Countermeasures for Sediment-related Disasters in Japan using Hazard Maps

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This is a review of the national policy related to hazard maps for sediment-related disasters in Japan. Until the 1980s, we focused mainly on rainfall-triggered sediment-related disasters, including debris flow, deep-seated landslides, and steep-slope failures, and until 2001, Japan did not have any laws related to hazard maps for sediment-related disasters. The Sediment-related Disaster Prevention Act became effective in 2001 and required all prefectural governments to publish hazard maps. Hazard mapping for volcanic sediment-related disasters started in 1991, and hazard maps have now been published for all 29 volcanoes that would have significant social impacts in the event of eruption. Investigations aimed at assessing the susceptibility to massive collapse and shallow seismic landslides recently started based on new methods.

1. INTRODUCTION

Approximately 1000 sediment-related disasters occur in Japan every year due to natural conditions such as steep mountainous landforms, seasonal torrential rains, and seismic and volcanic activity. Thus, in many areas, housing, public facilities, and human lives are likely to be affected by debris flow, deep-seated landslides, and steep-slope failures. According to an investigation conducted by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), about 210,000 areas have a risk of sediment-related disaster. National and local governments have started implementing countermeasures (Mizuyama et al., 2008); however, the work is only 20% complete.

Given these natural and social circumstances, establishing an early warning system is essential to provide time to evacuate residents to a safer place before the onset of a debris flow, deep-seated landslide, or steep-slope failure. Land-use control is also necessary in areas vulnerable to sediment-related disaster. Information on which areas are dangerous and the extent of affected areas must be readily available so these policies can be implemented. This has resulted in the conduct of much research and investigation.

Several hazard maps for sediment-related disasters have been published in Japan since the 1960s. Here, we review the national policy related to hazard maps for sediment-related disasters in Japan.

2. EARLY HAZARD MAPS FOR RAINFALL-TRIGERED SEDIMENT-RELATED DISASTERS

2.1 1960–70s

A nationwide investigation of the debris flow from hazardous torrents was first conducted in 1966 following the Ashiwada disaster. The small settlement of Saiko-Nenba in Ashiwada Village (presently Fujikawaguchiko-cho, Yamanashi Prefecture) was completely destroyed by debris flow. The original objective of the investigation was to collect basic administrative data for planning preventive sediment control facilities. Following that, investigations of the areas prone to steep-slope failure and to deep-seated landsides were conducted in 1967 and 1969, respectively. Since then, investigations have been carried out roughly every five years (Table 1).

2.2 1980–90s

The Nagasaki torrential rainfall event occurred in 1982. This disastrous event, rare in recent history, claimed 299 human lives, including 225 victims of sediment-related activities. This is an indication of the large potential impact on human life of such events. Based on this experience, the national government decided that residents needed to know the location of danger spots in the surrounding area in advance, and where to evacuate when necessary (Table 1).
Since the Nagasaki event, maps with records of sediment-related disaster danger areas have been distributed to residents and also publicized at town halls. Each prefecture has prepared 1:25,000-scale topographical maps showing sediment-related danger areas. Moreover, some prefectures provide this information on their websites while others send out the information on post cards to residents in and around the warning areas. Currently, 94% of the municipalities publish information on danger areas.

Table 1 Outline of countermeasures for sediment-related disasters using hazard maps in Japan

<table>
<thead>
<tr>
<th>Years</th>
<th>Disasters</th>
<th>Rainfall triggered disasters</th>
<th>Volcanic disasters</th>
<th>Seismic disasters</th>
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<tr>
<td>1966</td>
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<td>Start nationwide investigation on the debris flow from hazardous torrents</td>
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<td>1982</td>
<td>Nagasaki disasters</td>
<td>Start official announcement of information on areas prone to sediment-related disasters triggered by rainfall</td>
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<td>1990</td>
<td>Eruption of Unzen-fugendake</td>
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<td>Start the hazard mapping for volcanic sediment-related disasters</td>
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<td>1991</td>
<td>Hyogoken Nanbu earthquake</td>
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<td>1995</td>
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<td>1999</td>
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<td>2001</td>
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<td>Proposed the manual on the method for extraction of torrents prone to a massive collapse</td>
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<td>Now</td>
<td>Producing hazard map for sediment-related disasters triggered by rainfall</td>
<td>Nationwide investigation on the susceptibility of massive collapse</td>
<td>Producing an emergency countermeasure plan for mitigating volcanic eruption disaster</td>
<td>Promoting a project to countermeasure for steep slope failure</td>
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Fig.1 Example of a sediment-related disaster danger area (produced by Hiroshima Prefecture: http://www.sabo.pref.hiroshima.lg.jp/keikaimap/map.aspx) showing areas prone to steep-slope failure (yellow area outlined in green), steep-slope failure-derived damage danger areas (yellow area outlined in red), debris flow danger torrents (black line), and assumed debris flow-derived damage areas (yellow area outlined in black line).

Since the Nagasaki event, maps with records of sediment-related disaster danger areas have been distributed to residents and also publicized at town halls. Each prefecture has prepared 1:25,000-scale topographical maps showing sediment-related danger areas. Moreover, some prefectures provide this information on their websites while others send out the information on post cards to residents in and around the warning areas. Currently, 94% of the municipalities publish information on danger areas.
in some format.

However, information on how far debris may flow has not been published since this could not be determined with any great accuracy until the late-1990s. In 1999, an investigation was started to clarify the areas where debris flow or steep-slope failure could possibly reach. The possible affected areas were determined based mainly on topographical features and past records. However, because the hazard maps are an administrative service, the practical use of these results varied from one prefecture or municipality to the next. For example, although some prefectures did not publicly announce the existence of this information, other prefectures published the results of this investigation as hazard maps (Fig. 1).

3. SEDIMENT-RELATED DISASTER PREVENTION ACT

3.1 Outline of the Sediment-related Disaster Prevention Act

In 1999, 24 people were killed by debris flow and steep-slope failure in Hiroshima Prefecture. Residential areas in Hiroshima had expanded close to mountains and hillsides, areas that generally suffer serious damage due to debris flow and steep-slope failure. Therefore, the national government decided that the expansion of residential areas had a serious impact on the vulnerability to sediment-related disasters, which led to the Act for Promoting Prevention Measures against Sediment-related Disasters (Sediment-related Disaster Prevention Act), which became effective in 2001 (Table 1).

According to the Sediment-related Disaster Prevention Act, the prefectural governments must publicize areas subject to possible risk as “Sediment-related Disaster Warning Areas”, and establish early warning systems for these areas. Moreover, areas that are particularly vulnerable to extensive damage are designated as “Sediment-related Disaster Special Warning Areas” (Fig. 2). These special areas are subject to the following measures for mitigating disasters: licensing of residential area development, regulation of building structures, and recommendation for moving buildings that may suffer significant damage during a sediment-related disaster (Fig. 2).

3.2 Designation of sediment-related disaster special warning areas

MLIT announced methods for the designation of “Sediment-related Disaster Special Warning Areas” in March, 2001. Determining the degree of building damage is particularly important for the designation of special warning areas and takes place in the following sequence. First, an estimate is made of the debris force the buildings are subject to and their resistance to such force. Then, areas where the debris force exceeds the resistance of buildings are designated as “Sediment-related Disaster Special Warning Areas” [Terada and Mizuno, 2003; Osanai et al., 2005].

Since 2000, prefectures have conducted investigations into geographic features, soil types, rainfall, and land-use in areas at risk for sediment-related disasters to designate “Sediment-related Disaster Special Warning Areas”. Designated areas are generally indicated on 1:25000-scale topographical maps and made available to residents (Fig. 3).

3.3 Creation and application of the sediment-related disaster hazard maps

The Sediment-related Disaster Prevention Act was revised in July 2005. The revision makes it compulsory to map the designated sediment-related warning areas and distribute such hazard maps. Along with this revision, the Erosion and Sediment Control Division of MLIT and the National Institute for Land and Infrastructure Management (NILIM) produced the Guidelines and Exposition for Sediment-disaster Hazard Mapping [Erosion and Sediment Control Division of the Ministry of Land Infrastructure, Transport and Tourism, and National Institute for Land and Infrastructure Management, 2005]. The guidelines indicates that maps must include the following information stipulated by the Sediment-related Disaster Prevention Act: the means for transmitting information about sediment-related disasters, information about evacuation locations in the event of possible debris flow and steep slope failure, and other information required to ensure a smooth precautionary evacuation (Fig. 4). These hazard maps must be produced by the heads of municipalities, who are also required to ensure the smooth precautionary evacuation of residents through the dissemination of information using appropriate means.

4. HAZARD MAPS FOR MASSIVE COLLAPSES

Intense rainfall and accompanying typhoons and weather fronts can trigger damage, not only via shallow landslides, but also by causing massive collapses. We define a massive collapse as that in
Fig. 2 Summary of the Sediment-related Disaster Prevention Act

Fig. 3 Example of a map for sediment-related disaster and special warning areas (produced by Hiroshima Prefecture: http://www.sabo.pref.hiroshima.lg.jp/keikaimap/map.aspx) showing a warning area for steep-slope failure (yellow area outlined in green) and the corresponding special warning area (pink area outlined in dark pink), and a warning area for debris flow (yellow area outlined in blue) and the corresponding special warning area (red area outlined in dark red).
which both the soil and weathered bedrock failed simultaneously. Since a massive collapse often triggers the collapse of more than $10^3$ m$^3$ of sediment, large-scale debris flows and landslide dams may occur, causing extensive damage. For example, 15 people were killed by a large-scale debris flow triggered by a massive collapse at Minamata City, Kumamoto Prefecture, in 2003. Preventing or mitigating such damage requires advance knowledge of which areas are at risk of possible massive collapse. However, the factors involved in massive collapses, such as bedrock strength, water flow path in fractured bedrock, and geological structures, are complex. In addition, adequate data are still lacking for predicting the location of massive collapses. Thus, until quite recently, although hazard maps for steep-slope failures and deep-seated landslides have been published, methods for identifying torrents with danger of massive collapse were not formalized nationally.

In 2005, a large typhoon (Typhoon No. 14) hit Kyushyu Island (the main southern island of Japan) and triggered many massive collapses. More than 10 massive collapses occurred in the Waniizuka Mountains. As a result, the Public Works Research Institute conducted research into massive collapses, and in 2008, prepared an instruction manual describing a method for identifying torrents prone to a massive collapse. The method can be used nationwide, based on objective information estimated from aerial photographs, digital elevation models, and geological maps [Tamura et al., 2008] (Table 1). In particular, the manual identifies torrents according to the following three conditions:

1) Torrents that once generated a massive collapse in the past,
2) Torrents with many slopes that have large steep upslope contributing areas, or
3) Torrents with geomorphologic features that may be strongly related to collapse occurrence (e.g., arc-shaped crack)

Torrents that fit any one of these three conditions are considered to pose a danger of massive collapse. If a torrent fits more than one condition, it has a greater possibility of generating a collapse. Since 2008, MLIT is currently identifying torrents where there is a danger of massive landslides (Fig. 5).

5. HAZARD MAPS FOR VOLCANIC SEDIMENT-RELATED DISASTERS

Sediment-related disasters can also occur due
to volcanic activity. For example, volcanic activity at Mt. Usu and Miyake Island in 2000 was accompanied by sediment-related disasters in Japan. In Japan, hazard mapping for volcanic sediment-related disasters was started in haste after volcanic activity at Mt. Unzen-Fugendake intensified in 1990 (Table 1). But on June 2, 1991, 43 people were killed by a large-scale pyroclastic flow. After this event, the Sediment Control Department of the Ministry of Construction (presently MLIT) established the Volcanic Eruption Precautionary Evacuation Countermeasure Project and prepared Instruction Guidelines for Creating Volcanic Disaster Hazard Maps [Ministry of Construction, Erosion and Sediment Control Department, 1992]. In the same year, the National Land Agency also published Instruction Guidelines for Producing Volcanic Eruption Disaster Hazard Maps [National Land Agency, Disaster Prevention Bureau, 1992]. In addition, administrative agencies nationwide started producing volcanic sediment-related disaster hazard maps. Hazard maps are currently available for all 29 volcanoes that would have a strong social impact in the event of eruption (Fig. 6).

Based on the hazard maps, the MLIT, Forestry Agency, Fire and Disaster Management Agency, Meteorological Agency, and local governments are producing emergency countermeasure plans to mitigate volcanic eruption disasters. The plans will regulate emergency measures, in the case of volcanic eruptions.

6. HAZARD MAP FOR SEISMIC SHALLOW LANDSLIDES

Many steep slope failures or shallow landslides were observed during the Mid-Niigata Prefecture Earthquake in 2004 and the Iwate–Miyagi Nairiku Earthquake in 2008. However, the administrative agencies in these areas had never prepared separate sediment-related disaster hazard maps for earthquakes and intense rainfall. This was mainly because the areas subject to these two disasters generally overlap. At present, earthquakes are more difficult to predict than intense rainfall. Therefore, the design of a precautionary evacuation system before the disaster actually occurs is difficult. Hardware-focused measures play an important role in mitigating seismic sediment-related disasters. That is, a high-precision hazard assessment method is necessary to plan hardware-focused measures to prevent seismic landslides.

On the other hand, NILIM has established an empirical method based on the relationship between

Fig. 5 Example of identifying torrents with a susceptibility to massive collapse

Massive collapses occurred in 2005

Susceptibility
Very Large Fits all 3 conditions
Large Fits 2 of the conditions
Medium Fits 1 of the conditions
Small No conditions in the area

51
Fig. 6 Example of hazard map for volcanic sediment-related disasters (Produced by the Iwate Office of River and National Highway MLIT http://www. thr.mlit.go.jp/iwate/bousai/sonae/kazan_map/map_kakudai.htm) showing a thick volcanic ash deposit area (black broken line), the area where pyroclastic flow may reach (black coarse dots), hazard areas where a pyroclastic surge may reach (red solid lines), hazard areas where lava flow may drift (dark brown area), hazard areas where debris flow may drift (brown area), and hazard areas where volcanic mud may flow (blue area).

Fig. 7 Seismic slope failure hazard assessment system produced by NILIM
topographic factors and shallow landslide distributions based on the results of research in the Rokko Mountains after the 1995 Hyogo-ken Nanbu Earthquake (Table 1). This method was tested using landslide maps of the Kouzu Island earthquake in 2000 and the Mid-Niigata Prefecture Earthquake. Based on these tests, NILIM developed a new method for seismic shallow landslide hazard assessment [Uchida et al., 2004; Uchida et al., 2006]. This method assesses the susceptibility of seismic shallow landslides based on the slope gradient, mean curvature of the slope, and maximum ground acceleration of earthquake motion.

Further, NILIM has recently established a new system capable of assessing the susceptibility of seismic shallow landslides over wider areas [Matsushita et al., 2008] (Fig. 7).

MLIT and prefectural governments are currently promoting a project to counter steep-slope failures. In this project, the method established by NILIM is used to assess the seismic collapse hazard level. MLIT then constructs steep-slope failure prevention facilities in areas where there is a risk of significant damage to local communities.

7. A WAY FORWARD

Progress has been made on various research and technological developments for simulating debris migration phenomena. Moreover, the situation has been improved by the increased capability of computers and through the use of new technology such as geographical information systems. While to develop hazard map, we still mostly use empirical methods. So, we think that to improve the accuracy of hazard maps, it is important to combine empirical methods and new numerical simulating methods.

The probability and hazard levels are not indicated on the hazard maps of sediment-related disasters triggered by intense rainfall. While, we also think that the probability and hazard levels is a one of key issues for advancement of hazard maps.

In conjunction with improving the accuracy of hazard maps, their distribution to residents is particularly important. Sediment-related disasters do not occur on a daily basis and are therefore not of particularly great interest to many residents. Improved awareness and knowledge about the hazards of sediment-related disasters are extremely important.

REFERENCES


