Effects of Existing Prevention Works on Earthquake-Induced Landslides

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Abstract

We investigated the effects of existing drainage work on earthquake-induced landslides, in the areas of seismic intensity larger than 5-plus of the Mid Niigata prefecture Earthquake in 2004, the Niigataken Chuetsu-oki Earthquake in 2007 and the Iwate-Miyagi Nairiku Earthquake in 2008. The results showed that earthquake-induced landslides on the areas where countermeasures had been conducted were located within 12 km from the epicenter and 10 km from the source fault. Moreover, results revealed lowering of the groundwater level was less than 1.8 m after control works.

Keywords

Earthquake · Landslide · Landslide prevention works · Groundwater drainage works

1 Introduction

Many landslides have been reported in inland reverse fault earthquakes with a seismic intensity of 5-plus or higher which have occurred mostly in the eastern part of Japan in recent years, such as the Mid Niigata prefecture Earthquake in 2004 and the Iwate-Miyagi Nairiku Earthquake in 2008 (The Japan Landslide Society established a Special Research Committee of the Mid-Niigata Earthquake-induced Landslides 2007; Hasi Bateer et al. 2009; Geographical Survey Institute 2009). More earthquakes with a high seismic intensity are expected to occur according to a report (The Headquarters for Earthquake Research Promotion 2009; The Headquarters for Earthquake

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Research Promotion 2010) from the Earthquake Research Committee of the Headquarters for Earthquake Research Promotion, and it is feared that such earthquakes will trigger landslides.

Meanwhile, investigations were conducted after the Southern Hyogo prefecture earthquake in 1995 to examine the earthquake resistance of landslide prevention works (Ministry of Construction River Bureau Sabo (Erosion and Sediment Control) Department Slope Conservation Division 1996). The investigations found that the landslide prevention works retained their function even after the earthquake, and that facility designs which were not based on earthquake resistance could withstand earthquakes. Also, Ikeda et al. (Ikeda Nobutosi et al. 2006) investigated the effects of earthquakes on landslide prevention works after the Mid Niigata prefecture Earthquake in 2004. They reported that visible movements, such as cracks, were rarely found at slopes where landslide prevention works had been in place. At areas where landslide movement was observed, they were mostly small.

Yet, the effects of seismic motion on landslide slopes where landslide prevention works are installed are not necessarily clear. For example, slope movements is not usually observed at areas where landslide prevention works are in place. Also, there have been no studies that evaluated the relationship between earthquake-induced landslides and factors such as the lowering of groundwater levels caused by landslide prevention works at landslide blocks where countermeasures are in place (hereinafter referred to as "landslide blocks on which countermeasures have been conducted") and safety factors after countermeasures are taken. Therefore, for the purpose of clarifying how seismic motions affect landslide blocks with countermeasures, this study investigated the lowering of ground water levels before and after the installation of landslide prevention works, and examined the relationship between these aspects and landslide conditions. This study covered the Mid Niigata prefecture Earthquake in 2004 (hereinafter "the Mid Niigata Earthquake"), the Niigataken Chuetsu-oki Earthquake in 2007 ("the Chuetsu-offshore earthquake"), and the Iwate-Miyagi Nairiku Earthquake in 2008 ("the Iwate-Miyagi Nairiku Earthquake").

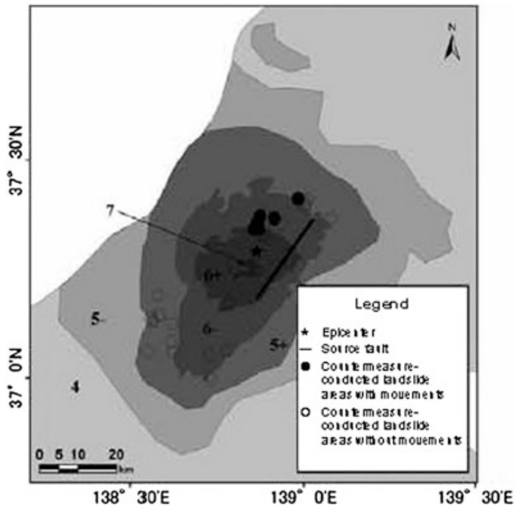


Fig. 9.1 Estimated seismic intensity distribution of the chuetsu earthquake modified from JMA 2004(Japan Meteorological Agency 2004)

Part of this report was presented at the 49th conference of the Japan Landslide Society (Nakamura Akira et al. 2010).

2 Investigation Methods

The study was conducted targeting the Mid Niigata Earthquake (M 6.8), the Chuetsu-oki Earthquake (M 6.8), and the Iwate-Miyagi Nairiku Earthquake (M 7.2). Figures 9.1 9.2, 9.3 show the distribution of the estimated seismic intensities of these earthquakes. Figures 9.1, 9.2, 9.3 separately show landslide prevention zones with countermeasures are conducted. Figures 9.1, 9.2, 9.3 indicate that landslides occurred at areas where the seismic intensity was higher than 5-plus during reverse fault earthquakes of about M 7.0 (Hasi Bateer et al. 2011). Therefore, the range of investigation was set at areas where the seismic intensity was larger than 5-plus as shown in Figs. 9.1 9.2, 9.3. The investigations were then conducted targeting landslide blocks with no by countermeasures.

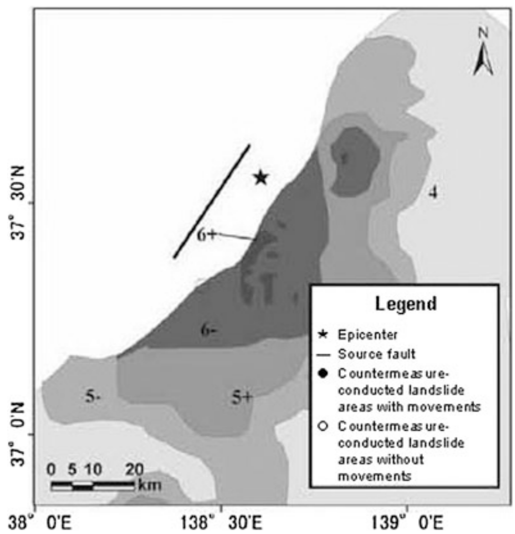


Fig. 9.2 Estimated seismic intensity distribution of the chuetsu—offshore earthquake modified from JMA 2007(Japan Meteorological Agency 2007)

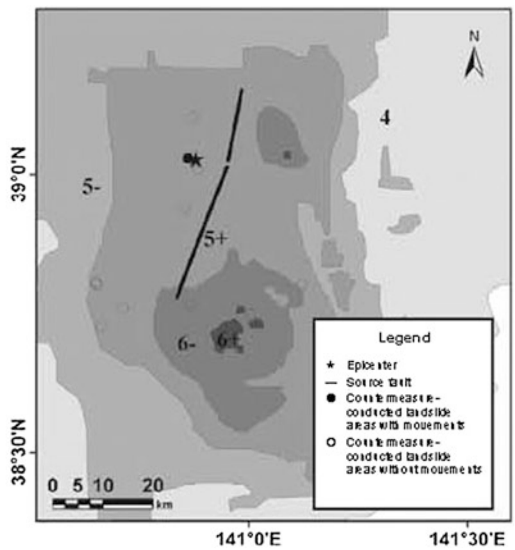


Fig. 9.3 Estimated seismic intensity distribution of the Iwate/Miyagi—inland earthquake modified from JMA 2008(Japan Meteorological Agency 2008)

The earthquake-induced landslide blocks were categorized by landslide damage investigation reports (Snow Avalanche and Landslide Research Center, PWRI 2009; Snow Avalanche and Landslide Research Center, PWRI 2010; Hokubu Engineering Works Office Kurihara Area Office, Miyagi Prefecture 2009). The construction methods of landslide prevention works and the conditions of movements were also investigated and their relationships were examined.

Baator, et al. (2010) (Hasi Bateer et al. 2011) studied the distributions of earthquake-induced landslides in the Mid Niigata Earthquake and the Iwate-Miyagi Nairiku Earthquake and the relationship with the distances from epicenters or sources of faults. He indicated a high correlation between areas with many earthquake-induced landslides and distances from source faults. Therefore, this study also examined the relationship between distances from epicenters and source faults and movements in landslides.

In addition, this study examined the groundwater levels before and after installing landslide prevention works using documents such as landslide damage investigation reports (Snow Avalanche and Landslide Research Center, PWRI 2009; Snow Avalanche and Landslide Research Center, PWRI 2010; Hokubu Engineering Works Office Kurihara Area Office, Miyagi Prefecture 2009) and studied relationships with the investigated damages.

3 Investigation Outcomes

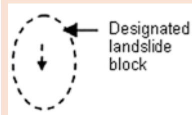
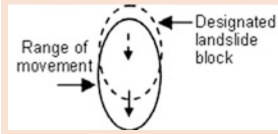
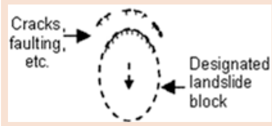
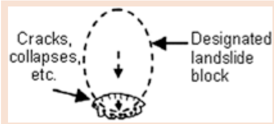
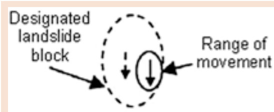
3.1 Conditions of Earthquake-Induced Movements

As shown in Table 9.1, there were 388 landslide blocks with countermeasures in the investigation area. Earthquake-induced landslides examined in this study are those where cracks, faulting, or collapse were observed in surveys(Snow Avalanche and Landslide Research Center, PWRI 2009; Snow Avalanche and Landslide Research Center, PWRI 2010; Hokubu Engineering Works Office Kurihara Area Office, Miyagi Prefecture 2009) conducted after the earthquakes. Small-scale collapses which the widths and lengths were up to about three meters were regarded as no movement.

Table 9.1 Number of landslide blocks in each earthquake

Name of Earthquake	(1) Number of studied blocks where counter measures were conducted	Number of blocks where movements were observed among (1)
The Chuetsu earthquake	300	15
The Chuetsu-offshore earthquake	9	0
The Iwate Miyagi inland earthquake	79	2
Total	388	17

Table 9.2 Number of landslide blocks in each earthquake

No movement	
Full movement	
Movement in upper parts	
Movement in lower parts	
Partial movement	

Among the three earthquakes covered in this study, there was overlap of some parts of the investigation areas of the Mid Niigata Earthquake and the Chuetsu-oki Earthquake. The study targeted earthquakes in which the distance to the epicenter was shorter in blocks where overlapping zones were located.

Among all 388 blocks, movements were observed at 17 blocks (hereinafter "blocks with movements"), and the incident rate was about 4 % (Table 9.1). The study covered 300 blocks at the site of the Mid Niigata Earthquake, and 15 of them were blocks with movements. At the site of the Chuetsu-oki Earthquake, the study covered nine blocks, and there were no blocks with movements. The study covered 79 blocks at the site of the Iwate-Miyagi Nairiku Earthquake, and two of them were blocks with movements. Yet, there is the possibility that earthquake-induced movements may vary depending on precipitation before the earthquake and conditions of groundwater during the earthquake, but this study was conducted without taking these aspects into account.

3.2 Categories of Movements

As shown in Table 9.2, blocks with movements are categorized into four types: full movement; movement in upper parts; movement in lower parts; and partial movement. "Full movement" means that movements or collapses were observed at most of the landslide blocks designated before the earthquake as shown in Fig. 9.4. "Full movement" is the category where landslide stability fell during the earthquake and triggered a relatively large movement. "Movement in the upper part" is the category where earthquake-induced movements such as cracks were

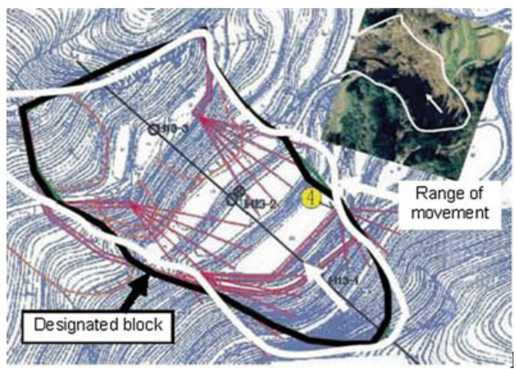


Fig. 9.4 Example of movement in whole lanslide

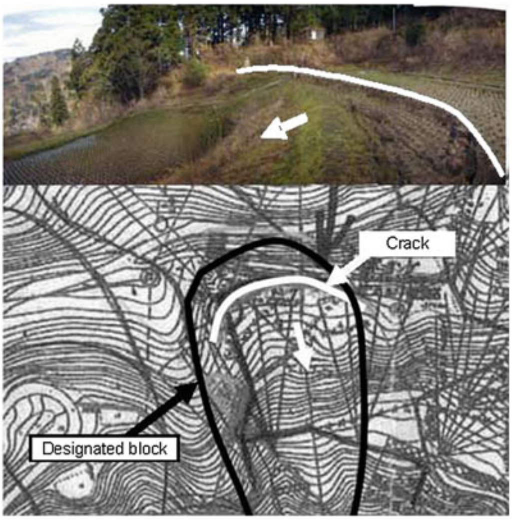


Fig. 9.5 Example of movement in upper parts

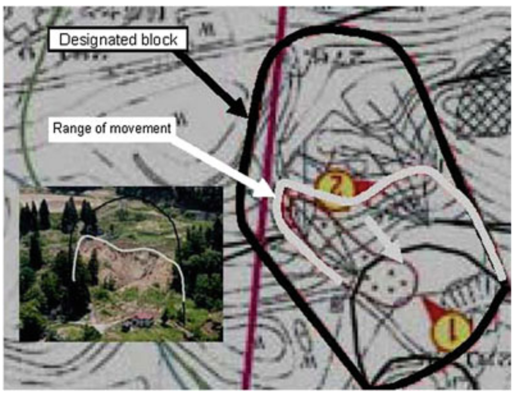


Fig. 9.6 Example of movement in lower parts

observed only at the upper parts of blocks designated before the earthquake, and new, continuous cracks and faulting were observed at an upper slope near blocks designated before the earthquake as shown in Fig. 9.5. "Movement in upper parts" means there is the possibility that the stability of a landslide fell during the earthquake and triggered a relatively small movement. As shown in Fig. 9.6, "movement in lower parts" is the category in which a movement or a collapse which is about the same size as the width of the landslide occurred at the lower part of blocks designated before the earthquake. "Movement in lower parts" means that there is the possibility

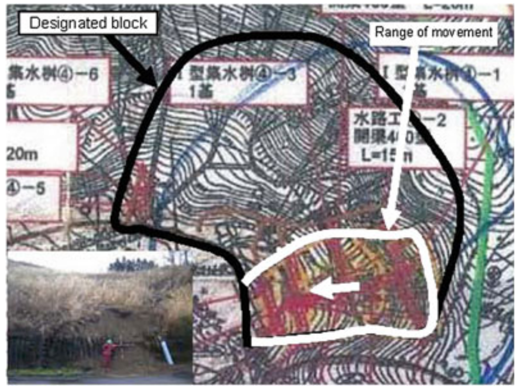


Fig. 9.7 Example of partial movement

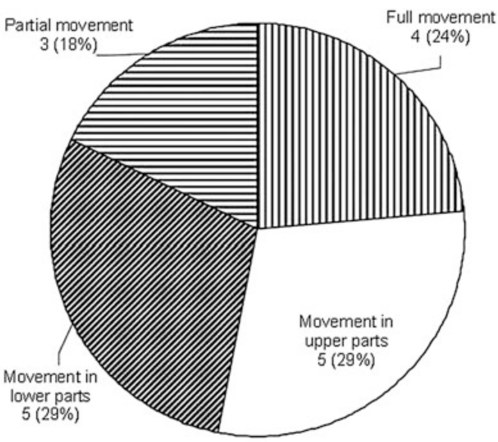
that a movement occurred by sharing some of the sliding surface of a landslide when the stability at lower parts of the landslide fell. As shown in Fig. 9.7, "partial movement" is the category where a movement might have occurred at some sections, such as the side of blocks designated before the earthquake, or movement might have occurred in unison with areas outside a designated block. "Partial movement" means there is the possibility that the stability of some part of a soil mass on a landslide or slopes around a block fell and triggered a movement.

3.3 Relationship Between Landslide Prevention Works and Movements

Multiple landslide prevention works were used together in the landslide blocks with countermeasures that were studied. Therefore, the relationship with landslide prevention works and movements was studied by categorizing landslide prevention works as shown in Table 9.3. For example, in blocks where horizontal boring and an infiltration well are in place, the infiltration well is considered the main facility of the block. Meanwhile, in blocks where an infiltration well and topsoil removal or counterweight fill are in place, the topsoil removal or the counterweight fill is considered the main facility. In blocks where prevention works and

Table 9.3 Classification of landslide prevention facilities

	Category of Preventive faciliities	Components of actual Preventive faciliities
Control Works	Horizontal boring	Horizontal boring
	Infilteration well	Infilteration well Infilteration wel + Horizontal boring
	Counter weight fill, soil removal	Counter weight fill soil removal Counter weight fill + Infilteration well soil removal + Infilteration well Counter weight fill + Infilteration well + soil removal soil removal + Infilteration well + Horizontal boring
Prevention Works	Pilling	Pilling Pilling + infilteration well Pilling + infilteration well + Horizontal boring
	Anchoring	Anchoring Anchoring + Infilteraion well Anchoring + Infilteraion well + Horizontal boring
	Other (channel, soil retaining)	Surface Channel Soil retaining wall,etc.



movement.”

Fig. 9.8 Status of occurence of moving areas

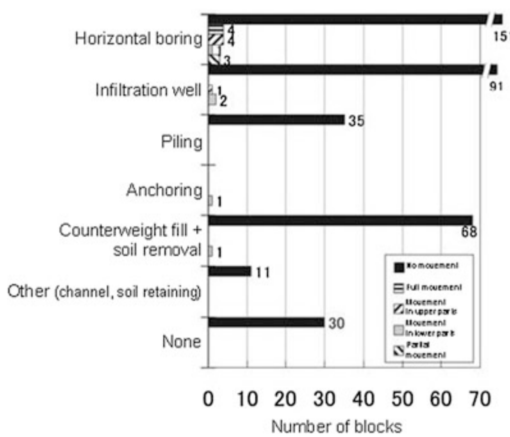


Fig. 9.9 Number of moving bloks in facilities

control works are in place, the restrain work is considered the main facility. The relationship between the construction types of landslide prevention works and movement categories were examined based on such categorization.

Categories shown in Table 9.2. There were five blocks each in “movement in upper parts” and “movement in lower parts,” accounting for 29 % of all the blocks, four blocks or 24 % in “full movement,” and three blocks or 18 % in “partial movement.”

Figure 9.8 shows the conditions of movements by type of facility for landslide prevention. According to Fig. 9.9, movements were observed at 12 of 163 blocks with horizontal boring, and the ratio of blocks where movement occurred with this construction type (hereinafter “movement ratio”) was 7 %. Movements were observed at three out of 94 blocks with infiltration wells, and the movement ratio was 3 %. Movements were observed at one block with a counterweight fill or soil removal and one block with anchoring. Yet, no movements were observed at blocks with piling or other construction works (ditches or sheathing).

The results of examining the relationship between landslide prevention works and movements as described above showed that earthquake-induced movements occurred at a slightly higher rate at blocks where only horizontal boring was in place compared to blocks with other construction methods.

We found that blocks with movements were mostly located within 12 km from the epicenters and about 10 km from the source faults.

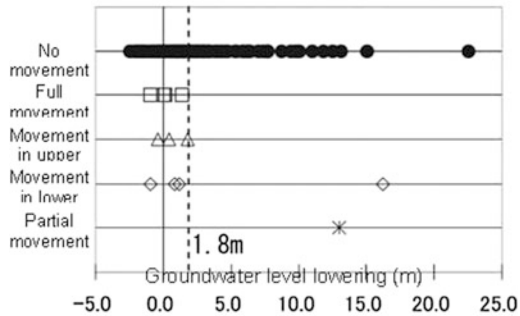


Fig. 9.10 Relationship between ground water lowering and type of moved area

3.4 Relationship Between the Groundwater Level Lowering and Movements

In terms of the lowering of the groundwater level caused by the existing landslide prevention works, the highest water levels before and after installing prevention facilities were studied based on the groundwater level observations(Snow Avalanche and Landslide Research Center, PWRI 2009; Snow Avalanche and Landslide Research Center, PWRI 2010; Tookamachi Promotion Bureau and Niigata Prefecture 2003; Osaki Engineering Works Office, Miyagi Prefecture 1997; Hokubu Engineering Works Office Kurihara Area Office, Miyagi Prefecture 2009; Miyagi Prefecture 1997) and the difference of the two levels was obtained. When multiple observation holes for groundwater levels are located within one study block, the lowest water level at each observation hole was obtained, and the average of all water levels was used as the value of groundwater level lowering.

Figure 9.10 shows the relationship between lowering value of the groundwater level and movement categories. The value of groundwater level lowering was 1.8 m or less at a total of ten blocks, including four blocks where "full movement" was observed, three blocks with "movement in upper parts," and three blocks with "movement in lower parts." Meanwhile, the groundwater level fell 10 m or more at one block with "movement in lower parts" and one block with "partial movement," while movements were also observed.

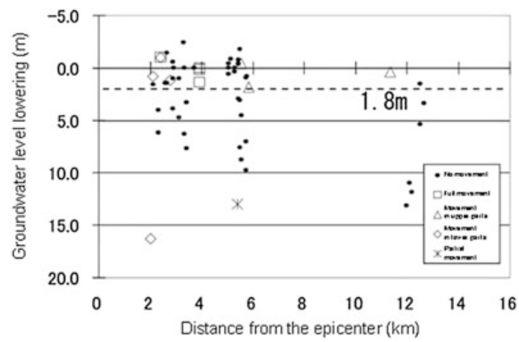


Fig. 9.11 Relationship between ground water lowering and distance from epicenter

Figure 9.11 shows the relationship between the lowering value of the groundwater level and the distance between epicenters and blocks. Figure 9.12 shows the relationship between the lowering of the groundwater level and the distance between source faults and blocks. Based on Figs. 9.11 and 9.12, no clear correlation between the lowering of the groundwater level and the distance between epicenters/source faults and blocks was found in blocks with movements. Two blocks in which 10 m or more of groundwater level lowering was recorded and which were categorized into "movement in lower parts" and "partial movement" were not especially close to epicenters and source faults compared to the other blocks.

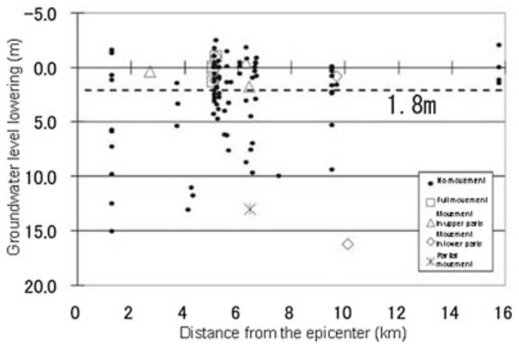


Fig. 9.12 Relationship between ground water lowering and distance from Source fault

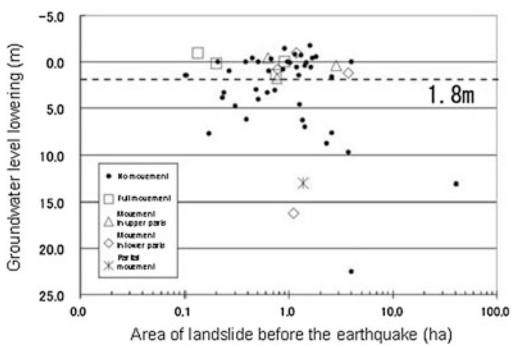


Fig. 9.13 Relationship between ground water lowering and landslide size

Even with the same degree of groundwater level lowering, levels of contribution toward stability improvement differ depending on the size of the landslide. Thus, the areas of the landslides are obtained to indicate the sizes by multiplying the landslide's length by its width, and their relationship with the lowering of the groundwater level. The results are shown in Fig. 9.13. Based on Fig. 9.13, no correlation between the lowering of the groundwater level and landslide size was found in blocks with movements. There is no clear difference between the sizes of the two blocks where 10 m or more of groundwater level lowering was recorded and which were categorized as "movement in lower parts" and "partial movement" and the sizes of other blocks with movements.

Groundwater observation holes were located on main traverse lines in two blocks where 10 m or more of groundwater level lowering was observed. The movement categories at these two blocks are "movement in lower parts" and "partial movement," and the cause of the movement might be partial instability. Examination of the plan views of these two blocks revealed that movements occurred away from locations where horizontal boring and infiltration wells had been installed. No groundwater observation holes are installed at areas where movements occurred, and the groundwater level conditions are unknown. Yet, it is possible that the effects of landslide prevention works on lowering groundwater levels were small at areas where movements occurred.

4 Summary

The study examined the relationship among the lowering of the groundwater, the safety factors of slopes, and the conditions of earthquake-induced movements, targeting landslide blocks with countermeasures at areas hit by earthquakes with a seismic intensity of 5-plus or higher which occurred during the Mid Niigata Earthquake, the Chuetsu-oki Earthquake, and the Iwate-Miyagi Nairiku Earthquake, which are earthquakes of about 7.0-magnitude. The study found the following.

(1) Landslide blocks with countermeasures where only horizontal boring is in place showed the trend that earthquake-induced movements occurred at a slightly higher frequency than with other construction types.
(2) Most of the values of groundwater level lowering at landslide blocks with countermeasures where earthquake-induced movements were observed were 1.8 m or less, except at two blocks.

The findings of this study are based on the analysis of limited cases; however, the study estimates that there are many landslides where no earthquake-induced movement occurs as long as the landslide prevention works function as initially designed, even when earthquakes with similar intensities occur at the studied areas. Also, the effects of seismic motion on landslide slopes with landslide prevention works can be further revealed if cases of earthquake-induced movements are accumulated in the future by continuously measuring groundwater levels and landslide displacement at slopes where landslide prevention works are installed.

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