Monitored Behavior of Landslide at the Mid Niigata Prefecture Earthquake in 2004

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Abstract

This paper reports the results of analysis of characteristics of landslide sites, and seismic, topographic and geological characteristics of landslides that occurred in the Imokawa Basin during the magnitude-6.8 the mid Niigata prefecture earthquake in 2004. It also describes the results of consideration of field observations during the earthquake at some landslide sites where no large mass movements were observed. Investigations revealed that the sites of landslides and slope failures were distributed mostly in areas subjected to ground motion with an intensity of more than six plus and were correlated more to the maximum vertical acceleration than to the maximum horizontal acceleration. Landslides and slope failures occurred more frequently on dip slopes and convex slopes. As a result of investigations in eleven areas where field observations were made of landslides during the earthquake, local or temporary mass movements due to ground motions were observed at landslide sites with a history of sliding, but no cumulative movements were detected such as sliding that may have started right after the earthquake. At landslide sites in two areas where sliding started before the earthquake, cumulative movements were found after the occurrence of the earthquake. Sliding was assumed to have been continuing free from the effects of ground motions.

Keywords: Landslide, Earthquake, Acceleration, Topography, Monitoring

Introduction

At the time of the magnitude-6.8 the mid Niigata prefecture earthquake in 2004, numerous landslides occurred in which soil masses moved a long distance intact. In the Hyogoken-nambu earthquake of magnitude 7.3 and the Miyagiken-oki earthquake of magnitude 7.2 with relatively strong ground motions that recently occurred in Japan, fewer landslides occurred but slipping of fills and surface failures were predominant. Landslides have therefore been considered to be relatively free from seismic effects. This paper reports the analysis results of characteristics of landslides sites, and seismic, topographic and geological characteristics of landslides that occurred in the Imokawa Basin during the magnitude-6.8 the mid Niigata prefecture earthquake in 2004. It also describes the results of consideration of field observations during the earthquake at some landslide sites where no large mass movements were observed.

Method

(1) Characteristics of sites of earthquake-induced landslides

To grasp an outline relationship between the distribution of seismic accelerations and the sites of landslides and slope failures, an analysis was made in the area shown in topographic maps of Nagaoka and Ojiya (Fig. 1). To examine the relationship of the geology and pre-earthquake topographic characteristics to the sites of landslides and slope failures, a more detailed analysis was made in the Imokawa Basin. Landslides were interpreted from aerial photographs based on the results of investigations of landslides and slope failures conducted by the Ministry of Land, Infrastructure and Transport (Ministry of Land, Infrastructure and Transport, 2005) (Fig. 2).

Soil masses that were found to have moved without deformation based on the aerial photographs were considered landslides (Photograph 1). Other types of soil movements were regarded as slope failures (Photograph 2). Landslides were further classified into two types as described below.

(i) Type A landslides
Landslides that occurred on the slopes where no or inexplicit old landslides were found on a pre-earthquake topographic map, and landslides with a scarp at their upper end that occurred on the slopes where old landslides were found before the earthquake.

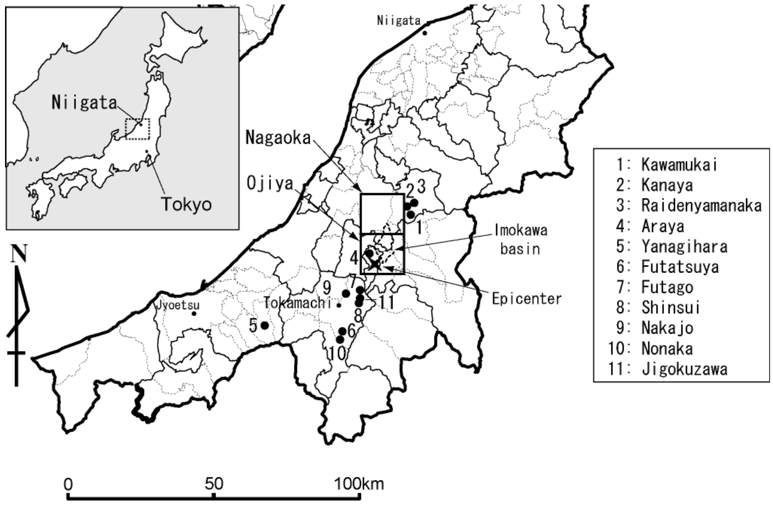

Fig. 1. Range in which landslides were interpreted from aerial photographs and locations where monitoring data were collected

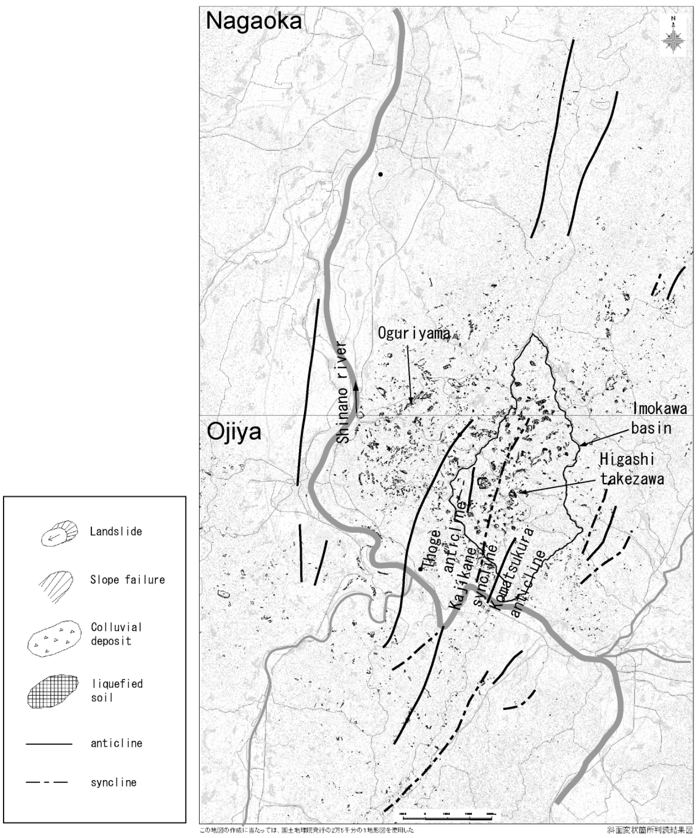

Fig. 2. Distribution of landslides and slope failures caused by the mid Niigata prefecture earthquake

(ii) Type B landslides
Landslides in the range where explicit old landslides were interpreted on a pre-earthquake topographic map.

The relationship between the distribution of seismic accelerations and the sites of landslides and slope failures was analyzed in the range shown in topographic maps of Nagaoka and Ojiya. The relationship of pre-earthquake topographic characteristics to landslide and slope failure sites was analyzed in the Imokawa Basin.

Photo. 1. Higashitakezawa

Photo. 2. Photograph-2 Naranoki

(2) Field observations during the earthquake

In relation to landslides that were affected by ground shaking with a seismic intensity of six or higher, the effects of seismic ground motions on landslides were investigated. Readings of pipe strain gages, extensometers, vertical extensometers and multi-layer movement meters up to November 2005 were collected and organized in eleven areas where field observations were being made (Fig. 1). Investigations were made of variations of readings, changes in variation pattern and the depths where variations occurred before and after the earthquake. Readings of pipe strain gages and multi-layer movement meters were checked approximately once a month and those of extensometers and vertical extensometers were monitored hourly.

Relationship of landslide and slope failure sites to seismic intensity and to maximum acceleration

A landslide and slope failure distribution map was superposed on the mid Niigata prefecture earthquake in 2004 isoseismal map (Japan Meteorological Agency, 2004) (Fig. 3). Landslides and slope failures were distributed in areas affected by ground shaking with an estimated seismic intensity of 6 or higher. Many were distributed in areas with an estimated seismic intensity of 6 plus or higher in particular. No concentration of landslides and slope failures were, however, observed in areas with an estimated seismic intensity of 7. The causes of this are not identified.

Maximum acceleration contours were developed for north-south, east-west and vertical directions, and the direction combining the three directions based on the measurements of maximum accelerations (Japan Meteorological Agency, 2004), and were superposed on the landslide and slope failure distribution map. Fig. 4 shows the distribution of maximum accelerations. Fig. 5 shows the distribution of maximum accelerations of vertical component. Fig. 4 indicates that the maximum accelerations were high in the area slightly southwest of the Imokawa Basin where numerous landslides and slope failures occurred. Maximum vertical accelerations, on the other hand, were high in the Imokawa Basin where numerous landslides and slope failures occurred (Fig. 5). The maximum vertical accelerations may have affected the occurrence of landslides and slope failures

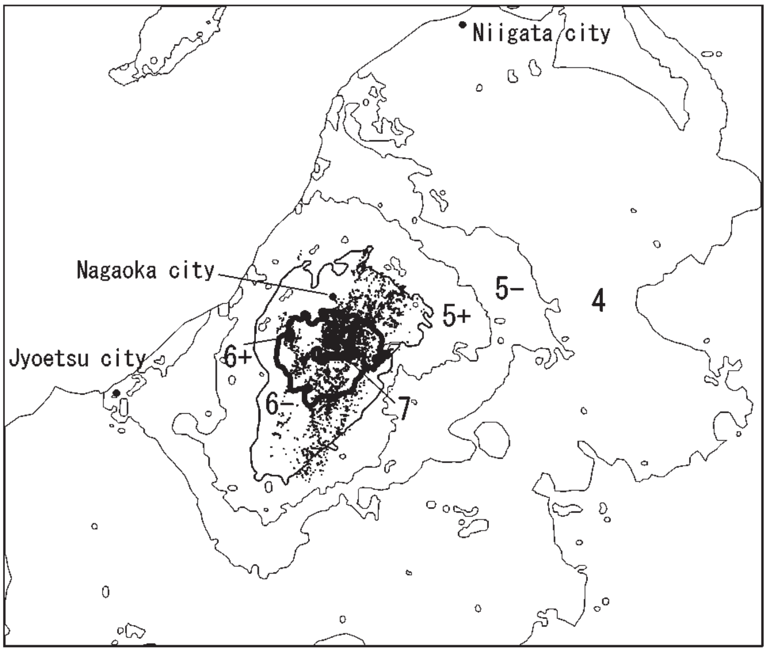

Fig. 3. Distributions of estimated seismic intensities and of landslides and slope failures

although detailed investigations and studies may be required in the future.

Topographic and geological characteristics of earthquake-induced landslide sites in the Imokawa Basin

(1) Earthquake-induced landslides

Aerial photographs taken in the Imokawa Basin were interpreted to extract 140 sites of relatively large landslides and slope failures. Landslides occurred at 53 sites, type A landslides at 34 and type B at 19. Slope failures took place at 87 locations (Fig. 6). More type A landslides occurred than type B.

(2) Geology

A map of distribution of landslides and slope failures caused by the earthquake was superposed on geological maps of Nagaoka (Geological Survey of Japan, 2001) and Ojiya (Geological Survey of Japan, 1996) to interpret the geology at landslide and slope failure sites. Geology was classified into six major types according to classifications in the geological maps. Percentages of respective soil types are shown for respective types of mass movements in Fig. 7. The Uonuma formation was classified as Quaternary sandy soil, the Wanazu and Shiraiwa formations as Quaternary sandstone, and the Ushigakubi and Kawaguchi formations as Neogene mudstone. The Araya formation was classified as Neogene mudstone or Neogene pyroclastic rock according to the rock type. Fig. 7 indicates that more than 80% of landslides or slope failures occurred in the Neogene mudstone or Quaternary sandstone. As high as 65% of type A landslides took place in Quaternary sandstone. Most of type B landslides occurred in Neogene mudstone. But the causes of this are not identified.

(3) Geological structure

According to the geological maps of Nagaoka and Ojiya, the Kajikane syncline runs north-north-east to south-south-west nearly at the center of the Imokawa Basin. The Komatsukura and Tohge anticlines are located on the east and west of the syncline parallel to the axis of the syncline. The axes of Kajikane syncline and Komatsukura and Tohge anticlines on the east and west of the syncline all dip southward (Geological Survey of Japan, 1996). The axes of the syncline and anticlines determine the dip and strike of the strata in the Imokawa Basin. The stratum in the area between the centerline of the Imokawa Basin and the axis of the anticline on the east of the syncline is oriented generally north-south to north-30 degrees-west and dips two to 35 degrees west. The stratum in the area between the centerline of the Imokawa Basin and the axis of the anticline on the west is oriented generally north-south to north-70 degrees-east and dips four to 50 degrees east. Dip on the east of the syncline is small in the north of the Imokawa and large in the south where the axis of syncline dips.

Superposing a map of distributions of landslides and slope failures on geological maps revealed that the

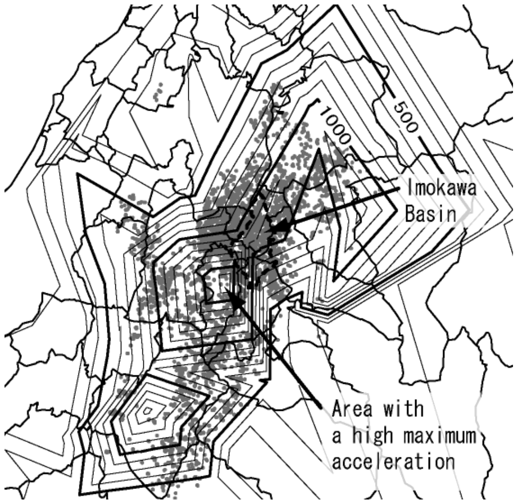

Fig. 4. Distributions of maximum accelerations and of landslides and slope failures

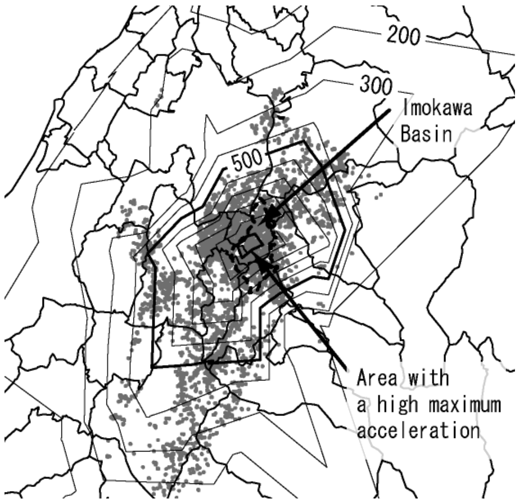

Fig. 5. Distributions of vertical maximum accelerations and of landslides and slope failures

landslides and slope failures in the Imokawa Basin were concentrated in areas between the Kajikane syncline nearly at the center of the basin and the Komatsukura and Tohge anticlines located on the east and west of the syncline, and near the Kajikane syncline in further north (Fig. 2).

The dip and strike of stratum in the Imokawa Basin have been affected by the axes of anticlines and syncline. The geological structures (dip slope or stratum of opposite dip) at landslide and slope failure sites were organized based on the dip and strike learned from geological maps (Fig. 8). In locations where classifying the geological structure as a dip slope or as a stratum of opposite slope was difficult because the directions of landslide or slope failure movements were close to the direction of strike or where the direction of strike was unknown, the geological structure was classified as other. Fig. 8 shows that many of the landslides and slope failures occurred on dip slopes. Landslides that took place on dip slopes accounted for approximately 60%. Some of type A landslides occurred in the strata of opposite dip.

(4) Slope orientation

Slope orientation before the landslides or slope failures occurrences was measured (Fig. 9). Landslides generally occurred on other slopes than north-south slopes. Old landslides recognized before the earthquake were distributed exclusively on east-west slopes because of the geological structure. Slope failures generally took place on other slopes than those at north 45 degrees west to north 45 degrees east. The stratum in the Imokawa Basin generally dips southward as an axis of syncline has developed in the north-south direction along the Imokawa and generally dips southward. One of the reasons for few slope failures is the fact that north-oriented slopes are in the strata of opposite dip. The direction of both wing of anticline is east-west. So, landslide and slope failure may be occurred east-west slope rather than north-south direction.

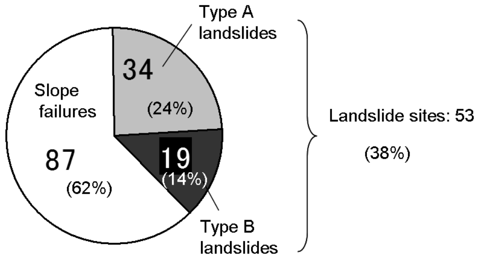

Fig. 6. Landslides in the Imokawa Basin caused by the mid Niigata prefecture earthquake

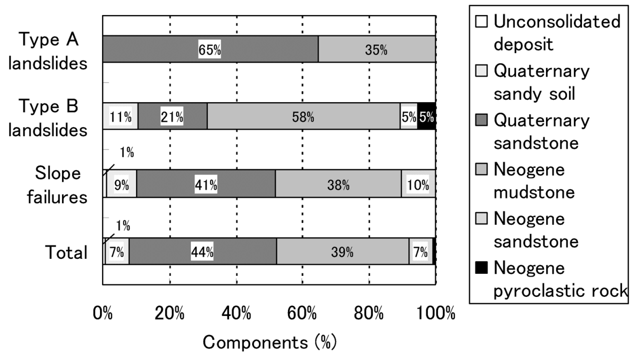

Fig. 7. Geology at landslide and slope failure sites

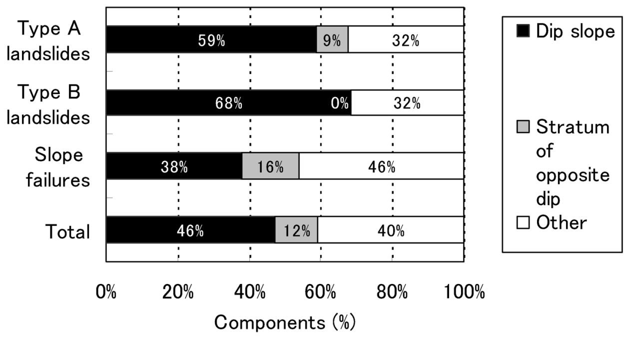

Fig. 8. Geological structure at landslide and slope failure sites

(5) Slope gradient

Percentages of slope gradients before the earthquake at landslide and slope failure sites were organized (Fig. 10). The gradients at the toe and head of landslide or slope failure were estimated from a pre-earthquake topographic map. Type A landslides occurred on slope with a gradient of less than 40 degrees. Many occurred on slopes with a gradient of 21 to 40 degrees. Numerous type B landslides occurred on slopes with a gradient of 11 to 30 degrees. Slope failures took place on slopes with a gradient of 11 to 80 degrees. Numerous slope failures occurred on slope with a gradient of 31 to 50 degrees. Many of precipitation-induced landslides generally occur on slopes with a gradient of 5 to 20 degrees (Fujita, Hisao et al., 1977). Slope failures tend to occur on steep slopes with a gradient of more than 30 degrees. Cumulative percentages of type A and B landslide represented by polygonal lines in Fig. 10 indicate similar tendencies. Existing landslides caused by precipitation listed in landslide survey statistics occurred on slopes with a smaller gradient than types A and B landslides. Earthquake-induced landslides occur on steeper slopes than landslides caused by precipitation.

(6) Slope shape at the toe of landslide

To investigate the effects of the pre-earthquake shape at the toe of landslide or slope failure on the occurrence of the event, gradients α and β were obtained (Fig. 11). Positive, zero and negative variances between the gradients (β-α) indicate convex, flat and concave slopes, respectively. Fig. 12 shows the percentages of respective slope shapes. Slope failure occurred evenly on slopes of all shapes. Landslides that occurred on convex slopes account for 70% of all landslides. More than 70% of type B landslides occurred on convex slopes.

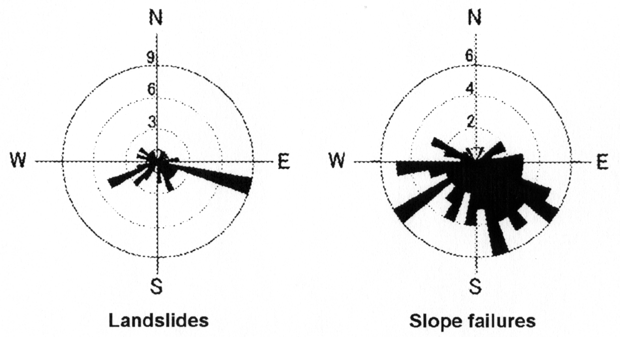

Fig. 9. Slope orientation at landslide and slope failure sites

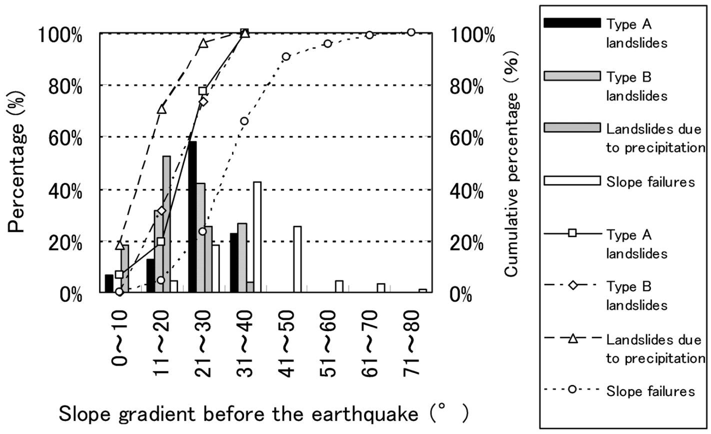

Fig. 10. Slope gradient at landslide and slope failure sites

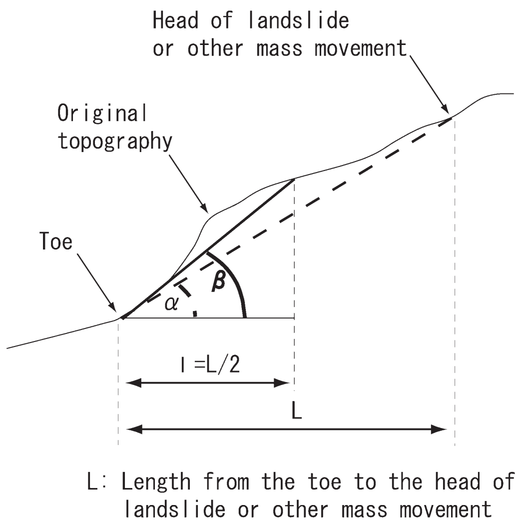

Fig. 11. Gradients for classifying slope shape (α, β)

Numerous earthquake-induced landslides occur on slopes with a convex slope at their toe. Slope failures frequently occurred on slopes with a gradient of 30 to 50 degrees at the toe (β in Fig. 11), and landslides frequently occurred on slopes with a gradient of 10 to 40 degrees at the toe.

Landslide behavior during the earthquake

(1) Ground displacement

Field investigations were being conducted during the earthquake on landslides in eleven areas that

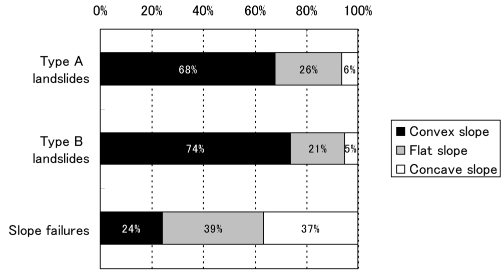

Fig. 12. Slop shape at landslide and slope failure sites

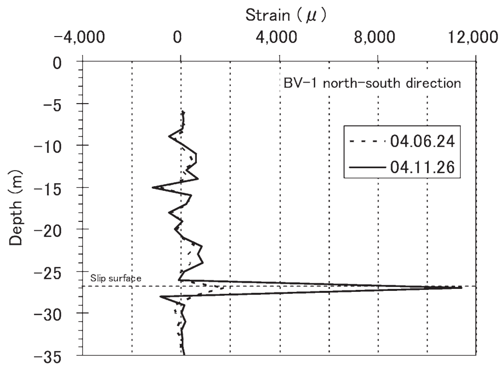

Fig. 13. Reading of pipe strain gages in the Futatsuya (BV-1)

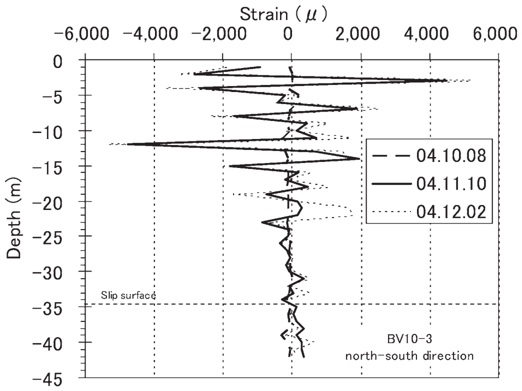

Fig. 14. Reading of pipe strain gages in the Raidenyamanaka (BV 10-3)

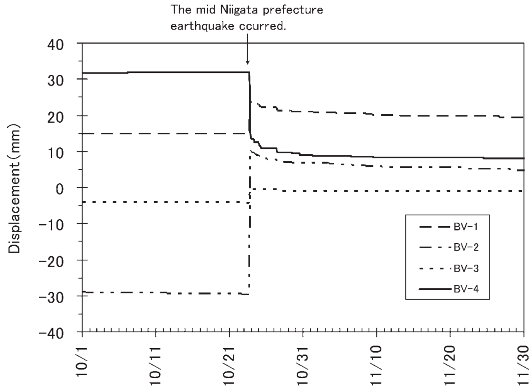

Fig. 15. Reading of vertical extensometer in the Futatsuya

were affected by ground shaking with a seismic intensity of six or higher (Fig. 1). Variations in readings of instruments are listed in Table. 1. In most areas, readings of pipe strain gages increased after the earthquake. Readings of all pipe strain gages exceeded 1,000μ (A or B in Table. 1) in six areas, Kawamukai, Kanaya, Raidenyamanaka, Futatsuya, Futago and Shinsui. In the Futatsuya area, strain varied near the designated slip surface before and after the earthquake (Fig. 13). Variations were also found near the slip surface designated before the earthquake in Kawamukai, Kanaya, Raidenyamanaka and Nakajo. Variations in readings were found at numerous depths above the designated slip surface in the Raidenyamanaka area (Fig. 14). Observations using pipe strain gages revealed that (1) shear displacements occurred at certain depths and that (2) variations in readings were found at numerous depths.

In the Futatsuya area, variations were found in readings of all pipe strain gages on the designated slip surface. Variations of more than 2 mm were also detected in vertical extensometer readings. There was a high possibility of the occurrence of landslides. Variations were, however, found only during the earthquake and ranged from 5 to 40 mm (Fig. 15). Geology near the slip surface is generally composed of soft clay. Temporary variations may have occurred due to seismic ground motions because the soil near the slip surface was weak. The field observation results suggest that seismic ground motions may have temporarily caused variations in readings of instruments in the landslide areas.

The results of observations before the earthquake show cumulative variations ascribable to landslides in readings of a pipe strain gages (BV11. 2) and multi-layer movement meter (BV14-2) in the Yanagihara, and a pipe strain gages (BV12-2) in the Nakajo area. Variations during the earthquake were, however, small, at 250 to 300μ, in these areas. Readings of a multi-layer movement meter in the Yanagihara area did not increase rapidly during the earthquake (Fig. 16), unlike in the Futatsuya (Fig. 15). In the Yanagihara and Nakajo,

Table 1. Variations in observation results in 11 areas

Landslide area	Municipality	Seismic intensity	Instrument	No.	Variation during the earthquake*1	Locations where variations were found*2: On the designated slip surface	Locations where variations were found*2: Above the designated slip surface	Locations where variations were found*2: Below the designated slip surface	Variation before or after the earthquake*2: Variation before the earthquake	Variation before or after the earthquake*2: Variation after the earthquake
Kawamukai	Tochio City	6 minus	Pipe strain gauge	BV13-1	A		+			
			Pipe strain gauge	BV15-3	A	+	+			
			Pipe strain gauge	BV15-5	A	+	+	+		
Kanaya	Tochio City	6 minus	Pipe strain gauge	BV12-1	A			+		+
			Pipe strain gauge	BV12-3	A	+				
			Pipe strain gauge	BV12-5	B	+	+			+
			Pipe strain gauge	BV12-9	A	+	+			+
			Pipe strain gauge	BV12-14	B	+	+			+
			Extensometer	S-1	A					
			Extensometer	S-2	A					
			Extensometer	S-3	A					
Raidenyamanaka	Tochio City	6 minus	Pipe strain gauge	BV10-2	B	+				
			Pipe strain gauge	BV10-3	A		+			+
			Pipe strain gauge	BV15-2	A		+			
Araya	Kawaguchi Town	7	Vertical extensometer	BV15-3	A					
Yanagihawa	Joetsu City	6 minus	Pipe strain gauge	BV11-2	C			+	+	+
			Multi-layer movement meter	BV14-2	D	+			+	+
Futatsuya	Toka Town	6 minus	Pipe strain gauge	BV-1	A	+				
			Pipe strain gauge	BV-3	B	+				
			Pipe strain gauge	BV-4	A	+	+	+		
			Vertical extensometer	BV-1	A					?
			Vertical extensometer	BV-2	A					?
			Vertical extensometer	BV-3	B					?
			Vertical extensometer	BV-4	A					?
Futago	Toka Town	6 minus	Pipe strain gauge	BV7-4	A		+			+
			Pipe strain gauge	BV7-6	A		+			
Shinsui	Toka Town	6 minus	Pipe strain gauge	H7-1	A		+			
			Pipe strain gauge	H7-3	A		+			+
Nakajo	Toka Town	6 minus	Pipe strain gauge	BV12-2	C	+	+		+	+
			Pipe strain gauge	BV12-3	B	+				
			Pipe strain gauge	BV12-4	A	+		+		
Nonaka	Toka Town	6 minus	Pipe strain gauge	BV1-3	B		+	+		
			Pipe strain gauge	BV7-1	D					
			Pipe strain gauge	BV7-2	C			+		
			Pipe strain gauge	BV12-1	B	+	+			
Jigokusawa	Toka Town	6 minus	Multi-layer movement meter	BV8-2	A					
			Multi-layer movement meter	BV9-2	A					

*1 Pipe strain gauge reading:
A: 5,000 μ or higher
B: 1,000 to 4,999 μ
C: 100 to 999 μ
D: 0 to 99 μ
E: Unusual value

Extensometer, Vertical extensometer, Multi-layer movement meterreadings:
A : 10mm or longer
B : 2 to 9.9mm
C : 0.1 to 1.9mm
D : 0m
E : Unusual value

*2 +: Variation was found
? :Unknown

cumulative variations were found even after the earthquake. Landslides may have been continuing without any effects of seismic ground motions.

Apart from the Yanagihara and Nakajo, variations were found in pipe strain gages after the earthquake in some observation wells in the Kanaya, Raidenyamanaka, Futago and Shinsui areas. No variations were, however, found on designates slip surface in any of these areas after the earthquake. Variations were found only in some, not all, of the observation well in these areas after the earthquake. Thus, no cases were found in the period from the end of the earthquake to December of the same year where sliding started throughout a landslide area.

No explicit correlation has been recognized between the availability of protection at the time of the earthquake and displacement. In the future, detailed investigations should be made on soil and geological characteristics in locations where variations were found in pipe strain gages readings, and the effects of ground motions on landslides should be analyzed.

(2) Groundwater level

Groundwater levels before and after the earthquake were available in five areas, Kawamukai, Araya, Yanagihara, Futatsuya and Futago. Water levels in boreholes generally rose during the earthquake. In the Futatsuya area, a rise of 8.26 m was observed in BV-1 (Fig. 17). A 4.5m rise of groundwater level was observed in the Kawamukai area. Conceivable causes of rapid rise of groundwater level after the earthquake include excess pore water pressure and appearance of cracks serving as water passages. Groundwater levels that rose or lowered in boreholes either returned to the original levels or lowered further. The causes of variations have not yet been identified.

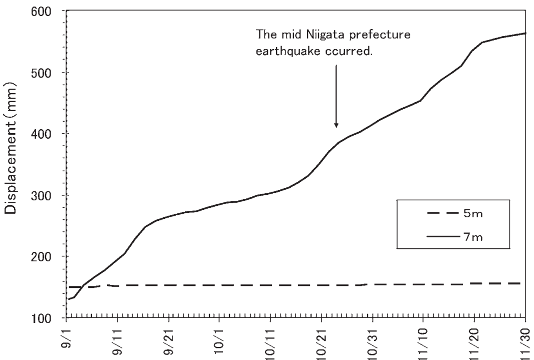

Fig. 16. Reading of multi-layer movement meter in the Yanagihara

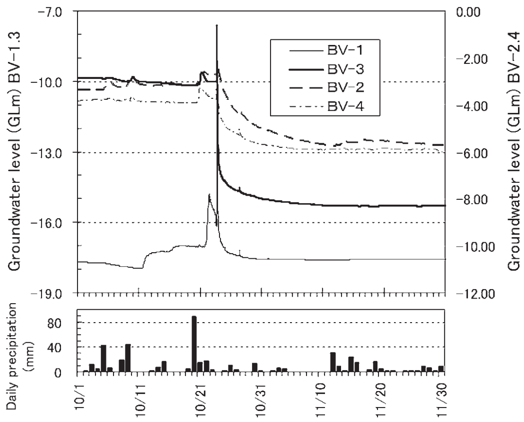

Fig. 17. Groundwater level in the Futatsuya

Conclusions

The relationship of characteristics of seismic ground motion and topographic and geological characteristics at landslide and slope failure sites to landslides and slope failures was analyzed. The findings are described below.

1) Landslides and slope failures occurred in areas where a seismic intensity of 6 or higher was recorded. Numerous mass movements were distributed in areas where a seismic intensity of more than 6 plus was recorded in particular.

2) Locations of landslide and slope failure sites were related more to the maximum vertical acceleration than to the maximum horizontal acceleration.

3) Many of types A and B landslides occurred on convex slopes.

4) Local or temporary mass movements due to seismic ground motions were observed at landslide sites with a history of sliding. No cases were found in the period from the end of the earthquake to December of the same year where sliding started throughout the landslide area.

5) At landslide sites in two areas where sliding started before the earthquake, cumulative movements were found after the occurrence of the earthquake. Sliding was assumed to have been continuing without any effects of ground motions.

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