Features of slope disasters on roads caused by the 2011 off the Pacific Coast of Tohoku Earthquake

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Abstract

In the 2011 off the Pacific Coast of Tohoku Earthquake, many slope disasters occurred on roads. For the road slope disaster prevention in the future, we collected and analyzed 168 cases of road slope disasters by this earthquake. In these 168 cases, failures of embankment or road shoulder occurred most (46%), rock slope failures (large scale rockfalls) occurred to the second much (28%), and other cases were rockfalls, soil slope failures (shallow landslides), deep-seated landslides etc. About the volume of collapsed mass, 39% of the cases were within 100m^3, 37% of the cases were 100m^3 to 1,000m^3, 24% were over 1,000m^3. Deep-seated landslide cases, particularly, contain large scale cases over 10,000m^3 in volume. JMA seismic intensity near the each site was 5 upper and over in 99% of the cases, and 6 lower in 65% of the cases. Rock slope failures occurred in the area of sedimentary and metamorphic rocks of Paleozoic to Mesozoic age, and 3/4 of these cases occurred on the ridge slope. Deep-seated landslides occurred in the area of the Neogene sedimentary and volcanic rocks, including many cases whose geological structure dip concordant to the slope, and cases occurred in the part of old landslide topography. In the area of granites, various type of disasters including rock slope failures, rockfalls, soil slope failures etc. occurred. Many of failures of embankment or road shoulder occurred at the site where water is likely to permeate such as embankment filling the valley. Moreover, past deformations or disasters have been recorded in 10% of the cases in this study. It needs to inspect and examine countermeasures against these sites particularly.

Keywords: road, slope, disaster, earthquake

1. Introduction

The 2011 off the Pacific Coast of Tohoku Earthquake caused not only tsunami disasters and an accident of the atomic power plant, but also many slope disasters on roads in the Tohoku District of Japan. These road slope disasters cut the road network at various points, and obstructed human activity. It is important to reduce such road slope disasters for improving reliability of road network.

Scientific approach is needed for the road slope disaster prevention in the future, and analyzing past disasters is one of the bases for this approach. Therefore, we collected and analyzed road slope disaster cases by this earthquake to reveal features of the disasters and notice points for road slope disaster prevention (Miyamoto et.al., 2012, 2013 and 2014; Asai et.al., 2014).

2. General features of the disasters

We could collect 168 cases of road slope disasters occurred in Iwate, Miyagi, Fukushima and Ibaraki Prefectures, northeast part of Honshu Island of Japan (Fig.1). These disasters were caused by the main shock on 11th March 2011 and aftershocks including aftershock on 11th April forming earthquake faults in Fukushima Prefecture. Fig.2 shows the percentage of the disaster types. In these 168 cases, failures of embankment or road shoulder occurred most (46%), rock slope failures (large scale rock fall) occurred to the second much (28%), and other cases were rockfalls, soil slope failures (shallow landslides), deep-seated landslides etc.

Fig.3 shows the distribution of the volume of failed mass. About the volume of failed mass, 39% of the cases were within 100m^3, 37% of the cases were 100m^3 to 1,000m^3, 24% were over 1,000m^3. Deep-seated landslide cases, particularly, contain large scale cases over 10,000m^3 in volume.

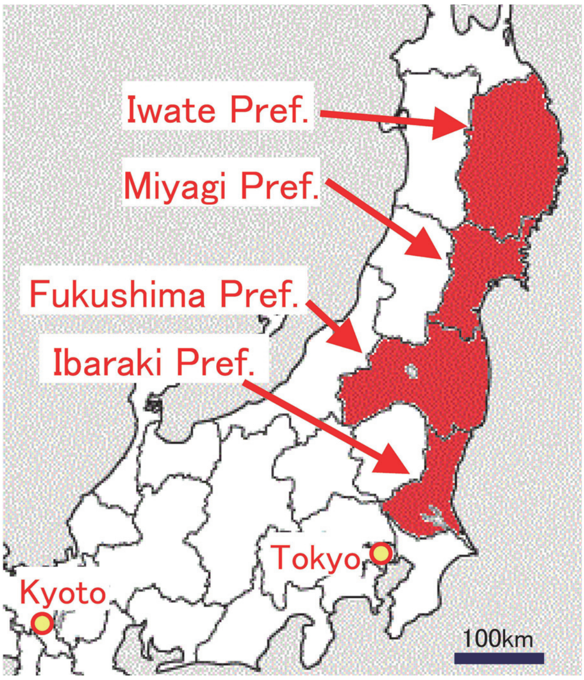

Fig. 1 Map of the study area
(red area in the map)

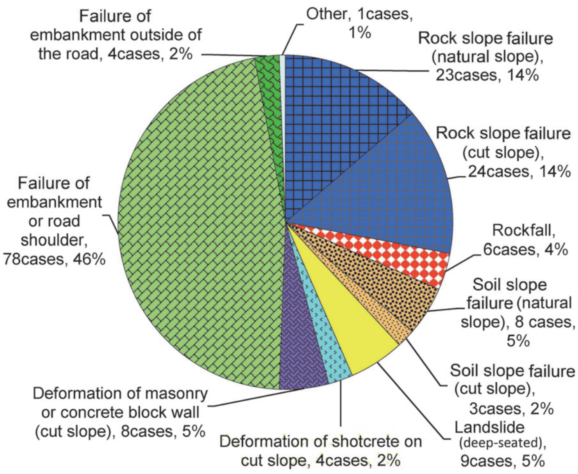

Fig. 2 Percentage of disaster type

Fig.4 and Fig.5 show the relationship between the occurrence of the disasters and seismic intensity. JMA (Japan Meteorological Agency) seismic intensity near the each disaster site was 5 upper and over in 99% of the cases, and 6 lower in 65% of the cases as shown in Fig.4. Maximum acceleration near the each disaster site was 400 gal and over in 92% of the cases as shown in Fig.5.

Fig.6 shows the relationship between the occurrence of the disasters and slope shape. Fig.7 shows the relationship between the occurrence of the disasters and basement geology. Rock slope failures mainly occurred in the area of sedimentary and metamorphic rocks of Paleozoic to Mesozoic age as shown in Fig.7, and 3/4 of these cases occurred on ridge slopes as shown in Fig.6. 28% of the rock slope failures occurred by the aftershock on 11th April in the Mesozoic schist area in Fukushima Prefecture.

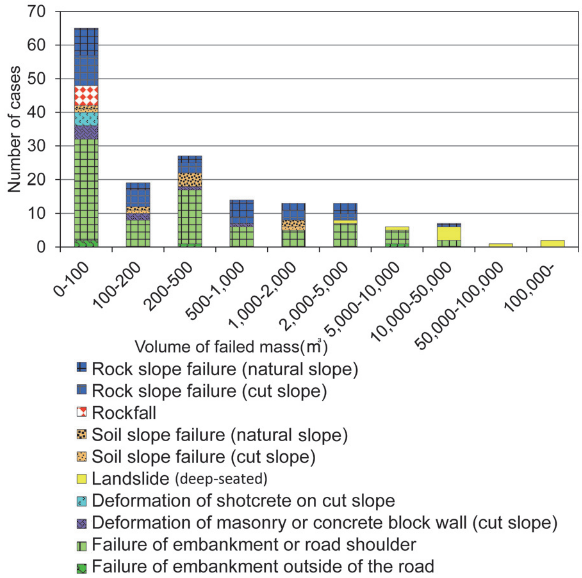

Fig. 3 Volume of failed mass

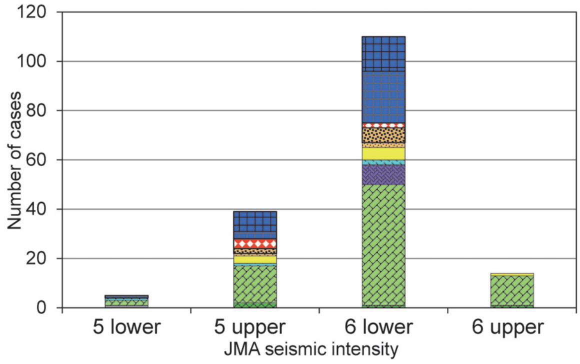

Fig. 4 JMA seismic intensity near the disaster site (Legend: same as Fig.2)

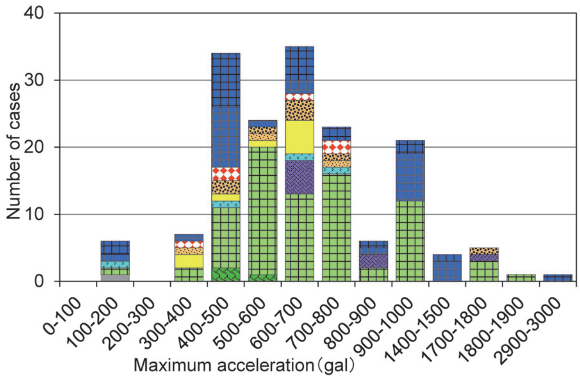

Fig. 5 Maximum acceleration near the disaster site (Legend: same as Fig.3)

Deep-seated landslides mainly occurred in the area of the Neogene sedimentary and volcanic rocks as shown in Fig.7. In many of these cases, geological structure dip concordant to the slope. Some of the cases occurred in the part of old landslide topography.

In the area of granites, various type of disasters including rock slope failures, rockfalls, soil slope failures etc. occurred as shown in Fig.7. Many joints generally exist in the granites, and opening of joints effects the occurrence of rock slope failures and rockfalls. And granites are often weathered severely to become soil what is called 'masa' in Japan, which effects the occurrence of soil slope failures.

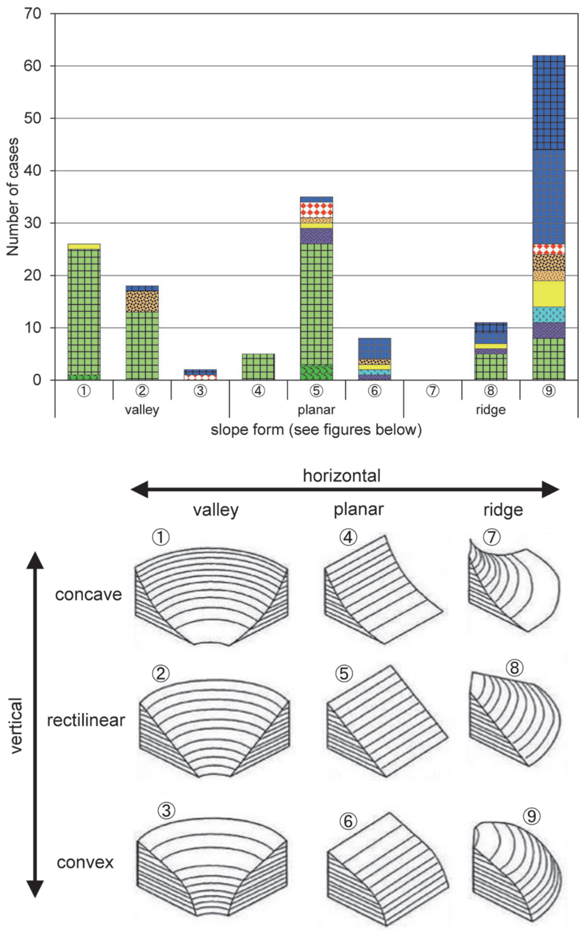

Fig. 6 Slope form at the disaster site
(Legend: same as Fig.3)

Fig.8 shows the percentage of the cases in which past deformations or disasters have been recorded or not. Past deformations or disasters have been recorded in 10% of the cases in this study. In other cases, records of deformations or disasters are unknown. (It does not always mean that no deformations or disasters have been exist.)

3. Typical cases of main disaster types

3.1 Rock slope failure

Photos 1 and 2 show a case of rock slope failure on a ridge slope, about 600m^3 in volume, caused by the aftershock on 11th April in Fukushima Prefecture. Basement geology is the Mesozoic schist. Open joints of reverse dip exist as shown in Photo 2, which

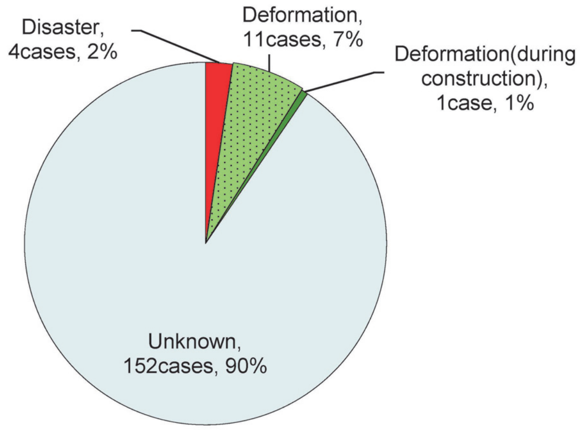

Fig. 8 Percentage of cases which past deformations or disasters have been recorded or not

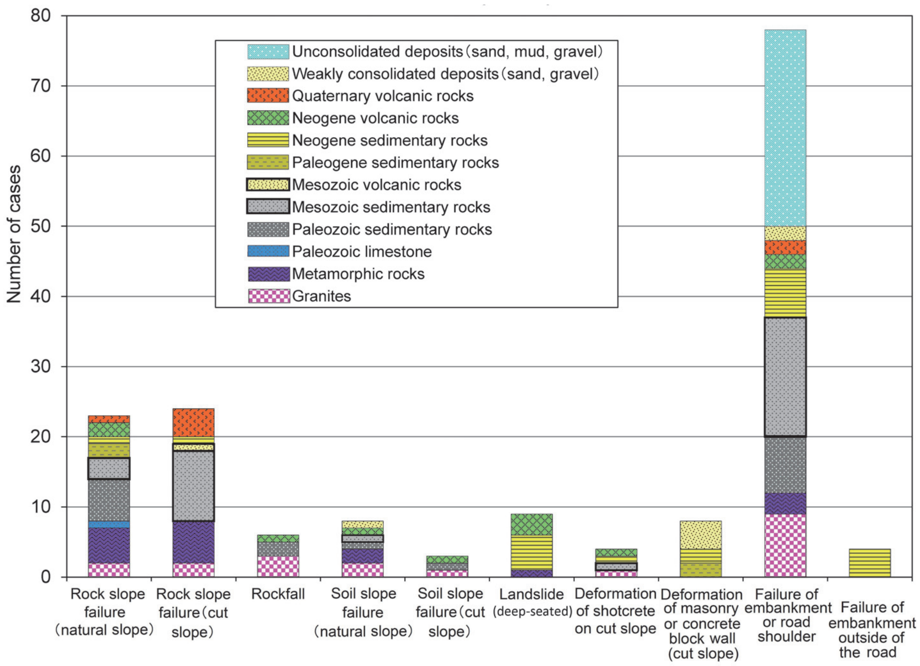

Fig. 7 Basement geology at the disaster site

suggests toppling movement of the slope before the failure.

Photos 3 and 4 show another case of rock slope failure on a ridge slope, about 3,000m^3 in volume, caused by the same aftershock. Basement geology is the Mesozoic granodiorite. Joints of dip slope exist as shown in Photo 4, which effected the occurrence of the failure.

3.2 Rockfall

Photo 5 and 6 show a case of rockfall caused by the main shock. Basement geology is the Paleozoic slate. Several rocks, a maximum diameter of 1m, fell from a loosen rock slope, broke the rock fence and reached the road.

Photo 7 and 8 show another case of rockfall. Basement geology is the Mesozoic granodioraite. One of the corestones, a maximum diameter of 0.6m, remained from weathering fell down to the road.

3.3 Soil slope failure (shallow landslide)

Photo 9 and 10 show a case of soil slope failure on a cut slope, about 1,100m^3 in volume and 1.5m in thickness, caused by the main shock. Basement geology is the Mesozoic granite. Surface soil 'masa' formed by weathering of granite fell down to the road.

3.4 Deep-seated landslide

Photo 11, 12 and 13 show a case of deep-seated landslide, about 775,000m^3 in volume, caused by the aftershock on 11th April in Fukushima Prefecture. Basement geology is the Miocene sandstone and siltstone. Its slip surface dips 10 degree, which is concordant to the dip of the bedding plane. No old landslide topography was recognized in this site.

Photo 14 and 15 show another case of deep-seated landslide, about 65,000m^3 in volume, caused by the same aftershock. Basement geology is the Mesozoic schist, but landslide mass consists mainly of weathered soil as shown in Photo 15. This landslide occurred in the side part of old landslide topography as shown in Fig.9.

3.5 Failure of embankment or road shoulder

Photo 16 and 17 show a case of embankment failure, about 900m^3 in volume, caused by the aftershock on 11th April in Fukushima Prefecture. This embankment was constructed filling a valley, maximum height of 20m. In the case of the embankment filling the valley like this, it is thought that ground water is likely to gather, resulting in the

Photo 1 A case of rock slope failure in the Mesozoic schist area

Photo 2 Open joints in the rock slope at the failure shown in Photo 1 (white broken lines)

Photo 3 A case of rock slope failure in the Mesozoic granodaioraite area

Photo 4 Joints of dip slope in the rock slope at the failure shown in Photo 3 (white broken lines)

Photo 5 A case of rockfall in the Paleozoic slate area

Photo 6 Source of the rockfall shown in Photo 5

Photo 7 A case of rockfall of a corestone remained from weathering in the Mesozoic granodiorite area

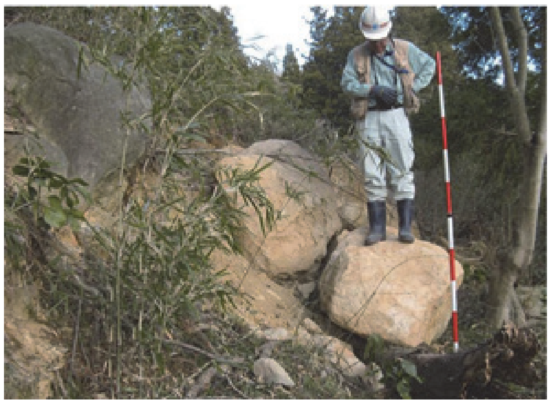

Photo 8 Source of the rockfall shown in Photo 7

Photo 9 A case of soil slope failure on a cut slope in the Mesozoic granite area

Photo 10 Upper part of the failed slope shown in Photo 9

Photo 11 A case of deep-seated landslide in the Miocene sedimentary rock area

Photo 12 Depression zone at the top of the landslide shown in Photo 11

Photo 13 Uplifted road at the toe of the landslide shown in Photo 11

Photo 14 A case of deep-seated landslide in the Mesozoic schist area

Photo 15 Outcrop in the lower part of the landslide shown in Photo 14

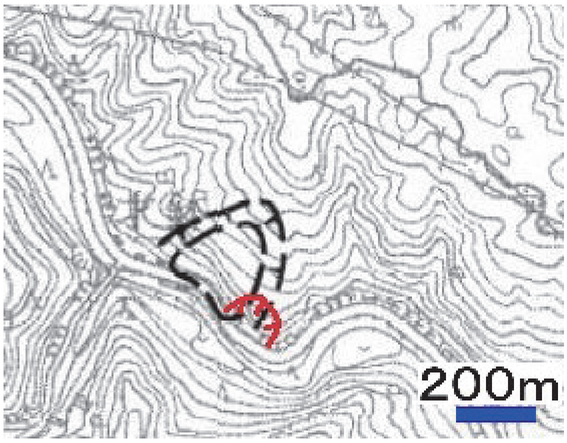

Fig.9 Landslide Map by National Research Institute for Earth Science and Disaster Prevention, Japan

Black line: Old landslide topography

Red line (added by the authors): New landslide shown in Photo 14

Photo 16 A case of failure of embankment constructed filling a valley

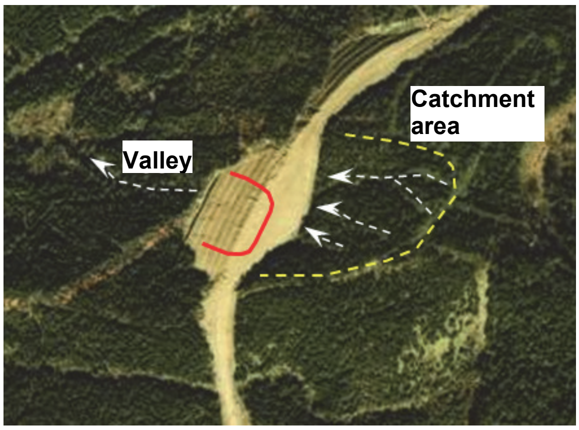

Photo 17 Aerial photograph of the embankment in Photo 16, taken 36 years before the disaster by Geographical Survey Institute (present: Geospatial Information Authority of Japan).

White broken line with arrow: Valley

Yellow broken line: Catchment area

(Broken lines were added by the authors) high water content in the embankment and high risk of collapse.

Photo 18, 19 and 20 show another case of embankment failure, about 9,800m^3 in volume, caused by the main shock. This embankment was a part of a pastureland near the road, which collapsed and filled the road. This pastureland looks like a gentle slope now. However, as shown in Photo 20, an aerial photograph taken 35 years before the disaster revealed that the pastureland was constructed by filling the valleys, and the failed embankment was just situated in one of the filled valleys.

3.6 Other cases

Photo 21 shows a case of the collapse of masonry wall on the embankment slope near the road. Many stones were scattered on the road. Many of masonry walls constructed in old age, and have a steep dip. They are likely to fail or deform by the strong earthquake.

Photo 18 A case of failure of embankment which filled a road

Photo 19 Upper part of embankment failure shown in Photo 18

4. Notice points for road slope disaster prevention

For road slope disaster prevention, it needs to inspect and examine countermeasures against these sites particularly. Notice points for the disaster prevention are suggested as follows.

1) The ridge slope which is loosen and joints or cracks have been opened is easy to be deformed or fail by earthquake.
2) Embankment slopes filling up the valley are weak points against disaster, which are likely to be deformed or fail by earthquake.
3) For finding the hazardous site of deep-seated landslide by the earthquake, especially the site which does not show landslide topography and the geological structure of which dip concordant to the slope, regional investigation of topography and geological structure is important.
4) The embankment filling up the valley on the slope near the road cannot always be found only by the

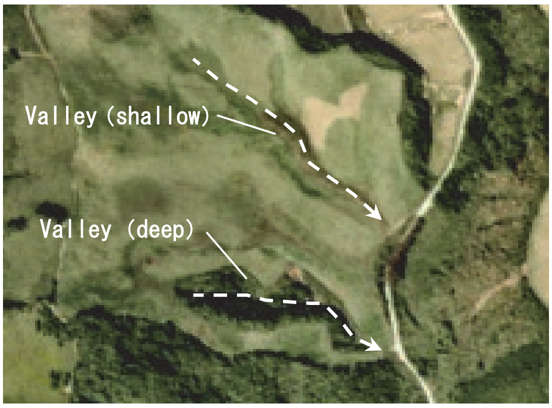

Photo 20 Aerial photograph around the site in Photo 18, taken 35 years before the disaster, by Geographical Survey Institute (present: Geospatial Information Authority of Japan). This photo shows the topography before filling the valley. The embankment filling the deep valley collapsed, and the embankment filling the shallow valley did not collapsed but deformed. (Broken lines were added by the authors)

Photo 21 A case of failure of masonry wall near the road

investigation of present geography. It needs to investigate history of topographic change by development using past aerial photograph, etc.

5) Many of masonry walls are likely to fail or deform by the earthquake because they constructed in old age and have a steep dip. It needs to find these sites as hazardous sites against disaster.

6) The disaster is easy to occur repeatedly at the site where the past disaster history exists and the cause of the disaster remains even now.

5. Conclusions

We collected and analyzed road slope disaster cases by the 2011 off the Pacific Coast of Tohoku Earthquake for the road slope disaster prevention in the future. We revealed the features of these disasters and suggested notice points for the disaster prevention as mentioned above. It needs to inspect and examine countermeasures against these sites particularly.

Acknowledgements

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