Detection of Increasingly Severe Natural Phenomena and Disaster Prevention for Railway Facilities

This paper describes detection of increasingly severe natural phenomena and disaster prevention for railway facilities operated by East Japan Railway Company (JR East). Recently, weather conditions have been changing quickly and drastically in Japan, and safe and punctual operation is greatly affected by disasters. Therefore, we have introduced systemized and sophisticated observation equipment to detect meteorological phenomena such as heavy rainfall, scouring by flood, heavy snow, and strong wind as well as to detect earthquakes. Also, we have been working to increase resilience of railway facilities against disasters and reduce forces acting on those caused by disasters. With these actions, we manage mass, rapid, and dense transportation safely and properly.

**Keywords:** Operation control, Natural disaster, Torrential rain, Rockfall, Strong wind, Earthquake

1 Introduction

Climate conditions have been changing recently, and incidents of localized torrential rain in a short period of time are increasing. Active faults all are said to have come into a period of increased activity. Efforts in safeguarding railways against natural disasters are regarded as important preparations to continue safe and stable transport into the future, and East Japan Railway Company (JR East) is therefore taking measures against expected natural disasters and hazards, aiming for building a railway capable of withstanding natural disasters.

Approx. 1.7 million people a day use JR East’s railway network. In the greater Tokyo area in particular, through operation with other railway operators and through operation of JR East trains on the Ueno-Tokyo Line now directly connecting Ueno and Tokyo stations are examples of projects to eliminate needs of transferring and shorten travel time. With the Tokyo-Ueno Line, through service is now possible from Tokyo Station with the Utsunomiya, Takasaki, and Joban lines by allowing those trains to run in the section where previously only the Yamanote and Keihin-Tohoku lines ran. On the other hand, those tend to result in greater operation disorder when operation suspension where train operation is suspended and/or when slow-down control where train speed is limited is needed to secure railway safety under severe weather phenomena such as heavy rain, strong wind, and earthquakes.

Efforts of JR East in disaster prevention and resilience are largely categorized into measures to enhance resistance of railway lines to natural phenomena by improving facilities and measures to secure running safety of trains by earlier detection of natural phenomena, and JR East combines those for actual application. In measures to enhance resistance to natural phenomena, it is essential and important to take measures based on the characteristics of individual lines and past experience. In measures to secure running safety of trains, JR East increasingly adopts meteorological observation and prediction equipment that have advanced remarkably in recent years for disaster prevention and resilience.

This paper introduces continuing and recent efforts, and it explains objectives and effects of those efforts and concepts of measures taken. Due to space limits, this paper does not cover aseismic reinforcement of facilities.

2 Disaster Prevention by Reinforcing Facilities

In order to secure disaster resistance against natural phenomena, we need to reinforce structures as a whole so they have a certain degree of required resilience against many natural phenomena such as rain, river rise, snow, wind, and earthquakes. Even for a single natural phenomenon, wayside environment and environment of the area along the railway line need to be fully taken into account. It is thus essential to take measures with clear objectives.

2.1 Measures against Rainfall

Damage such as slope failures, earth flowing onto track, and flooding of track due to localized torrential or long rain is a major factor in long-term transport disruption. JR East thus reviews sections subject to operation control under heavy rain and takes measure to eliminate need for operation suspension and improve criteria values at which operation control commands are issued. For the route of the Narita Express limited express to Narita International Airport (Sobu and Narita lines) and other lines mainly in the greater Tokyo area where disruptions greatly affect passengers, we have carried out intensive construction work for rainfall disaster prevention. In such work, we built RC lattice frames and cast preventive piles (Fig. 1) mainly to prevent slope failure of locations such as embankments and excavations. We also improved drainage for rainwater flow and set up fences and hoods to prevent earth flowing in to railway facilities from natural slopes.

The effects of transport stability improvement thanks to those preventive measures against rainfall disaster include 1) elimination of need for operation suspension on nine sections of eight lines, 2) improvement of criteria values at which operation control commands are issued on two sections of two
In order to shorten recovery time, it is necessary to identify the scale of the disaster once it has occurred and arrange recovery materials and personnel quickly. We have thus prepared carry-in routes and recovery work bases in areas with high disaster risk on mountainous lines and set fixed-point monitoring cameras along the line (Fig. 3).

2.2 Measures against Rockfall
As individual events of rockfall end within seconds, quantitative prediction and forecast of place, time and scale of occurrence of the event is said to be very difficult. JR East up to now has taken rockfall damage prevention measures based on soundness evaluation results. Those measures include fixing loose rock on slopes to the foundation using concrete and rock bolts to prevent rolling and sliding of that rock and construction of track protective facilities against rockfall, such as hoods, fences, and retaining walls (Fig. 4). For the locations where rockfall might cause serious train accidents among locations with particular high risk of rockfall, we have taken prioritized measures.

2.3 Measures against Scour
Scour at piers and river revetments is a phenomenon where abrasion of a river damages the stability of the supports of a structure and could lead to collapse of piers and river revetments. Due to a lack of large plains and to severe weather conditions such as heavy rain, flooding tends to easily occur in the environment of Japan. Moreover, gravel and sand that compose riverbeds are now not continuously supplied because many dams were constructed in flood control projects upstream on rivers that
cross bridges of JR East and large volumes of river gravel were extracted in Japan's period of high economic growth. We thus have protected the riverbed and reinforced piers and river walls of bridges and river revetments of JR East that cross or are located near rivers as measures against scour.

In that preventive work, we specify the construction method and scope based on characteristics of the rivers and bridges as well as analysis result of past disasters. One of those measures is installing concrete blocks on the riverbed near piers (Fig. 5).

2.4 Measures against Heavy Snow

Based on experiences in past snow disasters and transport disorders, we have taken measures combining different facilities according to the amount of snowfall and the environment along lines.

2.4.1 Snow Fences

Under some line conditions in areas where the amount of snowfall is large and strong winds blow, snowdrifts can occur and lead to serious accidents. In order to prevent such incidents, we have installed steel snow fences on the Yamagata and Akita Shinkansen lines (Fig. 6). The specifications of the snow fences are determined according to the height and distance from the ground surface and track as well as wind direction. The fences can be retracted in the summer.

2.4.2 Snow Cornice Preventive Panels

In areas of heavy snowfall, much snow can accumulate in the span of just one night. When wind blows in a certain direction, snow cornices can form and possibly cause snow dropping onto the track. Snow dropping from the upper part of a tunnel entrance to the track in particular can strike overhead contact lines and cause transport disorders. Conventionally, accumulated snow was manually and repeatedly removed at tunnel entrances in areas of heavy snowfall; however, the effect of this method was limited due to labor restriction. In light of that, we have installed steel snow cornice preventive panels to tunnel entrances (Fig. 7). With these preventive works, the Yamagata and Akita Shinkansen lines laid through the sharp mountainous areas are given priority in taking measures against snow cornices.

2.4.3 Stopper Wire

Trees and bamboo fallen due to accumulated snow or strong wind are a cause of disruption to transport. We basically deal with trees along the lines by, upon conducting periodical discussion with landowners, cutting or trimming them in advance of the snow season. Repeated discussions with landowners are needed for fast-growing bamboo; however, sometimes we are not able to take appropriate measures and bamboo falls onto the track because we could not obtain permission from landowners to cut bamboo in time. In light of that, at locations where we face difficulties in achieving agreement, we place stopper wires supported by wayside steel poles to control leaning of trees and bamboo due to accumulated snow (Fig. 8). Those wires have been placed on the Chuo, Sobu, and Narita lines and other conventional lines in the greater Tokyo area in particular.
water flowing onto slopes and in underground water. Those raise pore water pressure in slopes and lower slope stability, resulting in slope failure. As a preventive measure against such damage in snowmelt periods, JR East has improved drainage and carried out slope protection works (Fig. 9).

2.5 Measures against Strong Wind
In order to secure railway safety and mitigate transport disorders in strong winds, which can cause train derailment accidents and transport disorders, JR East has set up windbreak fences. Those windbreak fences to reduce wind force acting on trains are made of punched steel plates or FRP and constructed according to specifications based on wind direction and distance from rails (Fig. 10).

Since 1991, we have set up windbreak fences on 27 sections of 11 lines mainly in the greater Tokyo area. One effect of this measure for transport stability compared with before construction is a reduction in duration of operation suspension by approx. 50 to 90% and reduction in duration of speed control by approx. 60 to 80% on the lines where windbreak fences were put into use after fiscal 2007 (Keiyo, Musashino, and Joban lines).

2.6 Measures Using Detectors
We have taken the aforementioned measures of reinforcing facilities in areas with high risk of natural disasters and also taken measures using detectors in cases where direct measures cannot be taken immediately, such as when the origin of disaster is located outside of the property of JR East.

Those detectors using sensors and other devices give an alarm at occurrence of a disaster and stop trains to avoid the risk (Fig. 11).

Such detectors include rockfall detectors, landslide detectors, and scour detectors. With rockfall detectors, we have developed a type that can detect rockfall in a long section of a maximum length of 3,000 m for continuous areas with risk of rockfall.

2.7 Disaster Prevention by Railway Forests
A railway forest is a forest developed along railway lines. As with other measures to reinforce railway facilities, railway forests are effective in preventing disasters due to drifting snow, avalanches, earth failure caused by and rainfall, rockfall, drifting sand, strong winds, and the like; and thus JR East owns approx. 3,900 ha of railway forests. Recently, we have classified those focusing on the functions required for railway forests and on planting multiple species of trees, including indigenous species. By developing in those measures sustainable, diversified railway forests with ecological advantages, we are working on effective maintenance of those forests (Fig. 12).
JR East has placed observation devices for natural phenomena such as earthquakes and rainfall along lines at specified intervals. Thanks to advances in observation devices in quality and innovations in networking technology, we have been increasingly adopting disaster prevention measures applying those devices.

### 3.1 Earthquake Early Warning for Shinkansen

As Shinkansen trains run at high speed, it is quite important to detect occurrence of earthquakes at an early stage and take prompt actions to stop trains. We have thus built the Earthquake Early Warning for Shinkansen, which immediately stops Shinkansen trains before the main motion of an earthquake (secondary waves, S-waves) arrives at railway lines when a large-scale earthquake is detected (Fig. 13).

![Fig. 13 Overview of Earthquake Early Warning for Shinkansen](image)

For this system, seismographs are set not only along railway lines but also on the shore and at inland areas to detect earthquakes at an early stage. As the method to immediately stop trains based on such early earthquake information detected, the system employs a method of estimating the magnitude of the earthquake (M) according to the amplitude of the preliminary tremor (primary waves, P-waves) and the epicentral distance (Δ), which is the horizontal distance from the epicenter. The Δ is calculated from the rate of chronological increase of amplitude of the P-waves. Based on the estimated M and Δ, the system predicts the area where damage by the earthquake is expected and gives an alarm to that area (the “M - Δ method”). In the area to which an alarm is given, substations shut down the power for Shinkansen trains and emergency brakes are applied to Shinkansen trains in operation.

In the 2011 Great East Japan Earthquake, seismographs set on the shore nearer to the epicenter than those along railway lines detected the earthquake and activated emergency brakes of Tohoku Shinkansen trains in operation. As a result, the train that was running near the epicenter at approx. 270 km/h was able to decelerate to approx. 100 km/h before the largest seismic motion arrived.

### 3.2 Earthquake Early Warning for Conventional Line

For conventional lines, JR East have built a Conventional Line Emergency Train Stop System utilizing radio communications as a system to give alarms to conventional trains for emergency stopping when a large-scale earthquake is detected. We also have a Earthquake Early Warning for conventional line that initiates emergency stops for trains in the area according to the scale of the earthquake by fully applying Earthquake Early Warnings (EEW) issued by Japan Meteorological Agency (JMA) and earthquake information from the Earthquake Early Warning for Shinkansen (Fig. 14). In the Great East Japan Earthquake and its aftershocks, those systems activated and functioned properly.

![Fig. 14 Overview of Earthquake Early Warning for Conventional Line](image)

### 3.3 Operation Control Indices in Earthquakes

For traditional operation control in earthquakes, we used the Japan Meteorological Agency seismic intensity scale and the maximum acceleration as the indices; however, we now utilize spectrum intensity values (SI values). Those values show more correlation with damage to structures compared with the traditional indices and thus allow us to reduce impact on transport with fewer operation control commands issued.

In the operation control system according to the SI values introduced in 2003, criteria values for speed control and operation suspension are specified in three classes based on the line environment such as occurrence of rockfall and design specifications of structures such as viaducts and bridges, and we conduct operation control for individual lines based on those characteristics of the lines. The system has experienced the Great East Japan Earthquake and other earthquakes since its introduction, and we were able to confirm that no damage was caused to structures that had aseismic performance of a given level or higher in the areas subject to operation control even in seismic motion of a specified scale or larger. We are therefore working raise the class of criteria values applied.

Seismographs are placed along conventional lines at approx. 40 km intervals and at denser placement of approx. 20 km intervals in the greater Tokyo area. Furthermore, seismographs are placed along the major lines of Tokaido, Chuo, Tohoku, Joban, Sobu and Keiyo lines at approx. 10 km and along the Yamanote Line at approx. 5 km, aiming to shorten downtime due to security arrangements and the like when operation control is issued.
3.4 Indices for Operation Control under Heavy Rain

For traditional operation control under heavy rain, we used hourly rainfall and total rainfall combined as indices; however, we now utilize effective rainfall as the operation control index with an aim of shortening time subject to operation control while maintaining the disaster detection ability of former indices. Effective rainfall is a rational model of rainfall as soil moisture changing due to penetration or flowing out as time passes.

JR East measures rainfall using rain gauges placed along lines at approx. 10 km intervals. As incidents of localized and torrential rain in a short period of time have been increasing recently, we are reviewing rain gauge placement and increasing the number of those to improve ability to capture incidents of such heavy rain. In addition, technical advances in weather observation allow us to obtain and apply accurate rain information from weather radars and the like. We are therefore working on the introduction and application of accurate and two-dimensional rainfall information.

4 Conclusion

This paper has covered JR East efforts in disaster prevention and resilience to secure safety of railway operation under natural phenomena such as rainfall, rise of rivers, snowfall, strong winds, and earthquakes. While not covered here, rise of underground water level, for example, can cause disruption to transport, so we are making necessary efforts in observation and countermeasures.

It is important in disaster prevention and resilience of railway facilities to precisely identify and evaluate natural phenomena, which are changing and becoming more severe year by year. In order to secure or enhance disaster resistance of railway lines, we need to appropriately evaluate and analyze performance for natural disaster resistance of existing facilities and take steady actions areas of insufficiency.

Based on the experiences of maintenance engineers who have hitherto secured railway safety according to characteristics of individual lines, we will also introduce and develop new technologies for further improvement of safety and stability of railway operation.

This paper is a translation from Japanese by the JR East Technology and Planning Department.

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