Recent Research and Development about Disaster Prevention Technology

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This paper describes recent research and development on disaster prevention technology at RTRI. We developed some prevention techniques for extreme weather events such as tornados and localized heavy rainfall as part of RTRI’s long-term research plan “RESEARCH2020”. As part of this plan, a countermeasure against unusual or extreme weather events in the form of a real time hazard map system applying predictive meteorological information was developed. RTRI also built a method to evaluate resilience and a system for generating restoration strategies. A new long-term plan, called “RESEARCH2025” has been compiled, and RTRI is now working on developing two areas of research: a high precision operation control system applying observation data, and a method to evaluate slope stability after heavy rain.

Key words: disaster of extreme severity, real-time hazard map, resilience, recovery strategy, train operation control

1. Introduction

In recent years, violent typhoons of unprecedented weather, and extremely intense wide-area shakes caused by massive earthquakes have intensified natural disasters occurring in Japan. To respond to these extreme disasters, more than ever before, key infrastructures including railways must be made more resilient, while targeted measures are needed to prevent disasters. Taking into account the type of natural disasters which occur in Japan, this report explains the technological development that the Railway Technical Research Institute (RTRI) has been working on in recent years, and looks forward to future efforts.

2. Research and development in RESEARCH 2020

The 2011 off the Pacific coast of Tohoku Earthquake, highlighted the need for technology aimed at mitigating damage and to respond to unexpected natural external forces. As such, in the five-year Master Plan that started in 2015 (i.e. RESEARCH 2020), RTRI worked on the “Enhancement of Disaster Prevention and Mitigation Technologies for railways” intending to develop technologies that could contribute to damage reduction.

As such, RTRI worked on developing (i) a real-time hazard map for exceptional meteorological phenomena such as localized short-term heavy rain fall and wind gusts, (ii) technologies that could contribute to improving resilience against huge earthquakes which cause massive wide-area damage, and (iii) technologies that could contribute to pre-reinforcements and recovery strategies from major disasters. The following sections overview the outcomes to this work.

2.1 Mitigation technology to respond to exceptional meteorological phenomena

2.1.1 Wind gust detection using XRAIN

RTRI worked on the development of a method to evaluate the occurrence of gusts on the ground by detecting characteristic air flows in the sky using data from X-band MP radars (XRAIN) installed nationwide by the Ministry of Land, Infrastructure, Transport and Tourism.

Wind gusts are detected using radar data by extracting regions where the Doppler velocity distribution obtained from XRAIN changes significantly in the line-of-sight or azimuth direction (i.e. shear segment), with reference to a previously reported method [1]. They are detected as two-dimensional shear regions by integrating the surrounding similar shear segments (Fig. 1). A threshold is set for the maximum value of the wind speed difference in each shear segment that constitutes the detected gust region, and if the value exceeds the threshold, the wind is detected as a gust. The gust region in the sky is obtained for each radar observation time, and the moving direction and velocity of the gust region are obtained from the positions of the gust regions at the two most recent observation times by using the cross-correlation method, thereby estimating the position of the gust region after 10 minutes.

In addition, we decided to correct the difference between the sky and the ground by numerical calculation using the Weather Research and Forecasting (WRF) weather model.

We prototyped the gust detection / movement prediction system shown in Fig. 2 by using the above gust region detection and the above method that corrects the data into the on-ground gust regions. While updating and displaying the data at 5-minute intervals, this system shows on the map, the moving position of the gust after 10 minutes.

![Fig.1 Overview of feature detection by radar](image-url)
These outcomes, we developed a system that extracts large-scale landslides that could cause a slope failure of the same scale. On the basis of topographical analysis based on disaster occurrence cases and developed a method to extract from the topographical conditions, the locations where large-scale landslides are likely to occur in the future. In addition, we analyzed the rainfall amount that resulted when a large-scale landslide is divided into three ‘hazard sections’: the section running up to the hazard, the section where the actual hazard is, and the section following the hazard. The trains running in each section are obtained by calculation, and the necessity of stopping the operation of each train, and if necessary its stop position, are determined. Since the hazard position and range change with the predicted time, the system sequentially displays train operations accordingly. It can also show the evacuation route which passengers can take from the train where it has stopped to the nearest evacuation site, if the stopped train is expected to be damaged by, for example, an inundation. Also in this case, it can display safe evacuation sites and evacuation routes which avoid areas expected to be in the inundation range, calculated sequentially.

By using the real-time hazard map, we can predict each inundation and large-scale landslide hazard due to gusts or localized short-term heavy rain downpours using external weather forecast information, and from these results, obtain information to be used for train operation control and evacuation guidance.

2.2 Disaster mitigation technology for huge earthquakes

2.2.1 Anti-catastrophe evaluation method

For a huge earthquake with shaking on a larger scale than expected, ideally damage should be limited to a level which will allow rapid recovery.

Therefore, the concept of anti-catastrophe is introduced in Design Standards for Railway Structures (Aseismic Design Standard) (in Japanese), and we have developed a method to evaluate it. Anti-catastrophe evaluation uses six indices: redundancy and robustness of structures, the securing of buffer area around structures, the anti-aftershock resistance, the structural recoverability, and the recoverability in the network aspect (Fig. 5). The recoverability in the network aspect is evaluated by using the method for calculating the amount of transport volume loss generated by a disaster, detailed later. The redundancy evaluation includes whether or not self-weight supporting columns [2] exist (Fig. 6). Self-weight
supporting columns are column members that can support structures such as girders on top of themselves even if regular columns are damaged by an earthquake and can no longer withstand normal train loads. This makes it possible to prevent girders from falling, leading to probable early recovery. The robustness evaluation includes whether or not it is provided with rail buckling prevention measures [3] (Fig. 7), which are intended to prevent buckling of rails by constructing improved colonnade ground members at the joint between abutment and embankment (a weak point against earthquakes). The implementation of such measures improves the robustness, therefore contributing to maintaining the railway functionality even in the event of a huge earthquake.

2.3 Recovery strategies for major disasters

2.3.1 Detour/recovery plan making support system

We have developed a detour/recovery making support system for the purpose of supporting the recovery strategy of the railway networks that has been damaged over a wide area by a powerful natural external force exceeding expectations and the making of a business continuity plan (BCP) that assumes damage to them.

By using the input that includes the damage status of the railway network and the recovery resource amount that can be invested, this system can obtain the optimum restoration plan for the damaged route and the detour transportation plan during the recovery period and can determine the recovery status of the transport volume based on the recovery scenario of the damaged route. The recovery plan calculation obtains the recovery procedure of the damaged locations in the railway network and the amount of resources required for recovery amount so that the total transport volume loss can be minimized for the period from the disaster exposure to the complete recovery (Fig. 8). By utilizing the input sections available for train running, the detour transportation plan calculation obtains the daily detour transportation plan that minimizes the detour cost. In addition, the detour cost is calculated as the sum of the additional costs such as the increased transportation fee due to detouring and the cargo storage cost.

2.3.2 Method to evaluate the effect of measures assuming wide-area disaster

As for technologies for measures against huge earthquakes, RTRI has also worked on technological development contributing to the formulation of preventive measures plans, in addition to the technologies that are supposed to be used in the recovery plans after the disaster exposure. In this technological development, assuming that strong shaking caused by a huge earthquake could spread over a wide area, we aimed to develop a method for selecting effective countermeasure locations and construction methods to keep the railway network functioning.

This method uses the transport volume loss created by the detour/recovery plan support system. To determine the transport volume loss incurred during the disaster exposure, we need to evaluate the recovery progress of the damaged facilities. The calculations for this purpose require various types of specialized knowledge related to disaster recovery work, including the selection of the construction method according to the scale of the disaster and the period required for construction if that construction method is selected. Regarding our developed method, we have improved its usability by incorporating construction-method-related information into a database, assuming that railway operators will use it for studying countermeasure plans.

This database contains the required resources that are organized by structure type according to the degree of damage and the construction method selected. The use of this database makes it possible to automatically calculate the speed of recovery, just by selecting the construction method. Figure 9 shows an example of calculating the transport volume recovery rate using the developed method. In Fig. 9, when the four locations of (1) to (4) on the railway network shown on the left side are damaged, the evaluation results are as shown in the chart on the right side. It shows, for example, that if all the sections are damaged, it will take 32 days for the transportation recovery rate to return to normal levels. When comparing the cases where the sections are damaged independently, the chart also shows that it takes the longest time to fully recover the network when section (3) is damaged. We can, therefore, obtain the evaluation result...
that reinforcing the facility in section (3) in advance is most effective to ensure that the network continues to function.

3. Working on disaster prevention technology in RESEARCH 2025

As mentioned above, in RESEARCH 2020, we worked on the development of the technologies that contribute to the mitigation of damage by targeting unusual meteorological phenomena (e.g. sudden heavy rains, gusts) and huge earthquakes. In RESEARCH 2025, the new Master Plan that started in FY2020, we are working on R&D with the aim of strengthening the railway system in response to intensifying meteorological disasters. Its content is broadly divided into two: refinement technology for train operation control using live data and condition evaluation technology for early emergency recovery. In the refinement of operation control, we use external meteorological information as shown in Fig. 10 and centrally process it together with internal meteorological observation data to prepare high-density surface meteorological information. It will be used for operation control in heavy rains or strong winds. As for operational control during heavy rain, the focus is being placed on weak points along the wayside, to be able to evaluate changing safety levels from moment to moment, and develop a method to support control of operations. In terms of controlling operations in case of strong winds, the aim is to anticipate changes in various risks caused by strong winds and develop an operation control method based on these changes. Through these R&D activities, it is hoped that we will be able to develop a method which minimizes downtime due to train operation control, in order to avoid excessive disruption to operations.

In the field of status evaluation technology, we aim to be able to evaluate the proof strength of embankments after heavy rain based on rainfall data and the extent of defects and to develop indices for deciding the resumption of operation from the relationship with the train loads. We will conduct a watering experiment using a simulated embankment to clarify the bearing capacity characteristics of an embankment exposed to heavy rain (Fig. 11). By performing a case study by numerical analysis, we will also generalize stability indices based on both the rainfall amount and the embankment conditions.

The obtained outcomes should make it possible to make rapid decisions about when to resume train operations. We believe that this work will also allow us to prioritize locations where recovery work should be carried out and optimize the completion of this work.

4. Conclusion

This paper mainly overviewed disaster-related RTRI R&D carried out as part of RESEARCH 2020 and 2025. In addition to the projects presented in this paper, RTRI is also working on a variety of disaster-related R&D topics such as research on snowmelt and snow ice, on river-bed scour, on the aging of slope countermeasure works, on fallen trees, and on strength reduction by rock mass weathering. We would like to promote technological development targeting all natural disasters and lead it to the achievement of a safe and secure railway system.

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