Risk management for landslide disasters
– in the case of the Higashi-Yokoyama landslide, Japan –

Kazunori FUJISAWA[1], Joko OHARA[1], Fujihiro OKADA[2], Masami SHICHI[2],
Takao YOSHIDA[3], Youichiro HAGIWARA[3]

[1]Public Works Research Institute, Japan
1-6, Minamihara, Tsukuba City, Ibaraki Prefecture, 3058516, Japan
Email: fujisawa@pwri.go.jp
[2] Gifu Prefectural Ibi Civil Engineering Office
[3]Nippon Koei Co. Ltd

In recent years, the combination of natural phenomena such as localized severe rain and human intervention such as land development has greatly increased the risk of landslide. Damage to infrastructure such as roads and railways and the resulting disruption to transport networks can have a major impact on local communities and economies. Working to minimize the damage caused by landslides is therefore of paramount importance.

This report discusses landslide prevention and response strategies and risk management of landslide damage, based on the example of the May 2006 Higashi-Yokoyama landslide in Gifu prefecture (width 150 m, height 135 m). The Higashi-Yokohama landslide is one of only a few landslides to be captured on film. The report draws on the analysis of these images to describe the mechanisms of a landslide.

In the case of the Higashi-Yokoyama landslide, there were already measures in place designed to minimize the damage by a potential disaster of this kind. Landslide response procedures are dependent on accurate assessment of the probability of a landslide occurring and the associated warning period. To prevent landslides from causing damage, it is necessary to identify the most vulnerable locations and undertake continuous monitoring of sites where movement has been detected. Where roads and rivers are damaged by a landslide, the responsible government authorities need to set up information sharing structures to facilitate liaison with the authorities responsible for emergency response and repairs, and maintain a constant supply of information to local communities. Where emergency work is being carried out on ground that is considered unstable, ongoing landslide monitoring is necessary to ensure the safety of workers.

Analysis of images from the Higashi-Yokohama landslide indicates that the initial stage of the landslide involves disturbances such as falling rocks and ground collapse at the periphery, i.e., at the head and sides of the landslide and to some extent at the tail. It was also found that the major landslides were preceded by a higher frequency of falling rocks and ground collapse. This suggests that identifying the location and frequency of these phenomena at an early stage can provide a useful indicator of the expected timing and scale of the subsequent landslide.

Keywords: landslide, risk management, image analysis

Risk management for landslide disasters
– in the case of the Higashi-Yokoyama landslide, Japan –

Kazunori FUJISAWA[1], Joko OHARA[1], Fujihiro OKADA[2], Masami SHICHI[2],
Takao YOSHIDA[3], Youichiro HAGIWARA[3]

[1]Public Works Research Institute, Japan
1-6, Minamihara, Tsukuba City, Ibaraki Prefecture, 3058516, Japan
Email: fujisawa@pwri.go.jp
[2] Gifu Prefectural Ibi Civil Engineering Office
[3]Nippon Koei Co. Ltd

1. Introduction

Landslides can exert an enormous impact on local communities and economics by damaging key infrastructure such as roads and railways and causing major disruption to transport networks.

In recent years, the combination of natural phenomena such as localized severe rain and human intervention such as land development has greatly increased the risk of landslide. However it can be difficult to predict landslide risk probabilities in the absence of genuine evidence of disturbance such as slope collapse or cracking. It is therefore most important to develop strategies to minimize the damage caused by landslides, for instance, evacuation and road closure procedures, based on early detection of precursory disturbances and landslide movement.

This report discusses both preventative strategies and disaster response procedures for landslides, citing the example of the Higashi-Yokoyama landslide in May 2006. We will also consider risk management strategies for landslide disasters. The Higashi-Yokohama landslide is one of only a few landslides to be captured on film. The report draws on the analysis of these images to describe the mechanisms of a landslide.

2. Overview of the Higashi-Yokoyama landslide

The Higashi-Yokoyama landslide occurred on May 13, 2006 along the left bank of the Ibi river near the town of Ibigawa-cho in Gifu prefecture. Figure 1 shows the location of the landslide site, situated approximately two kilometers downstream of the Yokoyama Dam operated by the Ministry of Infrastructure, Land and Transport, and approximately 3.5 kilometers upstream of the Kuze Dam operated by the Chubu Electric Power Company. The landslide measured approximately 150 m in width by 135 m in height, with a volume of approximately 250,000 m^3 (see Picture 1).

Approximately 50,000 m^3 of debris was washed into the river during the landslide. As Picture 2 shows, this had the effect of blocking some two-thirds of the river across its width, and also causing damage to several local roads. Most of the moving body remained on the affected slope.

The site of the landslide is a steep slope alongside the Ibi river of height 135 – 270 m and average inclination 35°. The ground is composed chiefly of clay slate in a Mino zone from Permian period Mesozoic and Paleozoic strata, in a reverse-dip slope. The head and tail of the landslide showed evidence of severe weathering. A crush zone with reverse-dip slope was identified in the loose region around the tail.

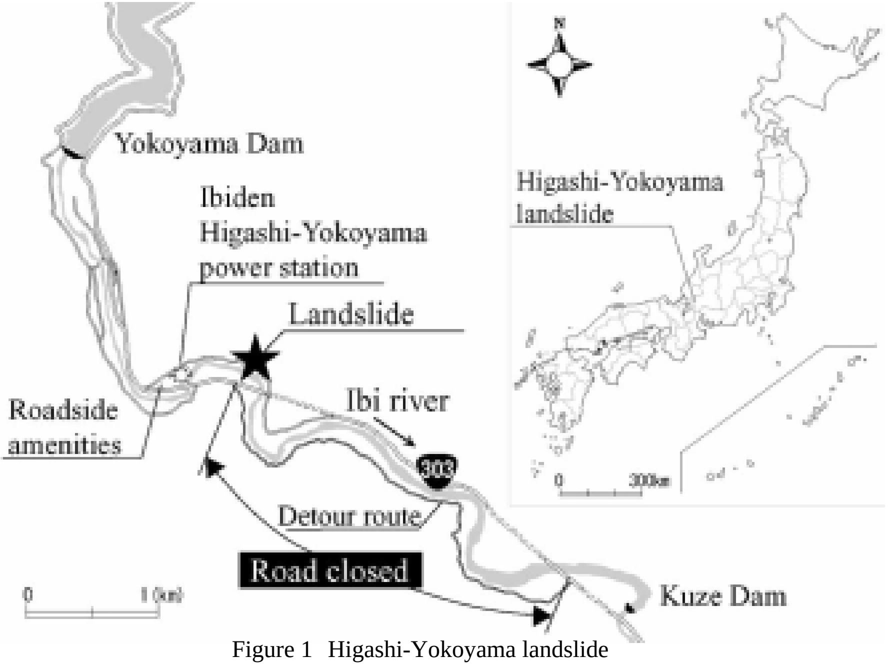


Figure 1 Higashi-Yokoyama landslide

Picture 1 General view of landslide site (May 14, 2006)

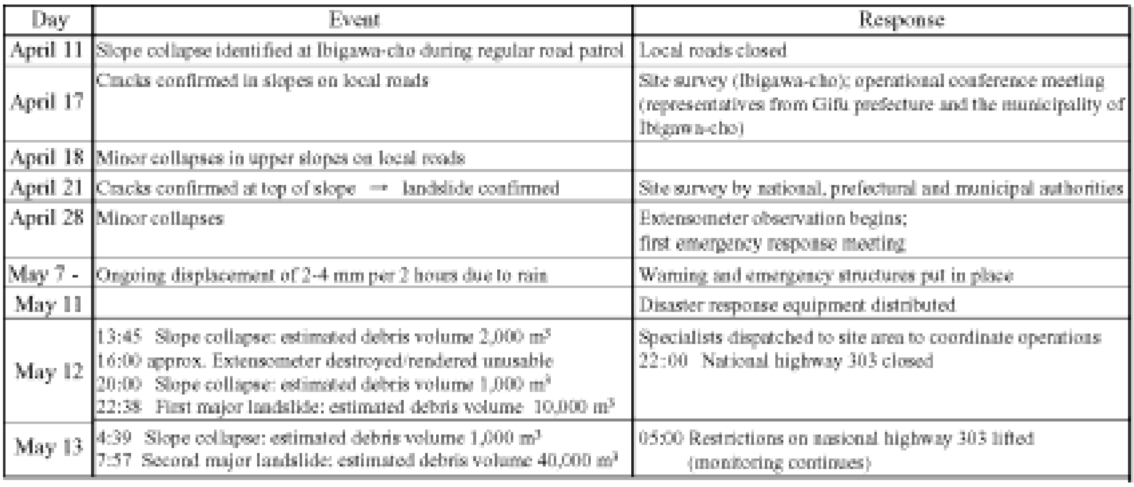
Picture 2 Rock deposits in river course at tail of landslide (May 14, 2006)

3. Damage minimization strategies

3.1 Prior history

Table 1 presents a timetable of events leading up to the landslide.

A roadway slope collapse was discovered on April 11. A site survey of the slope area on April 21 found the main scarp and concluded that the roadway slope collapse and cracking had occurred in conjunction with the landslide. A ground extensometer was then installed at the landslide head to record subsequent displacement. From May 10, the observed displacement began increasing significantly (in excess of 4 mm per two hours) due to the effects of rainfall, and 24-hour landslide monitoring was instigated. On May 12, the risk of a major landslide was adjudged to have risen markedly, based on the extensometer data and local conditions, and national highway 303 was temporarily closed between 10:00 pm on May 12 and 5:00 am on May 13. Several slope collapses occurred during this period, followed by a major landslide at 7:57 am on May 13.



Day	Event	Response
April 11	Slope collapse identified at Ibigawa-cho during regular road patrol	Local roads closed
April 17	Cracks confirmed in slopes on local roads	Site survey (Ibigawa-cho); operational conference meeting (representatives from Gifu prefecture and the municipality of Ibigawa-cho)
April 18	Minor collapses in upper slopes on local roads	
April 21	Cracks confirmed at top of slope → landslide confirmed	Site survey by national, prefectural and municipal authorities
April 28	Minor collapses	Extensometer observation begins; first emergency response meeting
May 7 -	Ongoing displacement of 2-4 mm per 2 hours due to rain	Warning and emergency structures put in place
May 11		Disaster response equipment distributed
May 12	13:45 Slope collapse: estimated debris volume 2,000 m^3 16:00 approx. Extensometer destroyed/rendered unusable 20:00 Slope collapse: estimated debris volume 1,000 m^3 22:38 First major landslide: estimated debris volume 10,000 m^3	Specialists dispatched to site area to coordinate operations 22:00 National highway 303 closed
May 13	4:39 Slope collapse: estimated debris volume 1,000 m^3 7:57 Second major landslide: estimated debris volume 40,000 m^3	05:00 Restrictions on nasional highway 303 lifted (monitoring continues)

Table 1 Timetable of events leading up to the landslide

3.2 Precautionary measures

A site survey of the slope following the roadway slope collapse on April 11 delivered confirmation of the landslide, enabling formulation of an appropriate response tailored to the extent of the landslide. After the main scarp on the slope was confirmed on April 21, an extensometer was installed in the ground and displacement monitoring began on April 28 (see Figure 2). Analysis of observation data for May 11 using the Saito method predicted a landslide at some point after 20:00 on May 12.

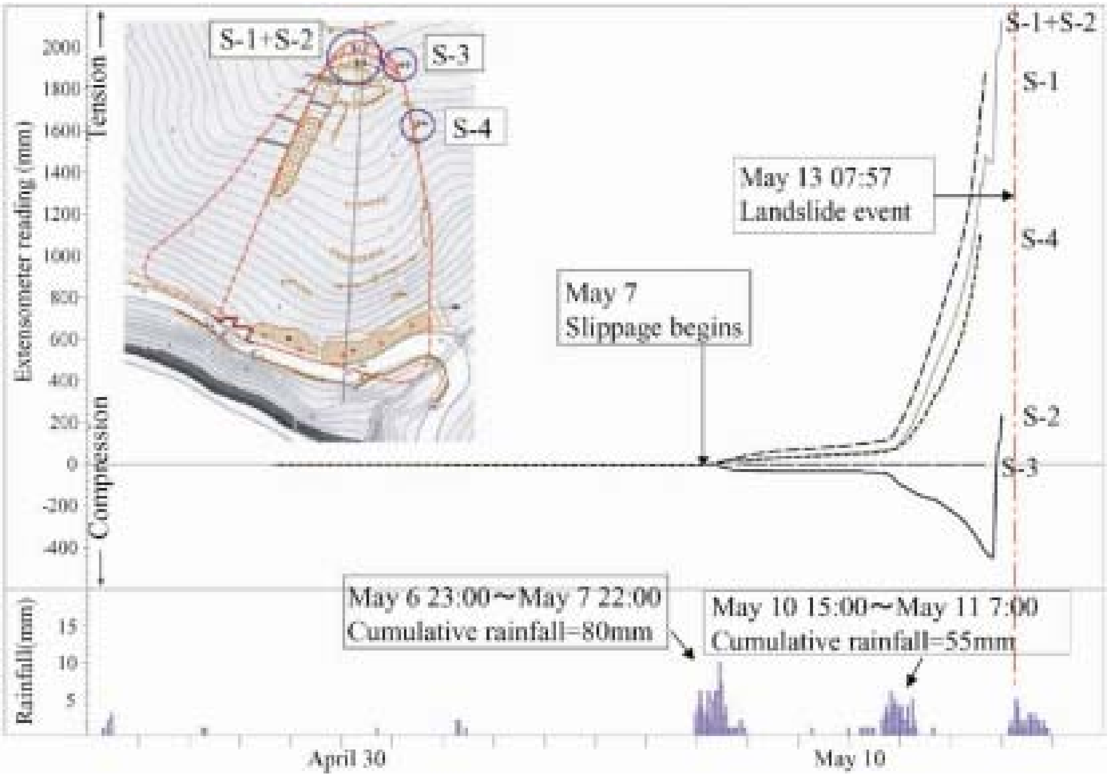


Figure 2 Extensometer observations

If the entire moving body were to fall in a landslide, the Ibi river could be completely blocked with the debris potentially reaching the roadway on the opposite bank. This would impact on the two dams located upstream and downstream of the affected region, as well as the roadside amenities area and local fishing operators. It was considered most important that these interests be kept up to date with information on the progress of the landslide.

To this end, the local civil works office convened an initial meeting on April 28 to bring together representatives of the fishing co-op, the power company and power stations, the police and fire services, and relevant government agencies (see Picture 3). The meeting resolved to set up a liaison structure to maintain the flow of information, and also delegated responsibilities among the various parties, including closure of roads, walking trails and river access, and notification to residents.

Further meetings were held, and every effort was made to keep local communities informed via press conferences and regular postings on the websites of the relevant government departments. A monitoring and response regime consisting of levels 1 through 3 was set up based on the extensometer readings.

Picture 3 Meeting of interested parties

A section of national highway approximately 2.9 km in length was closed to traffic from 22:00 on May 12 to 05:00 on May 13. Every effort was made to publicize the road closure. The police, fire services, dam construction office, and prefectural and municipal authorities were all notified directly. Barricades and signage were erected on national highway 303 and personnel were stationed at key points to redirect traffic. It was fortunate that there was a detour route nearby which is suitable for small vehicles, and also that the road closure was at night only, which minimized the impact on local communities.

3.3 After the landslide

Although the landslide on May 13 blocked the Ibi river approximately two-thirds of the way across, the majority of the moving body remained up on the slope in an unstable condition. The debris which fell into the river was thought to be holding up (and therefore stabilizing) the remaining moving body on the slope. In order to prevent the effect of river erosion from washing away this debris and destabilizing the remaining moving body, it was decided to widen the river course opposite the affected slope, and also to install 1,000 foundation blocks at the tail of the landslide (see Picture 4). This work was conducted around the clock on a 24-hour shift system to ensure completion prior to the rainy season, when the rate of erosion would increase due to the higher water level in the river.

Boring work was carried out on the moving body, together with emergency earth removal at the head of the moving body. Given that the slope had a gradient of around 40° it was considered unstable and too dangerous for workers to enter the affected area, so the debris removal work was conducted using remote-controlled backhoes and other machinery as shown in Picture 5.

Non-prism optical theodolite was used to measure movement of the slope. Supervisors stationed at the site also confirmed safety levels during operations.

Picture 4 River widening on the opposite bank of the river

Picture 5 Emergency earth removal using remote-controlled machinery

4. Analysis of landslide images

Images of the landslide captured by a monitoring camera were used to analyze the landslide in order improve our understanding of the mechanisms involved and develop countermeasures for the future. The analysis looked in particular at the phenomena involved in landslide movement, the sequence of slope movement events associated with landslide, and the speed of movement.

4.1 Methodology

Some 22 hours' worth of images from the period 12:00 on May 12 to 10:00 on May 13 were subjected to analysis. Based on the analysis results and topographical maps, the volume of debris was estimated to be quite large (in excess of 1,000 m^3). A sketch map of the collapse was produced, along with a summary of the events leading up to the landslide on the basis of the number of incidents of falling rocks, ground collapse and fallen trees. For the purpose of this study, ground collapse was defined as an earth movement where the images indicated a topographical change, while an earth movement with no topographical change was defined as falling rocks.

4.2 Analysis results

The analysis of images before and after the landslide indicated that the ground collapse involved an debris in excess of 1,000 m^3, and that six separate landslide events occurred. Figure 3 shows sketches for each landslide event, numbered 1 through 6. Based on analysis of the images, the sequence of events leading to the landslide is thought to be as follows:

1) Ground collapse confirmed on slope next to road on mountain on April 11. Major crack identified at top of slope on April 21. Ground collapse of approx. 2,000 m^3 (Collapse 1 in Figure 3) occurs in the vicinity of the downstream extension of the crack at 13:38 on May 12.

2) Several minor falling rock events occur in the region of Collapse 1 and a further ground collapse on April 11. Second ground collapse of around 1,000 m^3 (No. 2 in Figure 3) occurs at 20:02 on May 12 a short distance upstream of Collapse 1.

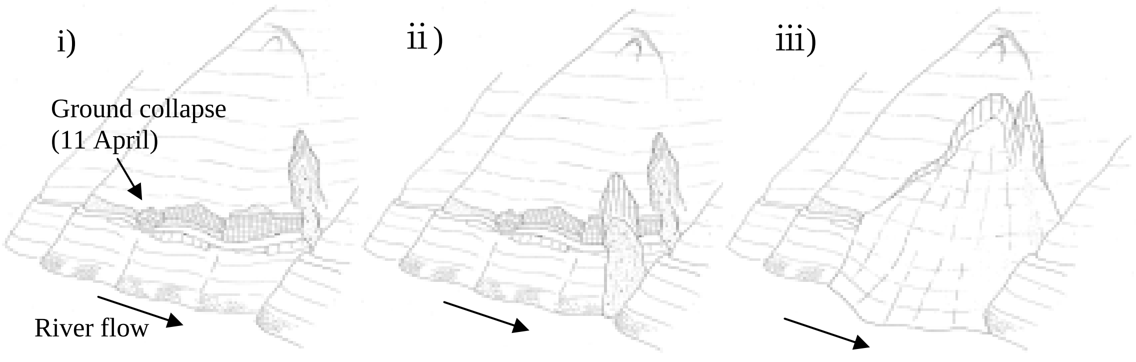
3) A steady succession of falling rock and ground collapse events begins at 22:23 on May 12, in the vicinity of Collapses 1 and 2, leading to a major ground collapse of approximately 10,000 m^3 at 22:40 (No. 3 in Figure 3).

4) After a brief hiatus following Collapse 3, the next major ground collapse (No. 4 in Figure 3, estimated at 1,000 m^3) occurred at 03:06 on May 13 in the vicinity of the slope tail on the upstream side. Due to the camera angle and poor visibility at night, the images provide only limited detail, although evidence of localized tree shaking suggests that the crack at the head of the landslide was beginning to extend towards the upstream side of the slope at this point.

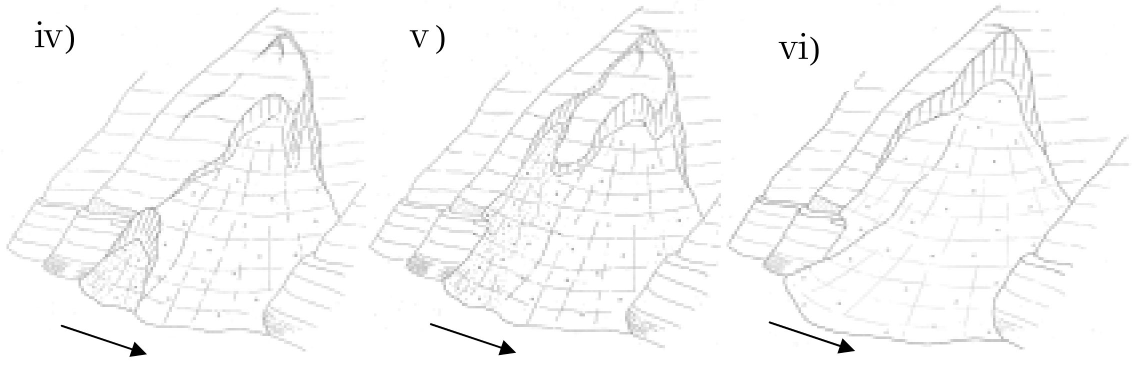
5) A further ground collapse (No. 5 in Figure 3, 1,000 m^3) occurred at 04:44 on May 13 on the slope further up the slope from Collapse 4.

6) Falling rock and ground collapse events began at approximately 07:40 on May 13 on the middle and lower section of the slope and became more frequent, culminating in a major slope collapse (number 6 in Figure 3, 40,000 m^3) at 07:59. This was followed by more falling rocks and minor collapses, but without any further significant topographical deformation. The slope today is thus in much the same state as it was after Collapse 6.

Thus, the sequence of events leading up to the landslide began with collapses at the periphery of the landslide area (from the head to the sides and tail), where the effect of stress caused by slippage is most apparent, followed by an increasing incidence of falling rocks and minor collapses in the area.



Collapse 1（13:38,12,May）　Collapse 2 (20:02,12,May)）　Collapse 3 (22:40,12,May)



Collapse 4 (03:06,13,May)　Collapse 5 (04:44,13,May)　Collapse 6 (07:59,13.May)

Figure 3 History of collapses

Figure 4 shows the count of falling rock events, ground collapses and fallen trees. Prior to the six major collapses, the frequency of these events steadily increased. The rate of increase was particularly pronounced prior to the two largest collapses (numbers 3 and 6).

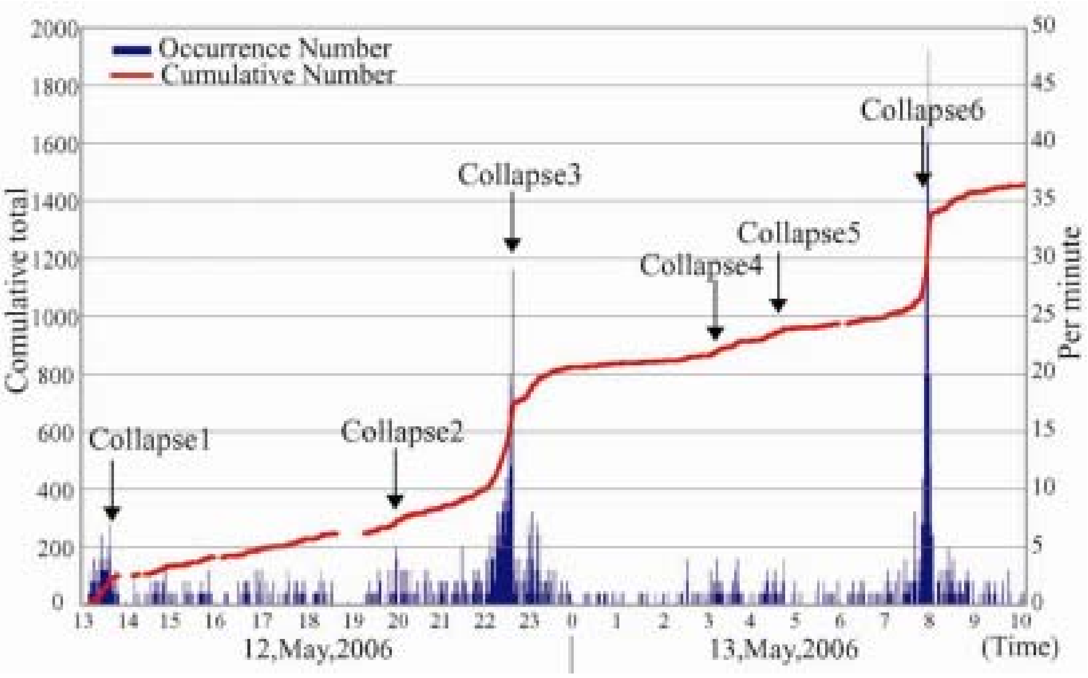


Figure 4 Other events — falling rocks, ground collapses and fallen trees

4. Risk management of landslide damage

Landslides have a definite life cycle, from the emergence of danger through to its subsequent containment. As Figure 5 shows, the life cycle begins with a period of dormancy, before the landslide activity becomes evident on the surface. Next is the warning period, when visible activity begins to appear and the level of damage steadily increases. Finally there is the settling period, when landslide movement drops off and equilibrium is eventually restored. Thus, if the potential danger can be identified at an early stage, it should be possible to institute emergency measures to minimize the damage caused by the landslide.

4.1 Identifying vulnerable locations

Successful identification of sites considered susceptible to landslide is a key factor for minimizing the damage caused by landslides. This is particularly important in relation to construction of roads and tunnels in mountainous areas. Where prior surveys indicate a propensity for landslide damage, rerouting may be necessary in order to avoid the danger. Where this is not possible, the areas of greatest vulnerability should be identified and incorporated into an early warning monitoring regime.

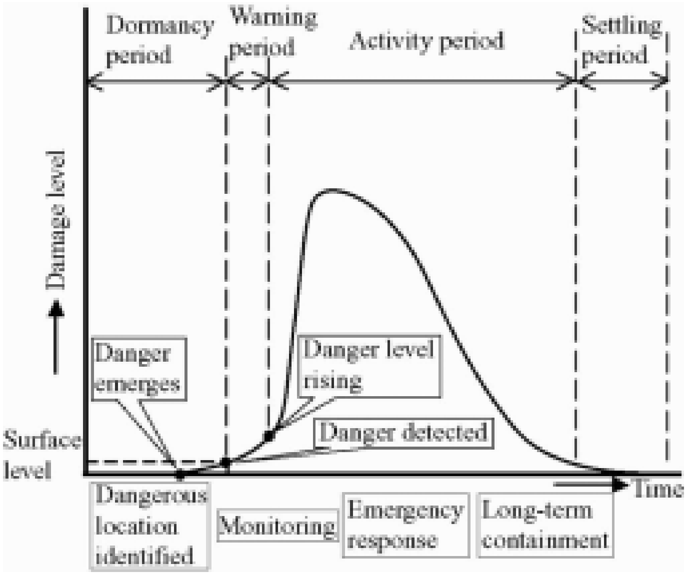


Figure 5 Life cycle of the landslide2) with modifications

4.2 Detection and monitoring regime

Landslide movement is manifested as phenomena such as cracks, minor ground collapses and upheavals in the affected region. It is important to detect these and recognize the need for slope surveys as a means of early prediction of landslides. Extensometers and video monitoring systems can then be set up to monitor movement in the affected slope and provide warnings for use in the preparation of evacuation orders and road closures.

4.3 Liaison networks and information sharing

Damage to roads, railways and rivers caused by landslides can have a major impact on local communities. In the event of a landslide, it is most important for the local authority with jurisdiction over the affected area to have liaison and communication structures in place stipulating the division of duties and responsibilities between local government, the police and fire services and other relevant groups and organizations. Ongoing sharing of disaster information facilitates a faster and better coordinated response. Naturally, it is also important to provide up-to-date information to local residents and communities.

4.4 Countermeasure work

Where countermeasure work are carried out directly after a landslide, it is important to measure the displacement of the landslide and to monitor the slope during the works and ensure the safety of workers, given the potential for further earth movement. Where the mechanism of the landslide is not well understood, it will be necessary to seek the advice of a specialist with a high degree of experience and expertise in landslides.

5. Conclusions

In the case of the Higashi-Yokoyama landslide, there was good liaison with the organizations responsible for dealing with the incident, and this helped to minimize the extent of damage associated with the landslide. A meeting of the relevant parties was convened prior to the major landslide event. All parties recognized the threat posed by the landslide, and were able to contribute their respective areas of expertise on emergency response procedures, thereby achieving an equitable allocation of duties and responsibilities. Similarly, information channels were set up promptly, which facilitated the sharing and public release of information.

It is important to be able to predict the scale and timing of major landslides, and to take appropriate action when a landslide occurs. To this end, it is important to study as many different instances of landslide as possible, in particular the characteristics, associated damage and type of response. Doing so will provide a body of knowledge that can be drawn upon to make accurate assessments and judgments regarding the danger associated with landslides.

Analysis of images from the Higashi-Yokohama landslide indicates that the initial stage of the landslide involves disturbances such as falling rocks and ground collapse at the periphery, i.e., at the head and sides of the landslide and to some extent at the tail. It was also found that the major landslides were preceded by a higher frequency of falling rocks and ground collapse. This suggests that identifying the location and frequency of these phenomena at an early stage can provide a useful indicator of the expected timing and scale of the subsequent landslide.

References

1) K. Fujisawa, M. Ikeda and K. Higuchi (2006): Preliminary report on the landslide at Higashi-Yokoyama, Ibigawa-cho, Gifu prefecture, Journal of the Public Works Research Institute, Vol. 48, No. 7, pp. 4 – 5

2) Risk Management Council (2002): Practical Risk Management, Gyosei Co., Ltd., p. 581

3) K. Fujisawa and J. Ohara (2007): Simultaneous monitoring of a collapsing landslide by video cameras, 2nd Alexander von Humboldt International Conference on the Role of Geophysics in Natural Disaster Prevention, pp. 30