Recent Research on Technology to Protect against Natural Disasters

Takehiro OHTA
Disaster Prevention Technology Division (Former)

Over the past few decades the frequency of serious natural disasters, i.e. large earthquakes, extreme meteorological phenomena (heavy rain bursts, tornados), volcanic eruptions, have become a source of concern. As such, it is necessary for the railways to take preventive action. This paper describes the characteristics of and how natural external forces have evolved over recent years, and will introduce recent progress made in the study of natural disasters. There is new research on innovative disaster prevention and reduction technology for railways focused on the resilience of railways against unknown large-scale natural disasters. This paper also outlines how this research is planned and organized.

Keywords: disaster prevention, disaster mitigation, resilience, natural external forces

1. Introduction

In recent years, there has been heightened likelihood of large-scale disasters caused by: heavy rainfall, violent storms and other extreme meteorological phenomena associated with the global warming; large-scale earthquakes along the Nankai Trough and directly under the Tokyo metropolitan area; and increasingly active and erupting volcanoes. With natural external forces becoming more powerful, the Japanese government has set disaster mitigation as a key part of its policy on disaster prevention [1]. Going forward, the railway sector, too, must prepare to counter this trend.

This paper will describe how the characteristics of natural external forces have changed over recent years and present some of RTRI’s recent research and development projects on related subjects. Finally, this paper will present the package of work entitled “Advanced disaster prevention and mitigation technologies for railways” launched in this fiscal year as part of the plan, “Research and development for the future of railways.”

2. How natural external force characteristics have evolved over recent years

Global warming has brought an increase, over recent years, in torrential rain, or heavy localized rain bursts, tornadoes, violent gusts of wind, inter alia. In addition, seismic activities in and around Japan appears to have intensified since the 1995 Hyogo-ken Nanbu Earthquake and especially after the 2011 off the Pacific coast of Tohoku Earthquake. Along with this surge in seismic activity, volcanic activity also appears to have intensified. This chapter will briefly present how the characteristics of natural external forces have evolved over recent years.

2.1 Recent trends in rainfall

Most of Japan has a temperate and humid climate with relatively high rainfall by global comparison, with long spells of rain and heavy rain typically brought on by the annual rainy season and typhoons. Global warming, however, appears to have altered normal rain patterns. For example, annual rain events with an hourly precipitation of 50 mm or more, or 80 mm or more per 1000 AMeDAS points (Fig. 1) are increasing [2], as are the annual events with a daily precipitation of 400 mm or more [2]. Annual precipitation data taken from 51 points since 1901, unlike hourly precipitation data, shows no clear indication of an increasing trend [2]. While the number of days per year with precipitation of 100 mm or more (Fig. 2) and those with 200 mm or more based on data from 51 points, is clearly rising, the number of days per year with precipitation of 1.0 mm or more is clearly falling [2]. This data suggests that while heavy rain events are increasing, the number of rainy days per year overall is decreasing.

Nearly all of the all-time Top Ten hourly rainfall events appear to be the result not of a typhoon but of low pressure or an unstable atmosphere [3]. Heavy rain bursts like this are typically the product of developing cumulonimbis. Typhoons however explain eight of the all-time Top Ten heaviest daily rainfall events [3]. While typhoons are one of the causes of heavy rain, there have been no clear indications of any long-term change in their frequency. Nor has there been any significant change in the frequency of typhoons classified as “Strong” and above (maximum wind velocity

![Fig. 1 Observed rain events with hourly precipitation of 80 mm or more [2]
Blue line: Five-year moving average Red line: Trend over the period]
2.2 Recent trends in strong wind

Many high-wind related disasters affecting the railways over recent years were brought by violent gusts. While most reported disasters were caused by tornadoes, there were also cases caused by downbursts or gust fronts [4].

Figure 3 shows the number of reported tornado related events per year [5]. One thing to note about the annual data is that the counting criteria changed over the same period, which makes it difficult to compare the data. The annual number of reported tornadoes on land in Japan between 2007 and 2014 averaged around 25. In the U.S., about 1300 tornadoes are reported every year. In terms of the number of reported tornadoes per unit area, Japan experiences about a third of the tornadoes reported in the U.S., which is not a small number.

Just as gusts have been reported all over Japan, tornadoes can occur anywhere in Japan [6]. While tornadoes are often reported in coastal areas, this is not true for downbursts and gust fronts.

2.3 Recent trends in snowfall

FY 2005 claimed the most lives due to snow, in a snow related disaster known as “the heavy snow of 2005/2006.” From 2010 on, annual fatalities were around 100 to 130, which is about the same or just above annual fatalities due to high winds and flooding [7]. Typically snow disasters come in the form of an avalanche or snowstorm. Avalanches occur every year claiming lives in places such as ski resorts. The snow storm of March 2, 2013, in eastern Hokkaido was particularly memorable due to the sudden change in weather which claimed nine lives. Of the deaths between 2011 and 2013, 70 to 80% were accidents involving snow falling from roofs or other snow clearing operations. Damage and casualties can also be caused by accumulated snow. An example of this was the spell of heavy snow from 14-16 February 2014, which hit the Kanto, Koshin and Tohoku regions, disrupting railway and other transport services, making the entire Yamanashi Prefecture and some other communities temporarily inaccessible and causing many houses and buildings to collapse or otherwise damaged under the weight of snow.

The maximum depths of snow cover between 1963 and 2013 show a clear declining trend for the Sea of Japan coast in eastern (Fig. 4) [2] and western Japan and almost no change for the Sea of Japan coast in northern Japan. This suggests that, despite falling figures snowfall continues to claim lives.

2.4 Earthquake characteristics

Some earthquakes occur near trenches while others occur as part of fault movement on land. The Islands of Japan are surrounded by trenches where earthquakes can occur, and are crisscrossed with about 2,000 active faults [8]. Many earthquakes occurring near trenches are generated when the continental plate is pulled down by the oceanic plate as it sinks beneath it causing strain until the built up energy exceeds frictional force causing the continental plate to spring back up. These earthquakes often have a large magnitude, and may generate tsunamis simi-
lar to the one in the 2011 off the Pacific coast of Tohoku Earthquake. Inland earthquakes however, typically occur at shallow depths (maximum 15 – 20 km below the ground surface) beneath the earth’s crust. While having lower magnitudes than trench earthquakes, inland earthquakes, occurring inland and therefore close to inhabited areas, can inflict extensive damage like the 1995 Hyogo-ken Nanbu Earthquake and the 2004 Niigata Prefecture Chuetsu Earthquake.

It is said that earthquakes that occur along active faults (and trenches) tend to be periodical. As such there are growing concerns that an earthquake with a magnitude of 8 or above in the Nankai or Tonankai trench or inland earthquake with magnitude of around 7 directly below the Tokyo metropolitan area, may be imminent.

2.5 Characteristics of volcanic activities

The Islands of Japan are home to 110 active volcanoes or about 7 % of all volcanoes in the world [8], that over the centuries have repeatedly caused tremendous suffering. Through a group of volcanic observatories, The Japan Meteorological Agency monitors 47 of the 110 active volcanoes selected by the Coordinating Committee for Prediction of Volcanic Eruptions, for early signs of possible eruptions [8].

Earthquakes of magnitude 9 or above before the 2011 off the Pacific coast of Tohoku Earthquake were always followed by volcanic eruptions near the epicenters, as shown in Table 1. After the 2011 off the Pacific coast of Tohoku Earthquake, it appears that volcanoes in and around Japan have become more active. However, it is unclear whether the apparently increased volcanic activity fits the pattern of eruptions following earthquakes of over magnitude 9.

3. RTRI work

RTRI has devoted significant efforts to finding ways to mitigate disasters caused by intensifying natural external forces as discussed in Chapter 2. Some of this work is presented in a series of PAPERS appearing in this issue of RTRI Report. The rest of the present paper introduces a number of other achievements.

Table 1 Magnitude 9 earthquakes in the past and subsequent volcanic eruptions

| Date of occurrence (Japanese calendar) | Location | Magnitude (Mw) | Subsequent volcanic eruption |
|----------------------------------------|----------|---------------|-----------------------------|
| May 23, 1960                           | Chile    | 9.5           | Cordón Caulle (2 days later), other 3 volcanoes erupted within a year |
| March 28, 1964                         | Gulf of Alaska | 9.2     | Mount Trident (3 days later), Mount Redoubt (2 years later) |
| December 26, 2004                      | Off the west coast of northern Sumatra, Indonesia | 9.1     | Mount Talang (4 months later), Mount Merapi (15 months later), Mount Kelud (3 years later) |
| November 5, 1952                       | Kamchatka | 9.0           | Mount Karpinsky (following day), 2 other volcanoes (erupted within 3 months), Mount Bezymianny (erupted 3 years later, after being dormant for a thousand years) |
| March 11, 2011                         | Off the coast of Sanriku, Japan (Off the Pacific coast of Tohoku Earthquake) | 9.0     | Nishinoshima Island?, Sakurajima Island?, Kuchinoerabu Island? |

3.1 Evaluation of slope stability in snow-melting season

While data over recent years shows that snowfall is declining in some regions as mentioned above, the number of disasters has increased. This is thought to be related to snow melting after warmer winters with rain. Given this context, a method for evaluating slope stability was developed which takes into account the effects of rainfall and snowmelt, both major factors contributing to slope-related disasters in the snow melting season.

The method, which is based on the close relationship between slope destabilization and soil moisture behavior, operates as follows: the volume of snowmelt seeping into a slope is computed using AMeDAS data through an analytical model, the snowmelt is then converted into an effective precipitation index which has a high correlation with soil moisture behavior, and the slope is determined as unstable when the index, defined as the "effective snowmelt index," exceeds the set limit.

Using this method, some typical snowmelt-related disasters of the past were reviewed. It was found that the effective snowmelt at the time of the disasters exceeded the established limits (Fig. 5), confirming the method as an effective tool for predicting landslides caused by snowmelt.
3.2 Velocity fluctuation characteristics of gusts measured by anemometers

It is often difficult to measure gusts, especially tornadoes, mentioned in 2.2, using anemometers on the ground because tornadoes occupy a small spatial area. Consequently, past wind data measured by anemometers was analyzed for wind velocity fluctuation during the hours when gusts occurred with the aim of identifying the velocity fluctuation characteristics of gusts that can be measured by anemometers on the ground.

The analysis revealed the following. Where gust velocity fluctuation was evident, the farther the anemometer from the gusts, the later the fluctuation peak occurred and the smaller the velocity. The intensity of the power spectra in the frequency range (indicated with a red circle in Fig. 6) during the hours when gusts occurred was generally higher than when there were no gusts, and was dominant in the frequency range representing gust-related velocity fluctuation. All this indicates the possibility that wind velocity fluctuations caused by gust-related disturbance of the atmosphere which occupy larger spatial areas than gusts can be detected by anemometers on the ground, even though they may be located far from where the gust occurs.

Fig. 6 Frequency characteristics of gust velocity fluctuations

3.3 Evaluation of river inundations near railway tracks

With the increase in heavy localized rain bursts, mentioned above, a higher number of inundations have been reported due to flooding from small and medium sized rivers near railway tracks in mesoscale mountainous regions. It is feared that urban line sections may also be inundated due to such high-intensity downpours.

Consequently, an inundation analysis method applicable to small and medium sized rivers in mesoscale mountainous regions and a drainage model were developed for verification. Currently, work is underway to expand their applicability to allow evaluation of inundations along urban line sections.

3.4 Clarification of damage to railways caused by volcanic eruptions

As discussed in 2.5, concerns have been growing over recent years about volcanic eruptions and related disasters, which has led to growing interest in these topics in the railway sector. In order gather and sort data related to the impact of past volcanic eruptions on railways, relevant documents were reviewed and interviews conducted with railway operators.

It was found that in most cases, falling ash had the most impact and could cause a wide range of problems. For example, ash falling on rails could cause electrical short circuiting, which could then cause level crossings and signals to malfunction.

4. Advanced disaster prevention and mitigation technologies for railways

As discussed earlier in this paper, increasingly powerful natural external forces could bring about disasters on a much larger scale. Aware of this, the Japanese government set disaster mitigation as a key part of its policy to develop disaster prevention measures [1]. To promote research and development on disaster mitigation technology, RTRI started in the last fiscal year a five-year program entitled, “Advanced disaster prevention and mitigation technologies for railways” as part of its plan called, “Research and development for the future of railways.”

The program aims to “develop and introduce comprehensive mitigation technologies to prevent disasters caused by unprecedented external forces, covering external force detection, disaster hazard evaluation, operation restrictions and securing passenger safety, to route diversion planning and restoration strategies, in order to enhance the resilience of railway services against catastrophes and enable faster resumption of railway operations.” “Resilience” here means, “the capacity to prevent catastrophic situations and swiftly restore all railway operation.”

As shown in Fig. 7, the program specifically covers three phenomena that have been growing in terms of external force over recent years, namely, “gust/tornado,” “localized violent rain bursts,” and “earthquakes of unprecedented magnitude.” Each of these phenomena will be studied in four phases, namely “prediction,” “evaluation,” “prevention” and “execution.”
5. Conclusion

As natural external forces intensify, it is critical for the railway sector to add fresh emphasis on understanding the phenomena which underlie natural catastrophes, an area which has not been a focus for attention until today, in order to develop and introduce disaster mitigation technologies centering on resilience. As mentioned above, RTRI, will contribute to this by promoting and conducting research and development into advanced disaster prevention technologies.

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Author

Takehiro OHTA, Dr. Sci.
Director, Disaster Prevention Technology Division (Former) (Currently Yamaguchi University)
Research Areas: Applied Geology