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Enhancement of Railway System Resilience Against Intensifying Meteorological Disasters

Introduction

In recent years, external meteorological forces, such as heavy rainfall and strong winds, have intensified, resulting in increasingly severe disasters. In response to this trend, our master plan, RESEARCH 2025, established the major research theme “Enhancement of Railway System Resilience Against Intensifying Meteorological Disasters,” under which related research and development (R&D) activities have been conducted. This article provides an overview of the principal achievements of these efforts.

Background and Objectives

The Ministry of Education, Culture, Sports, Science, and Technology and the Japan Meteorological Agency (JMA) project that rainfall patterns will continue to become increasingly extreme and that typhoons affecting Japan will intensify¹⁾. Railway operators currently ensure train safety during heavy rainfall and strong winds by implementing operation controls, such as canceling services or imposing speed restrictions. However, as these external forces become stronger and more frequent, both the

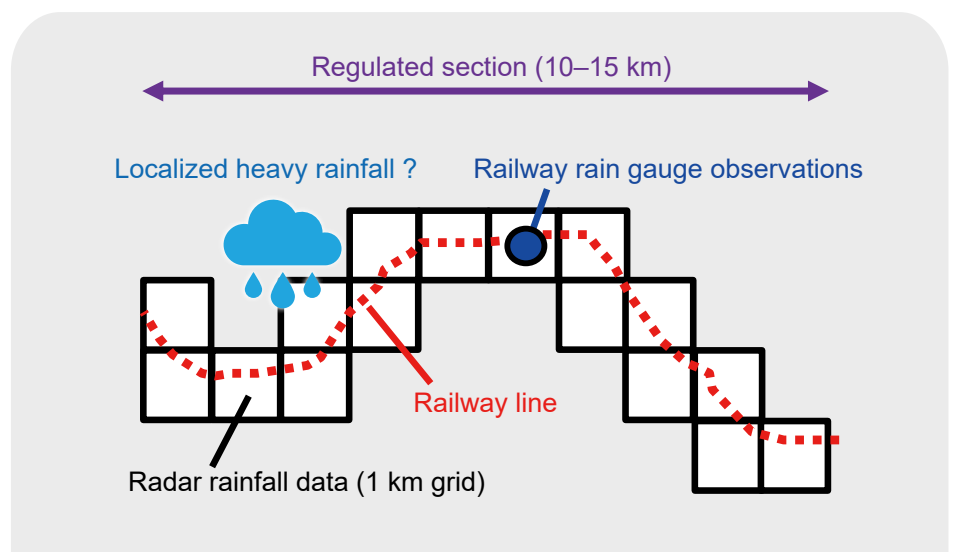


Figure 1 Conceptual relationship between railway rain gauge observations, radar rainfall data, and regulated sections

frequency and duration of such operation control measures are expected to increase. In addition, these changes raise concerns about a potential increase in slope-related disasters, including embankment collapse. In this context, two objectives were established for the major research theme: (1) to propose methods for enhancing operation control during heavy rainfall and strong winds to improve safety while maintaining punctuality, and (2) to propose methods for expediting responses to damaged embankments with the aim of reducing service downtime.

Enhancement of Operation Control During Heavy Rainfall

This section introduces a method for setting operation control thresholds during heavy rainfall using radar rainfall data. In recent years, national agencies and other organizations have improved the accuracy of real-time and forecast areal rainfall information ([radar rainfall data](#)^{*1}), and some railway operators have introduced operation control based on radar rainfall data²⁾⁻⁵⁾ to detect [localized intense downpours](#)^{*2}. As the use of radar rainfall data becomes more widespread, it is anticipated that rainfall observations currently obtained from railway rain gauges will eventually be replaced by radar rainfall data.

Currently, operational control during rainfall is implemented using point rainfall values observed by railway rain gauges, and restrictions are applied to a defined line segment, referred to as a regulated section. If operation control were implemented using radar rainfall data instead of railway rain gauge data, all radar rainfall data distributed in 1 km × 1 km grids within the regulated section would be used (*Figure 1*). In this case, if the operation control thresholds remained unchanged after the introduction of radar rainfall data, the increased number of observation points would, in turn, increase both the frequency and du-

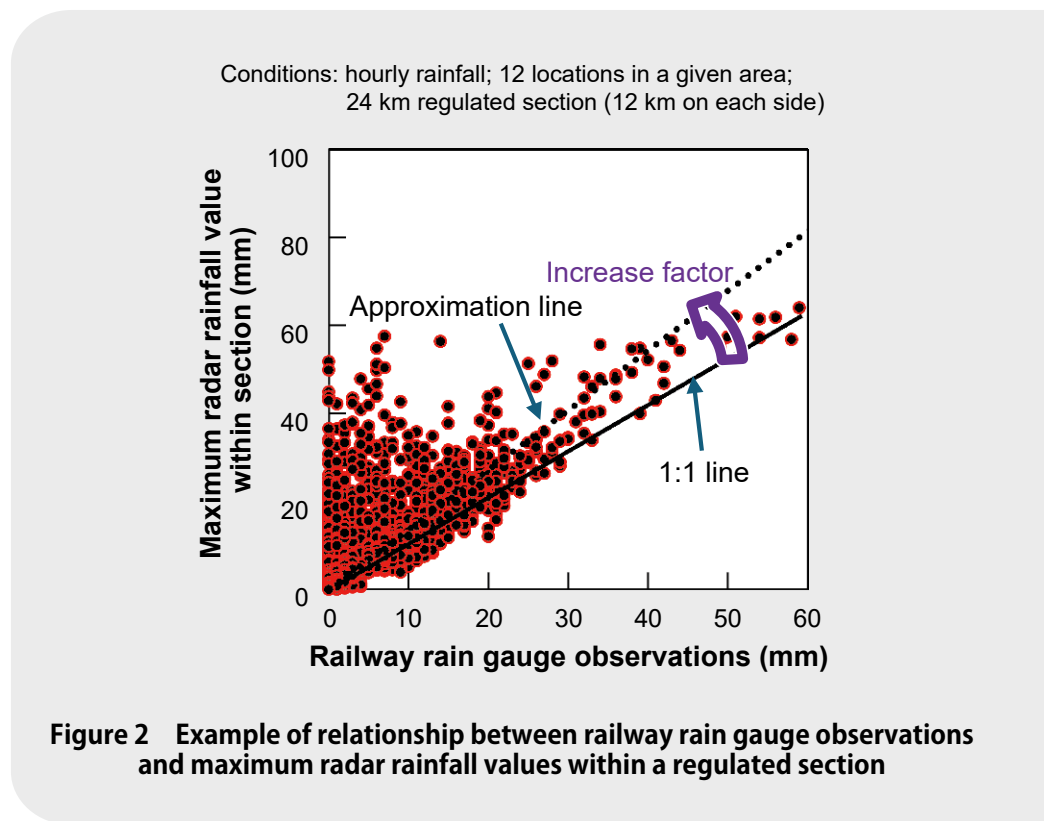


Figure 2 Example of relationship between railway rain gauge observations and maximum radar rainfall values within a regulated section

*1 Radar rainfall data

Information on the areal rainfall distribution observed by radar rain gauges.

*2 Localized intense downpours

A phenomenon in which a large amount of rain falls over a limited area in a short time, also called "guerrilla downpours."

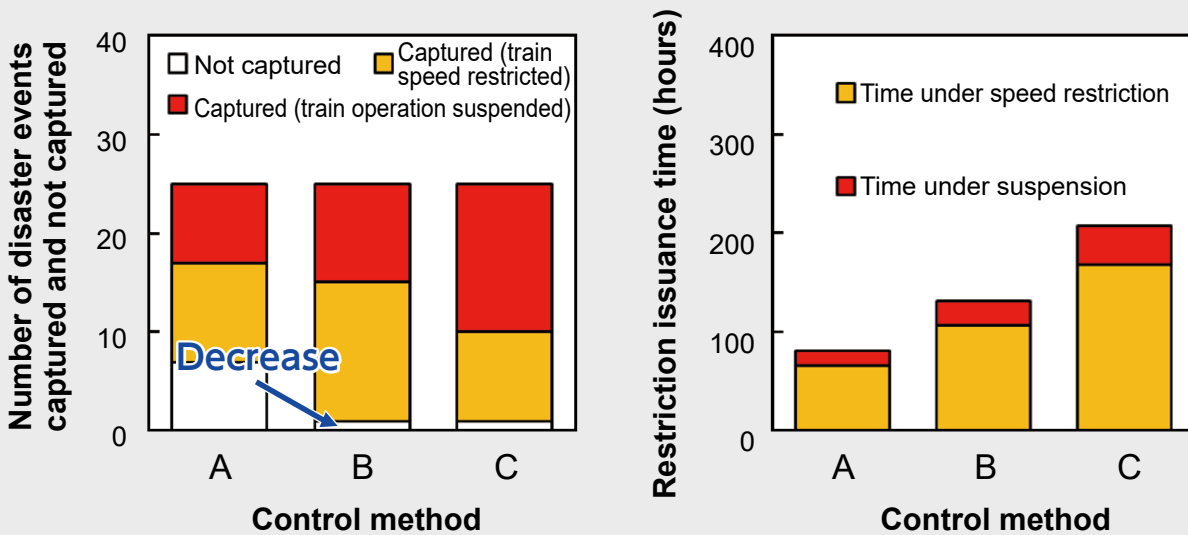
ration of restrictions. To address this issue, a method for setting radar rainfall control values was proposed.

An example analysis of the relationship between railway rain gauge observations and the maximum radar rainfall value within a regulated section for hourly rainfall (*Figure 2*) shows that the data are primarily distributed in a range where the maximum radar rainfall exceeds the railway rain gauge observations. Based on this relationship, an increase factor was derived using a linear approximation, and a method was pro-

posed in which radar rainfall control values were calculated by multiplying the existing control values by this increase factor.

Using the above method to set radar rainfall control values, we estimated, for both conventional operation control using railway rain gauge data and operation control using radar rainfall data, the number of disaster events captured and not captured, as well as the restriction issuance time (*Figure 3*). In this estimation, the proposed method was applied not only to hourly rainfall, which is a short-term rainfall index,

Control method	Railway rain gauge data	Radar rainfall data
A	[Existing control values]	Not captured
B	Not captured	[With correction]
C	Not captured	[Existing control values]



(Conditions: multiple regulated sections; 3–5 year period)

Figure 3 Number of disaster events captured and not captured and restriction issuance time for each control method

but also to long-term rainfall indices; cases in which the radar rainfall control values remained the same as the existing control values were also compared. As shown in *Figure 3* (left), radar rainfall data can capture disasters that conventional operation control fails to detect, thereby enhancing safety. As shown in *Figure 3* (right), restriction issuance time increases when radar rainfall data are used compared with conventional operation control; however, the proposed method suppresses this increase more effectively than simply maintaining the existing control values. In future stud-

ies, such estimations will be applied to a range of regions and line sections to identify remaining issues and establish a practical method for setting radar rainfall control values.

Enhancement of Operation Control During Strong Winds

This section introduces methods for creating real-time and estimated wind speed maps. As in the case of rainfall, wind speed has traditionally been monitored using anemometers installed along rail-

way lines, and operation control has been implemented when observed wind speeds exceed specified thresholds. However, anemometers are not installed along the entire length of a line; in many cases, they are located only at sites where strong winds are expected to occur, based on past experience (*Figure 4*). As noted earlier, because typhoons are expected to become stronger in the future, the likelihood of strong winds occurring at any location along the line will increase. Therefore, areal wind speed monitoring is increasingly necessary.

On the other hand, areal wind speed

Enhancement of operation control during strong winds

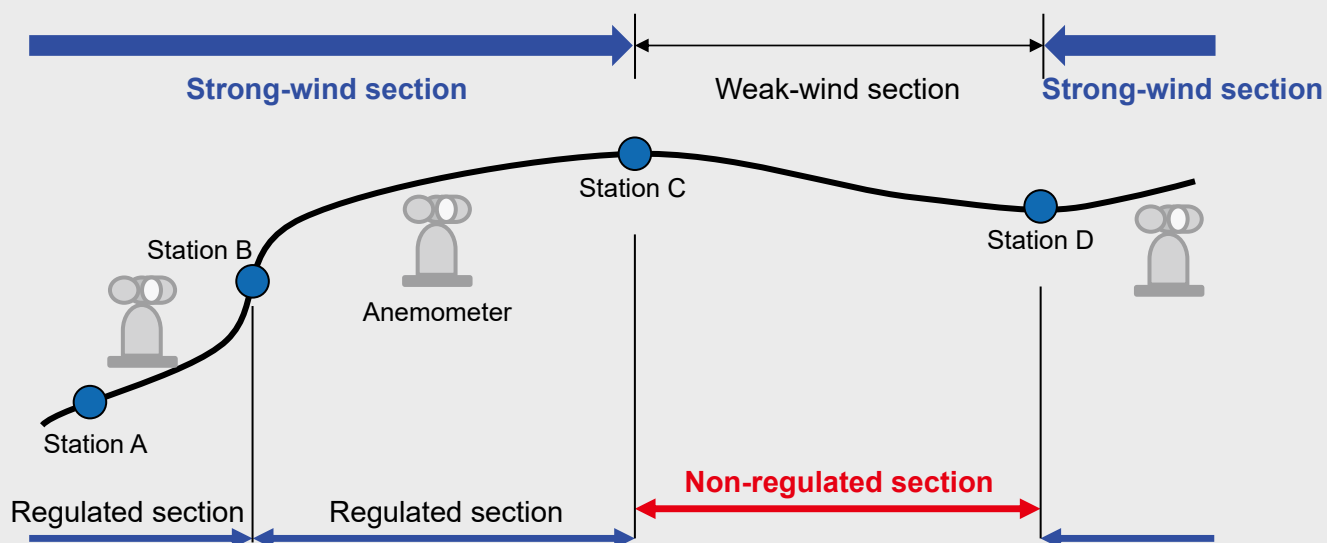


Figure 4 Conceptual relationship between anemometer locations and regulated sections

data distributed by national agencies and other organizations differ from rainfall data in that they currently lack the accuracy required for operation control and are provided as average wind speed^{*3} rather than the instantaneous wind speed^{*4} used for operation control. To address these issues, two approaches are proposed: (1) real-time wind speed maps aimed at improving safety by identifying wind speeds at low cost in areas without existing wind speed monitoring, and (2) estimated wind speed maps aimed at improving efficiency by supporting advance preparations for issu-

ing and lifting operation control.

For real-time wind speed map creation (*Figure 5*), average wind speed and average wind direction observed at point locations, such as Automated Meteorological Data Acquisition System (AMeDAS) sites, are used as input, and wind speeds equivalent to instantaneous wind speed are output as areal data. To ensure that the real-time wind speed map updates in step with the update interval of the observed wind speed, airflow analysis^{*5} is conducted in advance, and a table is prepared for

*3 Average wind speed

The value obtained by averaging wind speed over the 10-minute period preceding the observation time; when "wind speed" is mentioned, this value is typically meant.

*4 Instantaneous wind speed

The wind speed at a given observed moment can reach 1.5 to 3 times the average wind speed.

*5 Airflow analysis

A technique for analyzing airflow and related phenomena using computer-based methods grounded in theoretical principles, such as fluid dynamics.

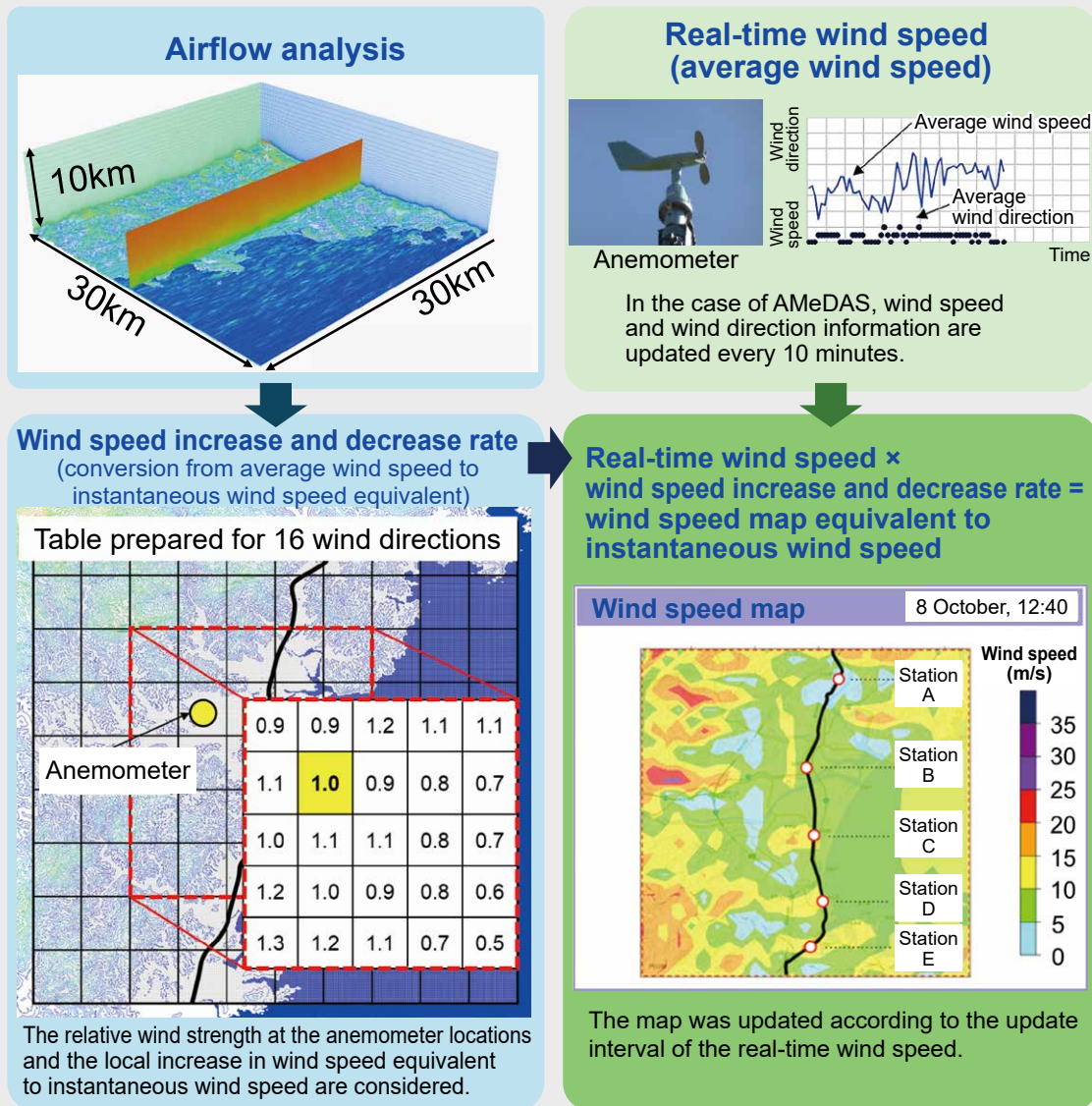


Figure 5 Overview of the method for creating real-time wind speed maps

each of the 16 wind directions. These rates serve as multipliers for converting the average wind speed at the observation point, normalized to 1, into an instantaneous wind speed. This approach makes it possible to instantaneously convert point-based

information into areal information.

To create the estimated wind speed map (Figure 6), areal forecast average wind speed data distributed by the JMA and other agencies are used as inputs. Airflow analysis is also performed in advance; however,

in this case, a table of wind speed increase rates for converting average wind speed to an instantaneous wind speed equivalent is prepared. Using this table, forecast maps equivalent to instantaneous wind speed can be generated in accordance with the

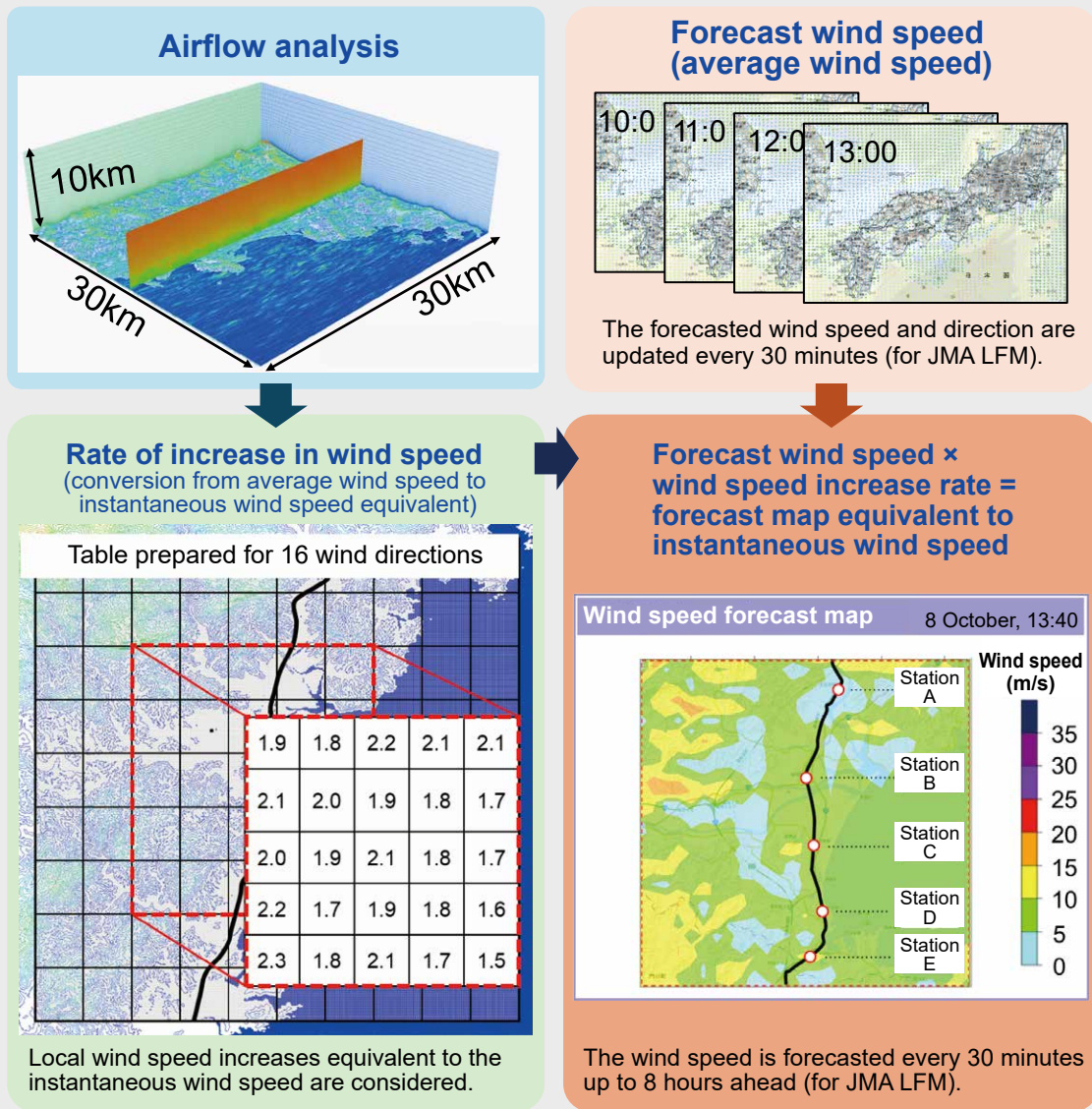


Figure 6 Overview of the method for creating estimated wind speed maps

distribution interval and forecast lead time of the forecasted average wind speed data.

The accuracy of both types of maps was verified using field measurements, and the resulting prediction error was found to be less than 5 m/s. Future work will focus on

further improvements in accuracy.

Expediting Response to Damaged Embankments

This section introduces a method for per-

manently restoring damaged railway embankments in a timely and cost-effective manner to a performance level equivalent to that prior to the damage. Emergency repairs using large sandbags, which offer excellent workability, are commonly imple-



Figure 7 Example of emergency embankment repairs using large sandbags

mented to enable the rapid resumption of train operations when a railway embankment is damaged (*Figure 7*). However, because large sandbags have limited long-term durability, permanent repairs are required after train operations have resumed in order to restore the embankment to its pre-damage performance level.

In conventional permanent repair methods (*Figure 8*), (1) temporary earth retaining walls are installed to protect trains, (2) large sandbags are removed, and (3) the embankment is reconstructed. However, this approach presents challenges in terms of both construction time and cost. To address these challenges, a permanent repair method is proposed in which the sandbags

used for emergency repairs are left in place.

In the proposed permanent repair method (*Figure 9*), (1) only the upper sandbags are removed, and (2) the embankment is constructed on the removed area and in front of the remaining large sandbags. Estimates have shown that, compared with conventional permanent repair methods, this approach can reduce construction time by approximately 60% and costs by approximately 80%. Experiments and analyses confirmed that embankments restored using this method exhibit performance equivalent to that prior to the damage. We plan to promote wider adoption of this method by including it in maintenance and management documentation and

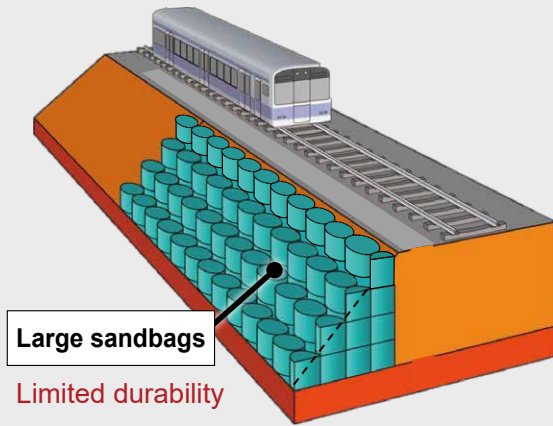
other related materials.

Conclusions

This article presents an overview of the main achievements of the major research theme, “Enhancement of railway system resilience against intensifying meteorological disasters,” under RESEARCH 2025. Although the intensification of natural disasters is projected to continue, some types of natural hazards are not addressed within this theme. Accordingly, beginning with RESEARCH 2030 in the current fiscal year, a new major research theme, “Enhancement of railway system resilience against intensifying natural disasters,” has been

Emergency repairs:

provisional resumption of train operation



Permanent repairs:

full restoration to original profile

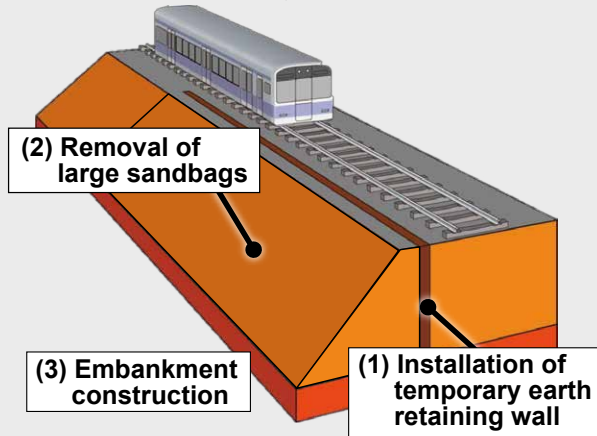


Figure 8 Conventional method and sequence for emergency repairs using large sandbags and subsequent permanent embankment restoration (Schematic)

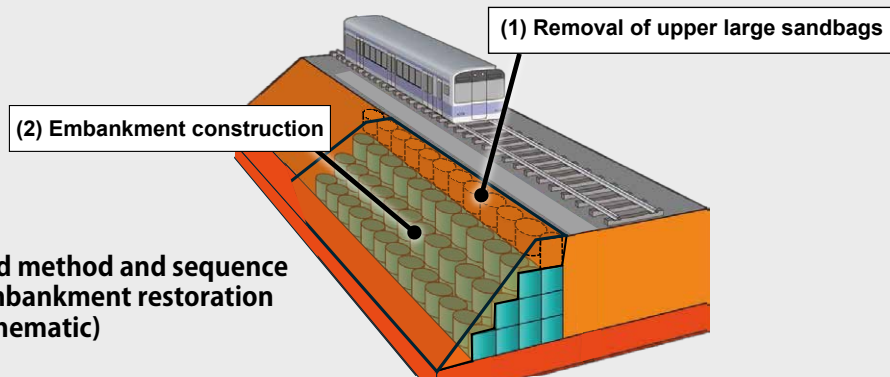


Figure 9 Proposed method and sequence for permanent embankment restoration (Schematic)

established, under which R&D will be pursued to strengthen railway system resilience against a wide range of natural disasters, including earthquakes, rainfall, snow, and falling rocks.

Note: Some of the achievements introduced in this article were obtained through joint research with Toshiba Energy Systems & Solutions Corporation.

References

- 1) Ministry of Education, Culture, Sports, Science and Technology and Japan Meteorological Agency: Climate Change in Japan (2020): Report on Assessment of Observed/Projected Climate Change Relating to the Atmosphere, Land and Oceans, 2020.
- 2) JR East News Release: Efforts in rainfall disaster prevention for Shinkansen in preparation for abnormal weather, 2021.
- 3) JR East News Release: Introduction of new train operation restrictions using precipitation radar on conventional lines, 2023.
- 4) JR Central News Release: Introduction of train operation restrictions utilizing precipitation radar on all conventional line sections, 2018.
- 5) JR West News Release: Further enhancement of safety against localized heavy rainfall, 2020.
- 6) Railway Technology Promotion Center, Railway Technical Research Institute: Railway Technologies Learned from Accidents (natural disaster version), p. 26, 2012.