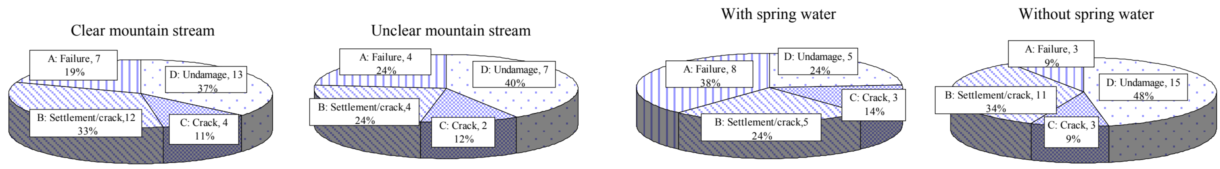
The results of field survey are summarized in Figures 2 and 3. Following trends can be seen from these figures.

1) The ratio of damage tends to be high in case embankments were higher than 15 meters.
2) The ratio of Failure tends to be high in partial embankments. This behavior suggests that damage became serious in borders between embankments and cut slopes.
3) No clear tendency in damage degree was observed based on the existence of swamps behind embankments or spring water on the fill slopes. This behavior indicates that it is difficult to ascertain the degree of permeation of groundwater inside embankments judging solely from the outside conditions of swamps and springs.
4) As for slopes of natural ground, the damaged embankments tend to increase with the increase of the value of a parameter Z defined as Figure 3(d), which is the ratio of the inclination of the natural ground at the toe of

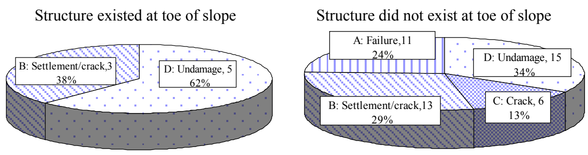


(a) Effect of embankment height (b) Effect of embankment type

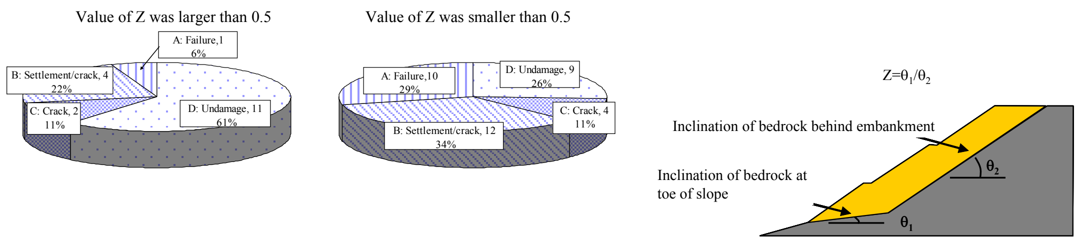
Figures 2 Relationship between embankment shape and damage levels



(a) Effect of mountain stream (b) Effect of spring water



(c) Effect of structure at slope toe



(d) Effect of bedrock inclinations

Figures 3 Relationship between ground conditions and damage level

the slope to the inclination of the natural ground behind the embankments.

5) The ratio of damage tends to be high if no slope toe structure exists. From this fact, the structures which were constructed at the slope toe is highly effective in controlling deformation of the slope toe of an embankment.

4. GROUND SURVEY

4.1 Survey Method

The 2007 Noto-Hanto Earthquake caused 11 relatively large embankment failures on the Noto Toll Road. Each of the 11 embankments was constructed by filling valley. The ground conditions along the Noto Toll Road were investigated so as to ascertain: (1) degree of compaction of embankments, (2) water level inside embankments, (3) existence of colluvial deposits in the foundation ground of embankments, and (4) relationship between damage level and soil properties of embankment materials.

Ground surveys were carried out at the sites of failure, settlement/crack and undamaged sites that had the

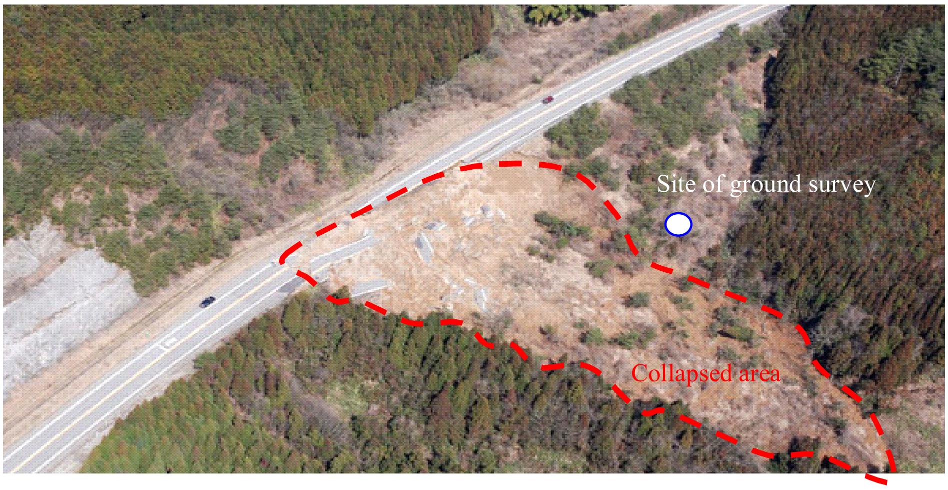


Photo 2 Embankment failure at Site 38

similar embankment shape as that in sites suffered embankment failure. The standard penetration tests were carried out at three sites: Site 22 (Settlement/crack), Site 26 (undamaged), and Site 38 (Failure). The level of groundwater was also measured using the boring holes. An aerial photo of the Site 38 suffered embankment failure is shown in Photo 2. It should be noted that the ground survey in the Site 38 was carried out at undisturbed area of the same embankment near the collapsed area (see Photo 2). Soil samples were also retrieved from the embankment by using thin wall sampling method in these sites.

4.2 Survey results

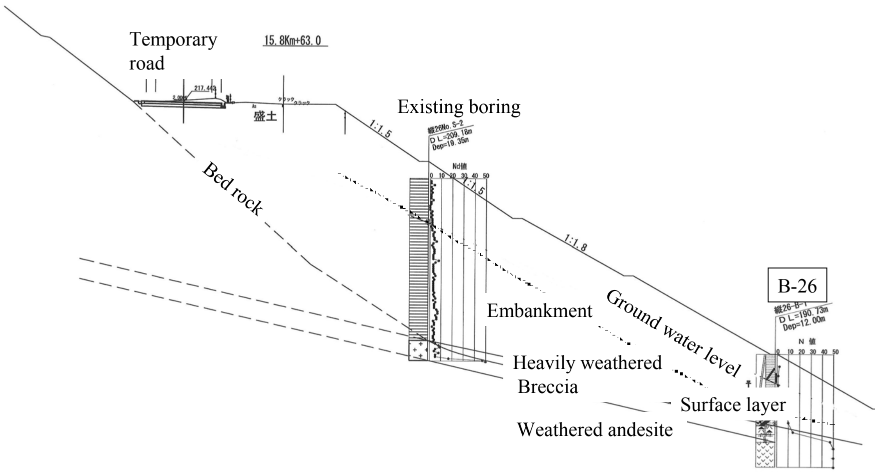
Figures 4 (a) to (c) show the soil profiles, and Figures 5 (a) to (c) show cross-sections of each boring site. Each of these boring was conducted near the toe of the embankments (B-26, B-22 and B-36 in figures 5). Boring at Site 38 (Failure) was conducted in the undisrupted area of the same embankment. These borings revealed that the N values within the embankments were lower than 5, irrespective of the damage degree in each boring site, but the water level within the embankment was low both in undamaged and settlement/crack sites, and high in failure site.

Figures 6 (a) to (c) illustrate the relationship between damage levels and degree of compaction of the embankments, those between damage levels and groundwater level near the toe of the embankments, and those between damage levels and N values.

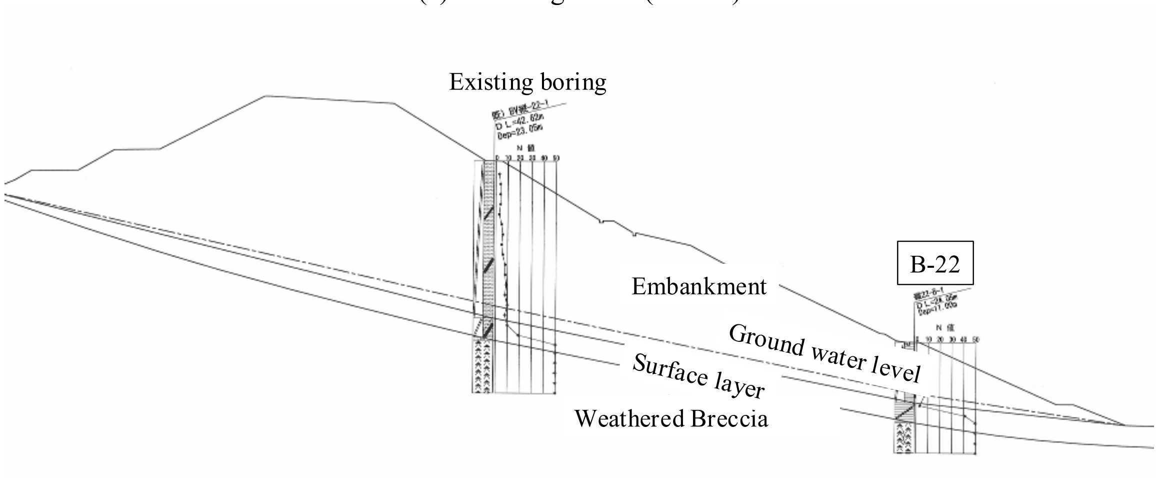
Degree of compaction D_c of the embankment in Figure 6(a) was obtained from the soil samples retrieved by thin wall sampling method and results of the compaction tests of disturbed sample obtained from near the surface of the embankment slopes. The ground water levels in Figure 6 (b) are shown as the ratio of ground water levels h_w to the thickness of the embankments h_e at boring site. The N values in Figure 6 (c) are the average N value of the embankment layers that were obtained from SPT. Although the degree of compaction D_c was high in embankment failure site, it varied within the range of 80% to 90% on the whole. No clear correlation was observed between damage level and degree of compaction D_c. The groundwater level near the slope toe of embankment reached near the surface ground in Site 36 suffered embankment failure. This behavior suggests that permeation of water into the embankment may be one of the causes of embankment failure. However, it should be noted that the water level shown in Figure 8 (b) is one in wells at the time of survey, and the water levels of Site 38 were measured value the undisrupted area of the same embankment.

As for N values, the Site 36 suffered embankment failure tends to show high N values. However, because N values are low in embankments on the whole, the difference between high N values and low N values was not significant.

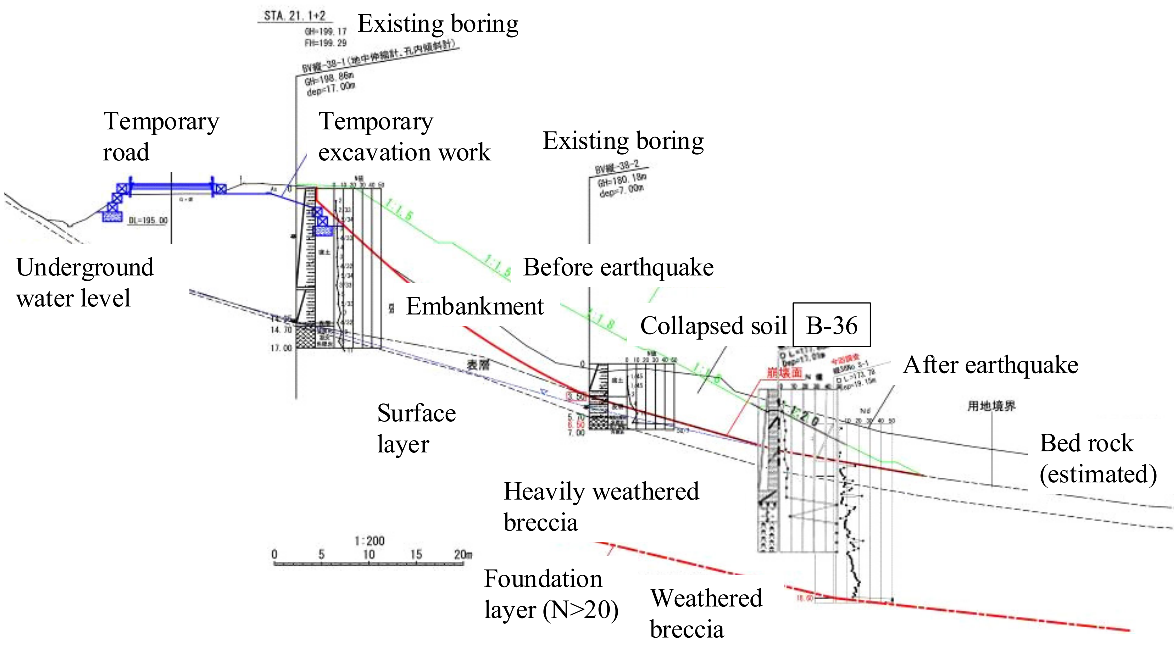
Figure 7 and 8 shows the grain size distributions and the relationship between damage levels and typical physical properties of the embankment materials, which were obtained by shin wall sampling method. The embankment materials, on the whole, contained many fine contents, and most materials were classified into silt and clay with a high liquid limit. The mean grain size D_{50} tend to be high and the fine contents FC tend to be low in the failed embankment. However, no great variation in plasticity index I_p could be observed according to the damage level.



(a) Undamaged site (Site 26)

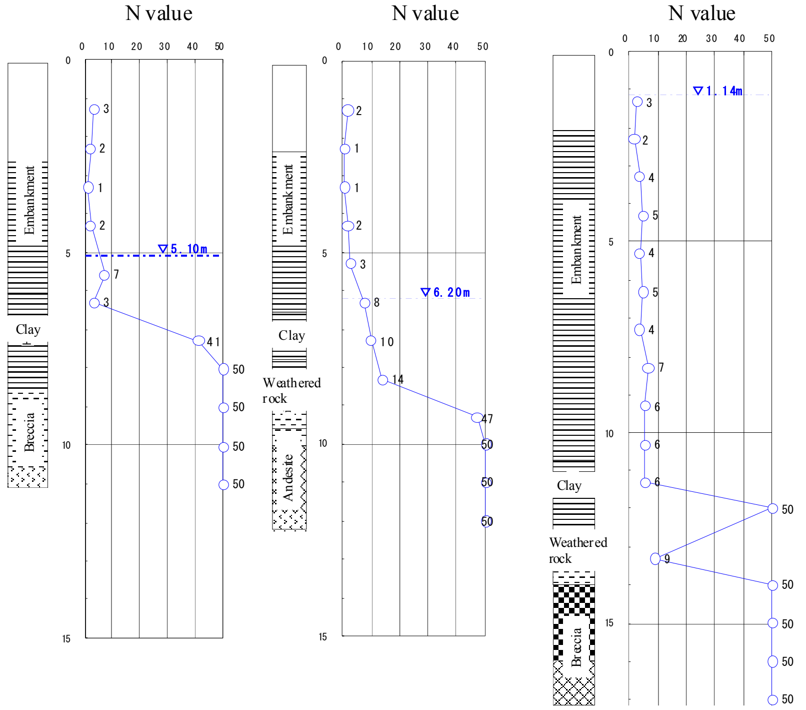


(b) Settlement/crack (Site 22)



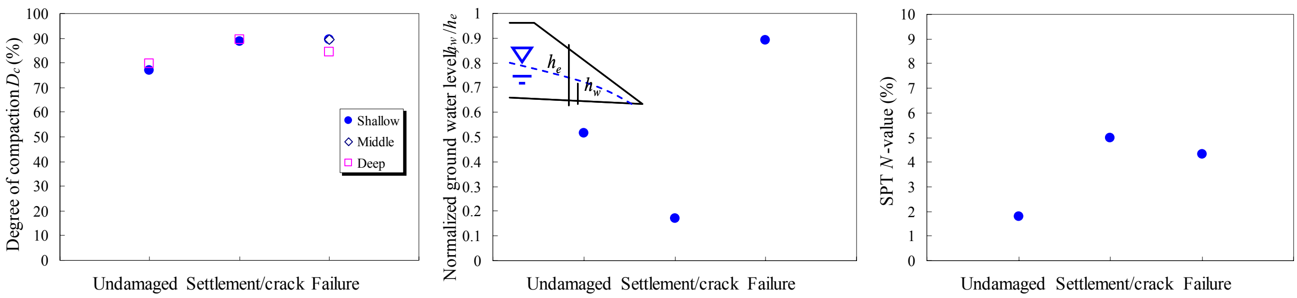
(c) Failure (Site 38)

Figures 5 Cross sections of surveyed embankments



(a) B- 26 (undamaged) (b) B- 22 (Settlement/crack) (c) B-38 (Failure)

Figures 4 Soil boring logs obtained from ground survey



(a) Effect of degree of compaction (b) Effect of ground water level (c) Effect of SPT N-value

Figures 6 Relationship between damage level and results from ground surveys

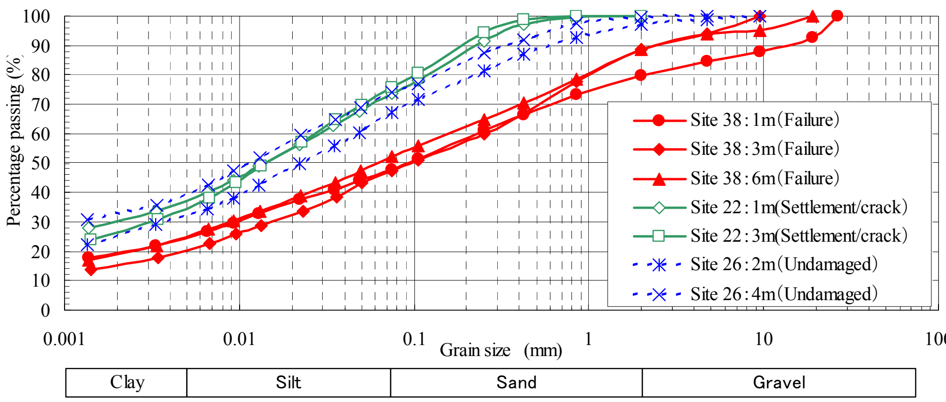
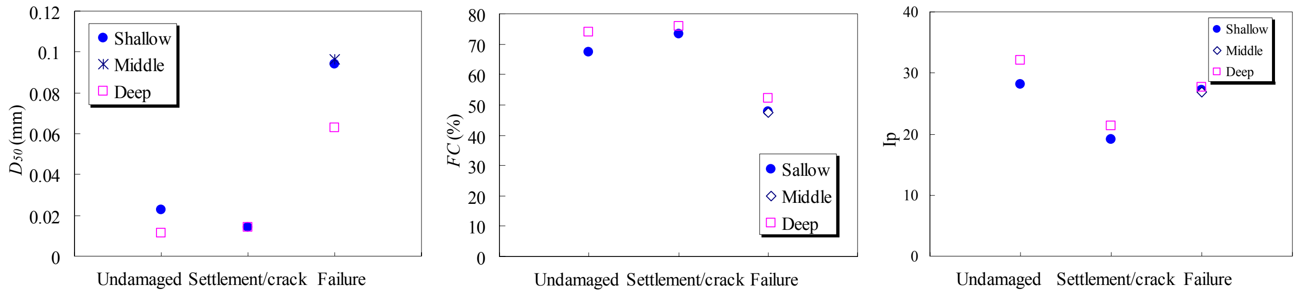


Figure 7 Grain size distributions of embankment materials obtained by shin wall sampling method



(a) Mean grain size D_{50} (b) Fine contents *FC* (c) Plasticity index I_p

Figure 8 Physical properties of embankment materials obtained by shin wall sampling method

4. SUMMARY

Based on the ground surveys and case analyses of the road embankments damaged by the 2007 Noto-Hanto Earthquake, the conditions of embankments and terrain that affected the road embankment failure were examined. The results of survey can be summarized as follows:

1) A strong earthquake motion damaged embankments mainly along the Noto Toll Road. Relatively large embankments were collapsed in 11 sites along the Noto Toll Road, where the existence of water in swamps and marshes at each of the 11 sites were observed. In these places, seepage water inside the embankments might have affected the sliding disruption.
2) Analyzing factors of damage along the Noto Toll Road, it was found that the characteristics of embankments that suffered embankment failure were: that the embankments were higher than 15 meters, and that they were made by filling in swamps.
3) Based on the ground surveys on damaged sites and undamaged site, it was found that there was no correlation between damage levels and SPT N-value of embankment. The degree of compaction of the embankment varied between 80% and 90%, but no significant difference was observed between damaged and undamaged sites.
4) In site suffered embankment failure, the groundwater level tended to be high near the slope toe of the embankment, suggesting the possibility that the existence of water within the embankment might have affected the level of damage.
5) As for embankment material, the mean grain size D_{50} tend to be high and the fine contents *FC* tend to be low in the failed embankment.

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