Issues Relating to and Possible Approaches for Developing Natural Disaster Countermeasures

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Japan is faced with three major problems: “climate change,” “a low birthrate and aging population” and “deterioration of infrastructure.” Researchers working in the field of disaster prevention technology must therefore develop measures to counter these problems. This paper reviews each problem in question and introduces a series of technologies that R.T.R.I. is developing in response to these problems. For example, a flooding hazard map in response to heavy rain. A hazard mapping system relating to the low birthrate and aging has already been designed. Furthermore, a method for evaluating slope stability and effective reinforcement methods have also been designed, as a remedy to infrastructure deterioration. Upcoming research and development will take into account social aspects.

Keywords: natural disaster, climate change, aging, hazard map, slope collapse, inundation, tornado, reinforcement

1. Introduction

Japan is frequently hit by heavy rain, heavy snowfall, gusts, earthquakes, volcanic eruptions and other natural phenomena, due to local climatic and geographic conditions. Of these natural disasters, the collapse of slopes and bursting rivers due to heavy rain occur almost every year, sometimes causing tremendous damages. The heavy rain in northern Kyushu in July 2017, led to serious destruction in various regions such as Fukuoka and Oita Prefectures: restoration work is still underway in some places, underscoring the gravity of the damage that occurred. Elsewhere, restoration and reconstruction is also still being carried out in the wake of the 2011 off-the-Pacific-coast-of-Tohoku Earthquake, and the 2016 Kumamoto Earthquake.

This report outlines the issues related to technologies developed in response to these disasters, and the current status and future direction of R.T.R.I. R&D that take these issues into consideration.

2. Disaster prevention related issues

2.1 Effects of climate change

The Climate Change Monitoring Report [1] issued in October 2017 revealed that the global average annual temperature in 2016 was the highest since 1891 and that the average annual temperature in Japan was the highest since 1898.

These records indicate that the rise in average annual temperatures for this 100-year period was 0.72 °C globally and 1.19 °C in Japan. It is assumed that the influence of rising temperatures appears in the form of changing rainfall patterns. Figure 1 shows the annual change in downpours of 80 mm of rain or more per hour in a year, recorded in the report mentioned above. These values were found by converting measurements obtained through AMeDAS (automated meteorological data acquisition system) into the number of downpours at 1000 points.

The graph shows that the number of these downpours tended to increase despite fluctuations, rising by 2.3 downpours per year over a decade.

Figure 2 shows a time history of rainfall created by using values observed by AMeDAS in Asakura City during the period of heavy rain in northern Kyushu in July 2017. Downpours of 88.5 mm/h and 106 mm/h were recorded in the hours preceding 13:00 and 16:00, corresponding exactly with the rainfall grouped into the short heavy downpours shown in Fig. 1. Based on this data it is assumed that...
bridge and large-scale debris flow damage will become increasingly frequent if the rising tendency for short intense downpours continues. Work to find technological responses to this situation is therefore essential.

2.2 Effects of an aging society

According to the Annual Report on Aging Societies [2], the percentage of people aged 65 or older in the total population in October 2016 reached 27.3% in Japan. Moreover, the productive-age population (15-64-year-old population) declined after having peaked in 1995 and has continued to gradually decrease. In addition to aging, birthrates are also expected to decline. The total Japanese population is said to be currently approximately 130 million people. However, it is predicted that it will drop to 88.08 million by 2065, at which time it is estimated that the productive-age population will have descended to 45,290,000 (Fig. 3).

Consequently, it is foreseen that the working age population in Japan will also decline in the near future. This prospect prompts the need for technological solutions to maintain a level of safety against disasters equal to that of the present day. Achieving this depends heavily on being able to ensure effective maintenance and management with fewer people and that the comprehensive know-how of skilled engineers is transferred on and made available to others. Technical solutions therefore have to be found to make this possible.

2.3 Aging infrastructure

According to the White Paper on Land, Infrastructure, Transport and Tourism in Japan [3], it is expected that the percentage of facilities of 50-years or more, will accelerate over the next 20 years. This forecast however encompassed all structures currently overseen by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), which includes highway bridges, tunnels and harbor quay walls, etc. Figure 4 gives the age of bridges as an example of the state of infrastructure on the railways [3].

This graph shows that the number of bridges constructed in or before 1920 exceeds 14000. It also reveals that the percentage of bridges older than 80 years is over 30% of the total (the total number of bridges investigated in this data: 102293 bridges). Railway bridges are periodically inspected and maintained, making it difficult to know exactly the state of health of bridges due to ageing, based solely on these values. However, it does give an idea of the age distribution of railway facilities. Similarly, the age of slope protection, disaster prevention and other railway structures is also increasing, etc., including those which have an effect on railways such as debris flow dams etc., which are constructed off railway land.

3. Development of countermeasures considering highlighted issues

As described above, railway disaster prevention issues can be grouped into three major categories. Technology is being in response to the highlighted issues. This section outlines key areas of work underway.

3.1 Effective inspection techniques

An example of an extreme downpour is the heavy rain that fell in northern Kyushu in July 2017 in the area along the Hitahikosan Line of JR Kyushu causing large debris flows which led to numerous railway tracks being covered with colluvial soils.

Debris flow is one of the typical forms of damage caused by violent downpours. It is expected that if these sudden heavy downpours increase due to the effect of climate change, other types of disasters, such as debris flow and sediment influx, will also rise. A major feature of these disasters is slopes collapsing away from railway tracks leading to colluvial soil flowing down mountain streams and onto tracks. To avoid an increase in this type of disaster, it is will therefore be important to inspect slopes along larges stretches of track. Wide-sweeping slope inspection requires people, time and incurs a cost. Among the areas of concern for the future therefore, is the shortage of staff and erosion of expertise.

A meteorological disaster hazard mapping system was developed as one method to address these issues. The system can display the probability of a rockfall or sediment disaster due to rain, high winds or avalanches. To prevent rain-induced sediment disasters, for example, the system can be used to determine the risk of collapse of slopes adjacent to tracks by using a 5m-mesh digital elevation model (DEM) published by the Geospatial Information Authority.
of Japan (GSI) and inputting an arbitrary rainfall pattern. The system can extract slopes with a risk of rain-induced collapse without the need for any specialized knowledge about slope disasters, and thereby enable a primary screening before any detailed investigation. The system is therefore expected to increase efficiency and reduce work related costs.

This is particularly relevant given that the scale of slope collapses is expected to grow as cumulative rainfall increases.

Research on large-scale slope collapses is underway, with a particular focus on for example, locating points of possible large-scale slope collapse and identifying the area that could be affected by the collapse, and the pluviometry that triggers collapses. Other work has correlated locations with a history of slope collapse with surrounding terrain characteristics, to develop a method for extracting other spots vulnerable to large-scale slope collapses, based on terrain conditions (Fig. 5 (a)). Another analytical tool is being developed to evaluate whether or not colluvial soil will reach railway facilities if a slope collapse actually occurs in one of the identified locations (Fig. 5 (b)). Research is also underway to clarify the pluviometry that increases the probability of a large-scale collapse, on the basis of analyses of past recorded data.

These hazard mapping and risk assessment techniques can contribute to increasing the efficiency of inspections, as described above, and are considered to be effective especially when a wide range of assessments need to be carried out with limited human resources and budget. Future work will aim to broaden the range of hazards that can be extracted and assessed.

![Fig. 5 Large-scale landslide hazard assessment](image)

### 3.2 Hazard assessment technique adapted to extreme changes in weather

#### 3.2.1 Technique adapted to sudden heavy rain

As shown in Fig. 2, during the period of heavy rain in northern Kyushu in July 2017, an hourly rainfall exceeding 80 mm per hour was recorded in the few hours after precipitation began. This type of sudden localized downpour is one example of the change in rainfall patterns brought about by climate change. It is hard to predict where and when these violent downpours will happen, and in some cases they cause serious damages because of their abruptness. We cannot deny the possibility of generating a case where such a sudden heavy rain cannot be dealt with by the conventional train operation control using the observed rainfalls. For example, the possible cases include a case in which a place where a train is waiting for another train to pass suddenly becomes submerged due to a heavy rain, which prevents the train from moving and a case where a further increase of inundation requires the passengers to evacuate. We are developing a system that allows us to assess the inundation or flooding hazards brought about by these sudden heavy rains, using the rainfall prediction information, and use the assessment results as reference information when requiring a train to wait or an evacuation guidance. Figure 6 shows an example of the type of result that can be obtained after an assessment using the flood analysis method in the system under development. This method enables sequential display of inundated areas and inundation depths which are based on rainfall information. Further details about this work can be found in the related report appearing in this issue.

![Fig. 6 Assessment of flood hazard caused by short time heavy rain](image)

#### 3.2.2 Technique adapted to wind gusts

Gusts, such as tornadoes, downbursts and gust fronts, are considered likely to be a serious hazard, and may turn a railway car over or damage windows if a train directly hits flying objects. Gusts however are among the phenomena that are hardest to predict in advance, unlike strong winds accompanying a typhoon. In addition, gusts usually occur over areas that are smaller than those affected by ordinary strong winds. Consequently, predicting where they will occur and when, is almost impossible using just an anemometer installed on the ground. The relationship between the occurrence of this type of gust and climate change has not been made clear. However, counting tornadoes alone, at least ten tornadoes occur annually in Japan [4], some of which have crossed railway lines.

A technique using radar data is therefore under development to detect gusts otherwise hard to identify with conventional methods used for strong winds. The new method is based on a technique using radars to capture regions in the sky where gusts are being generated, which is then used to find areas where gusts are being generated on the ground (Fig. 7). Figure 8 shows an example of tornado detection, where the encircled area has been identified as region where gusts are being generated, from the distribution of wind velocities observed by radar. The movement direction and speed of the gust region can be obtained.
3.3 Effective reinforcement techniques

Slope protections are one form of disaster prevention used close to railway tracks that need to be protected against aging. Among the reinforcement techniques that can be used is concrete pitching which has been applied for many years in the railways, with some concrete reinforcement dating back 80 years. Concrete pitching protects the stability of natural ground surfaces and was not originally designed to receive any earth pressure. The natural ground behind the concrete pitching has gradually weakened however, due to aging, and in some cases reached a state where the earth pressure has begun to act on the concrete pitching. If this mechanism has started to cause cracking or other damage to the concrete pitching, the concrete needs to be immediately reinforced.

The Shotcrete Anchor Plate Method was developed as an effective reinforcement measure in case reinforcement was deemed necessary (Fig. 9). This method covers the deteriorated slope protection with fiber reinforcement shotcrete whilst at the same time serving as a natural ground reinforcement earthwork through integrated installation of anchor plates mounted on top of the reinforcements used to reinforce the natural ground and the fiber reinforcement mortar. Compared to conventional methods the developed method has the advantage that the shotcrete anchor plates can enhance the natural ground reinforcement effect per piece of reinforcement. Other advantages are that it is economic, because it reinforces the surface making use of the deteriorated slope protection, instead of removing it, which also shortens the construction time. It also has an excellent safety performance because the method prevents accidents that could be occur during removal of the deteriorated slope protection.

An evaluation technique to select the slopes that need their protection reinforced is also under development. Since nomograms are prepared as tools used for evaluation, it is possible to decide the necessity of measures at the survey site. A new slope survey and diagnosis method is also being developed to further increase the efficiency of the surveying technique.

4. Conclusions

This report summarizes disaster prevention related issues, and provides an overview of results obtained and research and development still underway in response to these problems at RTRI. RTRI will pursue this line of R&D in response to emerging needs and situations in the future.

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