Recent Research on and Prospects regarding Disaster Prevention Technology

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Various natural disasters have occurred in Japan due to geological and meteorological conditions, causing significant human loss and economic damage. Disaster prevention technology for railways has been developed through experience and has contributed to mitigating damage. Since the 2011 off the Pacific coast of Tohoku Earthquake, however, the paradigm of disaster prevention has shifted. Japanese Government disaster prevention now focuses on mitigating the impact of and resilience against large-scale disasters caused by forces larger than those considered up until now. This paper introduces the results of recent research into disaster prevention technology, and describes research plans for mitigating the impact of and resilience against large-scale disasters.

Keywords: disaster prevention technology, disaster mitigation, resilience, rainfall disaster, strong wind disaster, seismic disaster

1. Introduction

Geologically, Japan lies along a plate boundary, close to one of the world’s most active belts. Consequently, the terrain is precipitous with high seismic and volcanic activity, and has a geology which is young and fragile compared with other areas of the planet. At the same time, much of Japan has a temperate and humid climate with monsoons, and is inevitably subject to typhoons in summer and the northwest monsoon and heavy snow in winter. These terrestrial and climatic characteristics mean that Japan has experienced all sorts of natural disasters including strong winds, heavy snow fall, heavy rain, coupled with landslides, debris flows, earthquakes, tsunamis, volcanic eruptions, and the concomitant human loss and economic damage. Even recent years have seen a number of natural disasters afflicting the country due to enormous external forces, such as: The 2011 off the Pacific coast of Tohoku Earthquake, heavy rain on the Kii Peninsula in the wake of Typhoon Talas in 2011, heavy rain in northern Kyushu in July 2012, heavy rain on the Izu Oshima Island as a results of Typhoon Wipha in October 2013, a large scale landslide disaster causing scores of casualties due to heavy rain in Hiroshima City in August 2014, an unusual heavy snowfall that occurred in February 2014 in the Kanto Koshinetsu district, which is not normally subject to heavy snow, and sudden volcanic eruptions on Mount Kirishima in 2011 and on Mount Ontake in September 2014.

Despite this hostile environment, it is still necessary to guarantee safe and stable railway operations. To this end, a broad range of disaster prevention technologies have been developed drawing the lessons from previous catastrophes, which have proved successful in reducing the number of railway accidents over recent years due to natural disasters. Disaster prevention is achieved by implementing physical measures, such as reinforcement of actual structures which have been identified as being vulnerable to damage, and by applying regulatory or operational measures, which for example require trains to slow down or stop, when the risk of potential disaster is detected through monitoring of disaster related indicators. RTRI is engaged in research into both types of measure to protect the railways against external forces, such as rain, snow, wind and earthquakes, and inherent issues, such as deterioration and weathering. This paper presents some of the technologies which have been developed in the course of this work.

Over recent years, and in the light of increasing extreme weather and natural events, the Japanese Government has also moved towards placing disaster mitigation at the heart of its disaster prevention policies. Given the importance attached to this field of work, this paper outlines RTRI plans for future technical development in disaster mitigation technology.

2. Latest RTRI research and development

RTRI has and continues to conduct research and develop counter and preventive measures against a broad range of external forces, such as rain fall, strong winds, earthquakes, etc, while also developing methods to detect such forces, gauge their magnitude, and evaluate the related hazard level and resistance of structures against such threats. RTRI then carries out research to develop means to detect and evaluate the risk of potential hazards on the railway network due to structures weakened by weathering and deterioration. This issue only describes a selection of the developed measures, then this paper gives a brief introduction of others to demonstrate the breadth of development.

2.1 Evaluating flooding from medium to small rivers

Recent RTRI research has centered on developing a method for evaluating the topical subject of flash floods from sudden violent downpours in the vicinity of small to medium–sized rivers.

In order to form an assessment of such floods, it is vital to be able to accurately measure the volume of rain running off nearby slopes into these rivers, etc. The volume of surface run-off flowing into adjacent rivers is found by subtracting the volume of water infiltrating the ground from the total volume of precipitation. However, there is a
lack of insight into how water infiltrates the ground during sudden violent downpours. Rainfall infiltration experiments were therefore conducted on a ground model to measure surface water flows in the case of a violent downpour. Test results showed that there was less infiltration in the case of violent precipitations than for light rain, increasing the volume of surface run-off water. It is now planned for these results to be analyzed in further detail, so that any findings can be incorporated into and used to improve the evaluation method.

2.2 Evaluating the spatio-temporal representativeness of wind observation values

Research was conducted to establish a method to quantitatively evaluate the spatio-temporal representativeness of wind observations obtained with anemometers in order to produce a spatio-temporal correlation model of wind speed and direction. Wind observations were collected from 8 anemometers located along a spatial scale, i.e. at intervals along a standard-length operation control section of track (several km ~ 10 km long). The collected data then underwent a correlative analysis where the parameters were distance between 2 anemometer locations and time taken to measure wind speed. As a result, we found that the correlation coefficient of wind velocity between two anemometers at the same time increases with the increase of wind velocity evaluation time, and it increases with the decrease of distance between two anemometers (Fig. 1). This confirms that correlation between two anemometer readings is affected by the environment on the windward side in the dominant wind direction. Future work will be aimed at validating the spatio-temporal representativeness of wind observation values, and the spatio-temporal correlation model through airflow analyses on a model reproducing the flat terrain where field observations were taken, in order to develop more sophisticated models, capable of reproducing more complex topography.

![Fig. 1 Layout of anemometers and relationship between wind velocity determination time and correlation coefficient (an example of mean wind velocities)](image)

2.3 Development of a method for estimating snow-fall distribution

In order to estimate the external forces needed for snow-fall related hazard analysis, a method is being developed to estimate surface distribution of snow fall. This snow-fall distribution method comprises a model for snow fall and another model for redistribution of fallen snow due to wind. The WRF (Weather Research and Forecasting Model) [1] was used for the first model on actual snow fall. Reproducibility of the model was tested by varying the combination of calculation conditions which influence snow fall, such as topographical data, calculation range, and physical processes such as cloud physics and radiation. Snow redistribution due to wind, was estimated with reference to the model used to calculate snow particle flux based on temperature and wind speed, using either estimated meteorological ground condition values obtained using the WRF model above, or estimated values found through airflow models and analyzed radar observation values or live AMeDAS (Automated Meteorological Data Acquisition system) observation data.

Comparing data calculated through this method with measured data collected from snowfall observations on the Ishikari Plain in Hokkaido, demonstrated that the method was able to reproduce snowfall distribution to a certain degree. Future work will include adapting this model to mountainous and highly irregular terrains.

2.4 Improving the performance of the earthquake and disaster early warning system

The current earthquake early warning system used on Shinkansen lines comprises an S-wave warning function for when seismic motion exceeds a specified value, and a P-wave warning function, which issues warning based on various estimated earthquake parameters from initial seismic motion. Current research is focusing on improving the performance of the P-wave warning function. In order to achieve P-wave warning efficiency, it is important to 1) ensure reliable P-wave detection, 2) produce rapid and accurate earthquake parameter estimations. To this the following concrete steps have been taken:

In order to improve P-wave detection performance, a method has been devised to enable the system to discriminate between seismic motion and train-induced vibrations more accurately. Given that the majority of seismographs used in the earthquake early warning system are adjacent to railway lines, they are heavily exposed to train vibrations. In order to eliminate false alarms triggered by train-induced vibrations, the devices must be able to distinguish accurately seismic motion from train vibrations. A new method based on discriminating the two types of motion from differences in waveform characteristics was therefore developed, and a proposal made to add this to the conventional method which is based on seismic waveform component amplitude ratios (Fig. 2). Compared to seismic motion, train-induced vibrations have a dominant high-frequency component. Within a suitably defined frequency range, train-induced vibrations will tend to display a large high-frequency to low-frequency ratio. It was verified that using this characteristic together with the conventional method raises the discrimination rate by 10%. A prototype device, combining the two methods, is now being developed and tested with a view to investigating practical implementation.

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2.5 Evaluating the intactness of and reinforcement measures for masonry retaining walls

Although masonry retaining walls are considered to be now obsolete civil structures, no satisfactory method has so far been developed to assess their stability and state of health in a simple and effective manner. Accordingly, a masonry wall diagnosis method was researched in order to provide a simple means to assess their state of health, while considering that the method had to be suitable to be part of a general inspection.

Figure 3 shows the full-scale model masonry retaining wall which was constructed to conduct loading tests. Based on the relationship between earth pressure acting on the masonry retaining wall and magnitude of deformation, data from these tests was collected and a diagnostic "swelling index" was designed with indicators showing fitness of the wall. The swelling index used here is a stability index used for castle retaining walls, and is based on values obtained by dividing the maximum horizontal displacement of the wall by its height. Although masonry retaining walls adjacent to railway lines differ from castle walls, applicability of the swelling index for both cases was validated through tests, which demonstrated that a swelling index value of 4 or more equated to extremely low stability. Similarly for cases where the swelling factor is 4 or less, deformation can be considered as minor, where only minor reinforcement work is required. Reinforcement measures for this using steel members and rock bolts were designed, and their effectiveness was verified through model experiments.

2.6 Method for evaluating rock block stability with hammering tests

Rockfalls are among the most difficult natural disasters to predict in terms of timing and location, since they are influenced by a great number of different factors. RTRI has been working on adapting hammering tests for practical use, in methods which assess rock block stability on rock slopes, which is one of the factors influencing rockfalls. Based on mode analysis of experimental results and measured data, it is possible to obtain information about how firmly a rock block is attached to a rock slope from sound pressure waveforms obtained in hammering tests. At the same time, it was found from various on-site...
and sample experiments that the stability of loose rock blocks on slopes could be evaluated by comparing Fourier amplitude peaks in the 0-0.5 kHz range. These results were used to propose a rock block stability hammering test method, which is illustrated in Fig. 4.

3. Future disaster prevention research areas

As explained earlier, since the 2011 Off the Pacific Coast of Tohoku Earthquake, it has become clear that reducing damage to nothing in the case of extremely violent external forces is practically impossible and therefore state policy and measures for disaster prevention focus primarily on damage and loss mitigation. The CSTI (Council for Science and Technology Innovation), established by the Japanese government, set out a policy called, “Enhancement of Societal resilience against natural disasters,” as part of a cross-ministerial strategic innovation promotion program (SIP), which will receive substantial funding for research and development.

Based on the aggravating natural disasters and the consequent embrittlement of society, the concept of resilience (to minimize the damage and losses and allow the people to get back to their normal life) that has been born as a result of damage after 2011 off the Pacific coast of Tohoku Earthquake, this program aims at the realization of “early detection (prediction),” “prior determination of the limits of preventive capabilities (prevention),” and “victory goes to the swiftest (countermeasures)” by maximizing the use of latest science and technology, sharing the disaster related information by the authority and public, and by enhancing the disaster prevention literacy of citizens, particularly sharing the disaster information through utilization of latest science and technology, thereby allowing the nation to overcome natural disasters (Fig. 5).

RTRI has been participating in the SIP initiative to “strengthen disaster resilience and improve mitigation” since 2014, by developing technologies to reduce damage caused by sudden localized violent events such as downpours, designing methods to detect localized meteorological phenomena, suited to the railway system comprising linear structures, hazard assessment of localized weather events, and devising optimal operational regulations and passenger evacuation procedures in case of sudden localized violent downpours.

As to the disasters caused by rainfall, strong winds and other weather events, conventional railway systems are kept safe with operational regulations based on observations gathered from precipitation gauges and anemometers distributed along railway tracks. However, there are many cases where localized and extremely singular weather phenomena, such as “guerrilla rainstorms,” cannot be detected by using these traditional observation systems.

Likewise, railway facilities are sometimes damaged by debris flows from localized heavy rainfall in an area far away from the railway track. Accordingly, to prevent disasters due to local weather events, it is essential to be able to identify weather signals with broad, high-density observation methods. Weather radars for example are used for High-resolution Precipitation Nowcasts from the Meteorological Agency delivering weather information, is considered to be effective. Utilization of such radar observation data is being studied by some railway operators. Since the existing radar observation systems are designed to observe the airspace above, the measured values may differ from the rainfall data at the ground level. However, simultaneous use with local weather simulations is considered to be a means to obtain higher precision ground level precipitation predictions.

Operational regulations aimed at preventing rainfall related accidents were designed on the basis of past measured precipitation values. Precipitation limit values used for regulating train operations are based actual rainfall data from past precipitations, including rainfall which led to a disaster. Therefore, it could be assumed that rainfall related hazards could be predictable in these sections where rainfall data is measured. However, it is rare for precipitation measurement points to be exactly in the place where a rainfall hazard is going to occur. Therefore, this data can only be used as an indication of relative probability of disaster. Weather radars however can observe precipitation in a spatial range, therefore when the risk of disaster occurrence against an absolute precipitation of an individual slope is determined, radar observation values can be used to assess the risk based on individual degree of disaster occurrence probability. Research will be car-

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Fig. 5 Concept in SIP tasks of overcoming natural disasters

Fig. 6 Further studies on localized heavy rain disasters
ried out therefore to find a method to produce a sequential updating type hazard map by assessing the probability of flooding and debris flow disasters along a railway line, commensurate with precipitation rates and by taking into consideration the affected area along the line and the application limits of physical measures. An algorithm is also being designed help operational decision-making based on the sequentially updated hazard map which should also help determine optimal evacuation routes for the passengers. Current research and development plans are to propose an entirely systemized methodology comprising the detection of extreme weather phenomena, estimation and forecasting of disasters, as well as the train operation control and passenger evacuation guidance (Fig. 6).

4. Future plans

The concept of disaster mitigation or resilience improvement is a necessary for coping with huge external forces. Through its participation in SIP, RTRI is promoting research and development for sophisticated disaster reduction technologies geared towards resilience.

References

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