

# Center for Railway Earthquake Engineering Research



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Among natural disasters, earthquakes are particularly destructive, capable of causing exceptionally severe damage when they occur. The Center for Railway Earthquake Engineering Research focuses specifically on earthquake-related disasters, aiming to ensure the safety and security of railway systems against seismic hazards. Our comprehensive research and development (R&D) efforts span from preventive measures to post-disaster restoration, addressing both software and hardware aspects. Moreover, as the only organization at the Railway Technical Research Institute (RTRI) officially designated as a research center, we are committed not only to R&D but also to actively disseminating information about our R&D outcomes externally. Here, we introduce some of the representative R&D projects undertaken by the Center for Railway Earthquake Engineering Research.

## Introduction

Japan is a country highly prone to earthquakes, and various structures—not only railways—have suffered significant damage over the years. In January 2024, a 7.6-magnitude earthquake with its epicenter in the Noto Peninsula of Ishikawa Prefecture occurred, extensively damaging infrastructure such as railways, roads, and water supply systems. The figure titled *Damages to railway structures caused by*

*earthquakes* shows examples of damages caused by some earthquakes. The upper row illustrates the conditions immediately after the disaster, while the lower row depicts the situation following restoration.

The year 2023 marked the 100<sup>th</sup> anniversary of the Great Kanto Earthquake, a pivotal event that led to the introduction of seismic design in railways and had a profound impact on earthquake disaster prevention in railway systems. This centennial milestone provided a valuable opportunity to

reflect on past disasters and the responses to them, underscoring the importance of continuously strengthening railway disaster prevention over the next century.

Based on the belief that continuous efforts to address earthquake risks are indispensable for ensuring the safety and security of railways, the Center for Railway Earthquake Engineering Research conducts comprehensive R&D across three laboratories: Seismic Data Analysis, Soil Dynamics and Earthquake Engineering, and Struc-

tural Dynamics and Response Control. Our work covers a broad range of topics, from earthquake occurrence to post-disaster response, addressing seismic challenges in an integrated manner. The figure titled *Example of seismic reinforcement for railway structures* illustrates the improvements achieved (top: before reinforcement, bottom: after reinforcement), while the figure on *Seismometers used in railways* shows a device employed for earthquake detection. This report presents representative R&D projects that we have been advancing to date.

### Toward Realization of Earthquake-Resilient Railways<sup>1)</sup>

The term “resilience” has become increasingly familiar in recent years. It refers to the capacity to recover or the robustness of a system, and its application has expanded across various fields. In the context of railways and earthquakes, resilience encompasses two key aspects: reducing the loss of railway functionality caused by earthquakes (robustness) and restoring lost functions as quickly as possible (restorability). By advancing measures to strengthen both aspects, it is possible to build earthquake-resilient railway systems. The figure titled *Resilience and countermeasures against earthquakes* presents a schematic diagram illustrating the concept of earthquake resilience and a timeline of corresponding response measures.

The Center for Railway Earthquake Engineering Research categorizes responses to earthquake-induced damage to railways into four stages: prior measures, emergency response, initial action, and long-term restoration. By streamlining processes

and enhancing expertise in each stage, we are advancing R&D to ensure immediate and effective responses to earthquakes under any circumstances. Among various efforts to realize earthquake-resilient railways, we focus here on two key priorities: “stopping trains quickly to ensure safety at the time of an earthquake” and “resuming train operation as swiftly as possible after an earthquake.” In the following sections, we present related R&D activities of the Center for Railway Earthquake Engineering Research in these areas.

### Detecting Earthquakes Earlier and Stopping Trains Quickly

To ensure the safety of trains traveling at high speeds during an earthquake, it is crucial to stop them as quickly as possible. For this purpose, the Center for Railway Earthquake Engineering Research has developed an early earthquake warning system.

Since shortly after the opening of the Tokaido Shinkansen in 1965, systems for detecting earthquakes and stopping trains have been developed and implemented. The current operating system detects P waves (primary waves)—the faint initial tremors preceding destructive S waves (secondary waves)—to stop trains before the arrival of the subsequent strong shaking. This system can determine whether to stop a train within as little as 1 s after detecting the P waves. The figure titled *Early earthquake warning system* illustrates the workflow from earthquake detection to warning output.

Since the P waves used for detection in the current system are extremely weak, it is crucial to quickly and accurately distinguish seismic motion from various other vibrations (noise), such as those generated by passing trains or nearby vehicles, and to determine whether the identified vibration is indeed an earthquake. The

### Damages to railway structures caused by earthquakes



Damages to railway structures caused by earthquakes  
(by courtesy of JRJT, Japan Railway Construction, Transport and Technology Agency)



Damages to railway structures caused by earthquakes



Restoration status  
(by courtesy of JRJT, Japan Railway Construction, Transport and Technology Agency)



Restoration status

Center for Railway Earthquake Engineering Research has newly developed a method incorporating machine learning, which has recently begun to be applied across various fields, for this identification task<sup>3)</sup>. The figure titled *Noise identification using machine learning* illustrates the conceptual diagram of this approach. The method involves training on a large dataset of seismic motion and train-induced vibrations in advance, enabling the system to determine whether the detected vibration is caused by an earthquake. Specifically, the method employs a convolutional neural network (CNN)\*, a representative technique actively used in recent years to solve problems in image recognition. The figure titled *Examples of noise identification based on machine learning* presents an example of how this method is applied. Here, the Center investigates the extent to which seismic motion and train-induced vibrations can be distinguished. While current technology



Before seismic reinforcement



After seismic reinforcement

Example of seismic reinforcement for railway structures



Seismometer used in early earthquake warning system



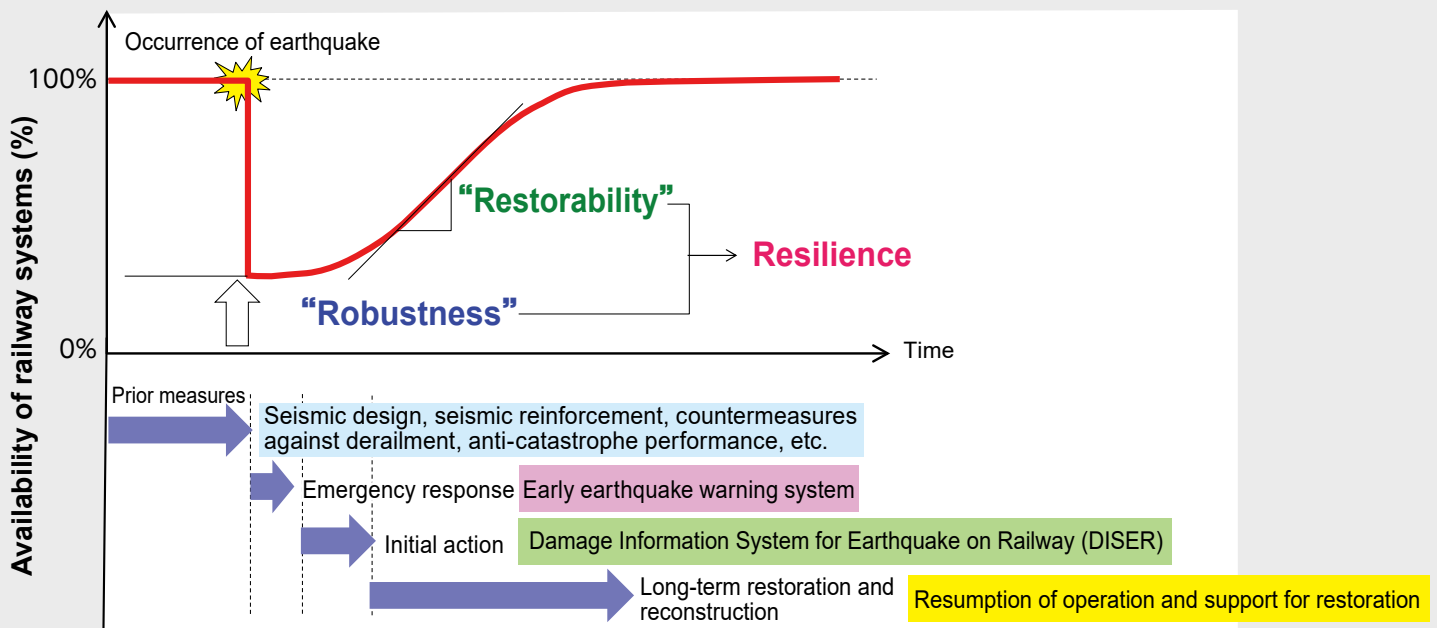
Ocean bottom seismometer (by courtesy of NIED, National Research Institute for Earth Science and Disaster Resilience)

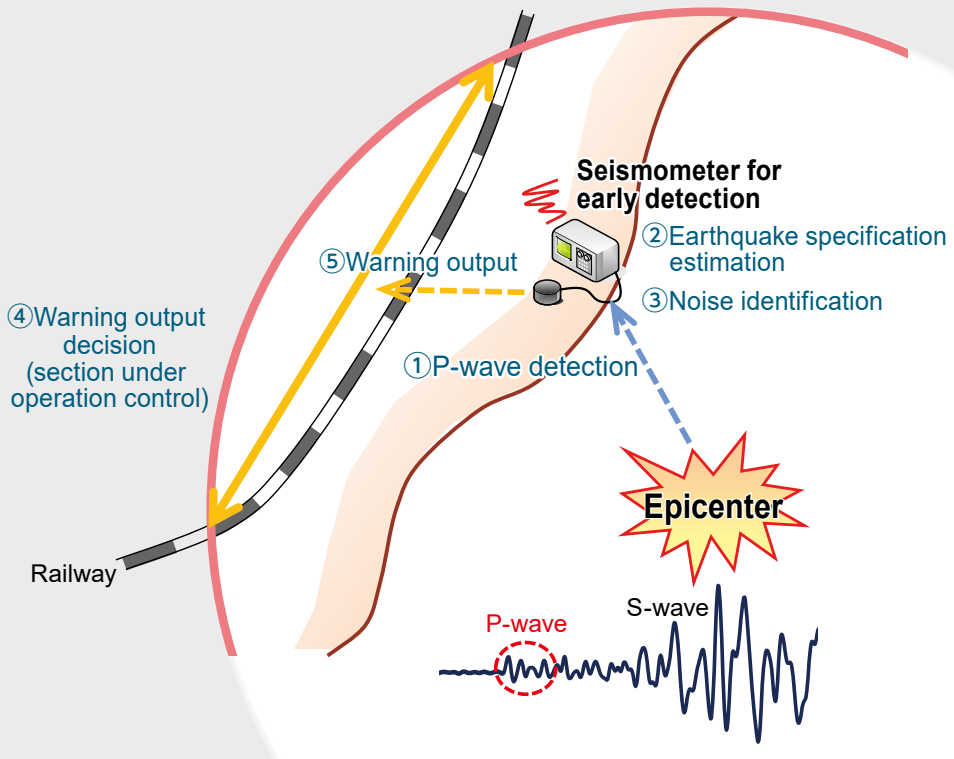
Seismometers used in railways

**\* CNN**

A CNN (Convolutional Neural Network) is a mathematical model inspired by neural circuits in the human brain. It is primarily composed of processes such as convolution (feature extraction) and pooling (reducing computational complexity), enabling it to perform advanced recognition and classification tasks.

**Resilience and countermeasures against earthquakes**





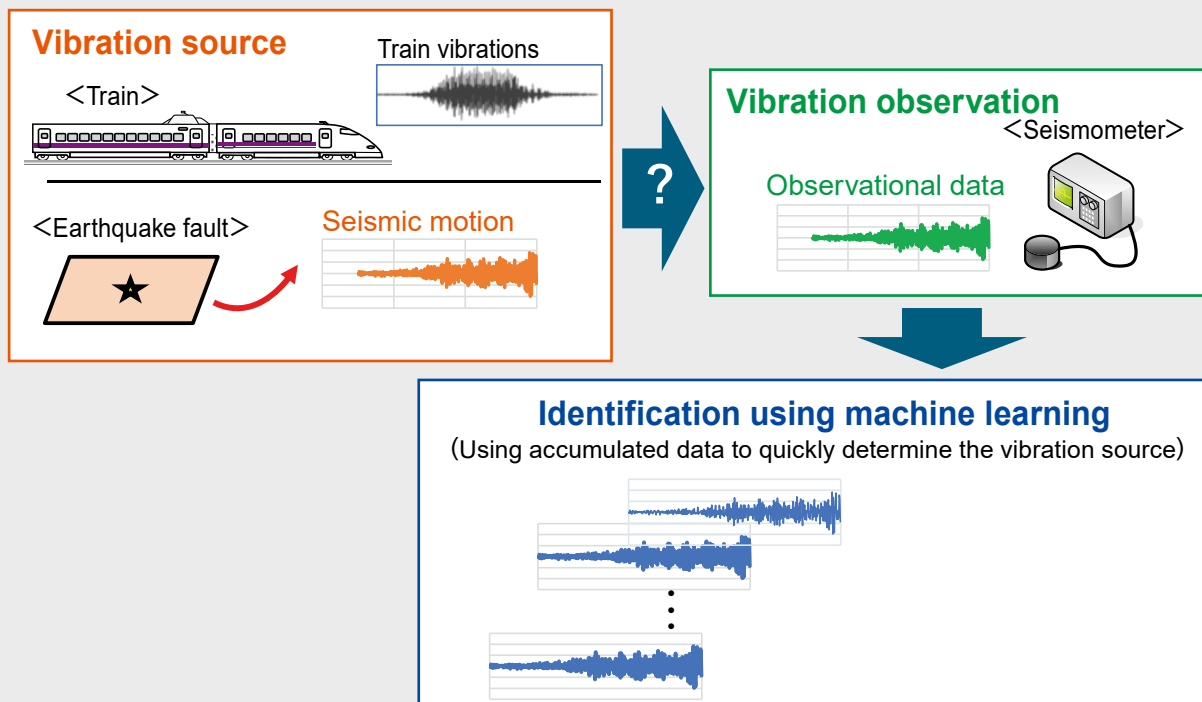
**Early earthquake warning system**

achieves a discrimination rate of approximately 90% for both train-induced vibrations and seismic motion, the machine learning-based method demonstrates a remarkably high discrimination rate of over 99% for both types of vibrations.

### Improving Restorability of Railway Systems

One of the key measures to enhance resilience is the early restoration of functions lost due to earthquakes. Restoring railway operations to normal as quickly as possible after an earthquake—such as promptly resuming train services that were halted during the seismic event and rapidly repairing damaged infrastructure—is critically important for maintaining the normal functioning of society. The Center for

### Noise identification using machine learning



## Examples of noise identification based on machine learning

Vibration data (1 s)	Determination results			Discrimination rate (%)
	Determined as train vibrations	Determined as seismic motion	Classified as others	
Train vibrations	3959	2	2	99.90
Seismic motion	0	3797	4	99.89

Railway Earthquake Engineering Research is actively conducting research aimed at achieving such post-earthquake “restoration.”

To ensure safe operation after an earthquake, it is necessary to confirm the conditions of various elements of the railway system, including structures and equipment involved in train operation. For this purpose, the Center has developed the Dam-

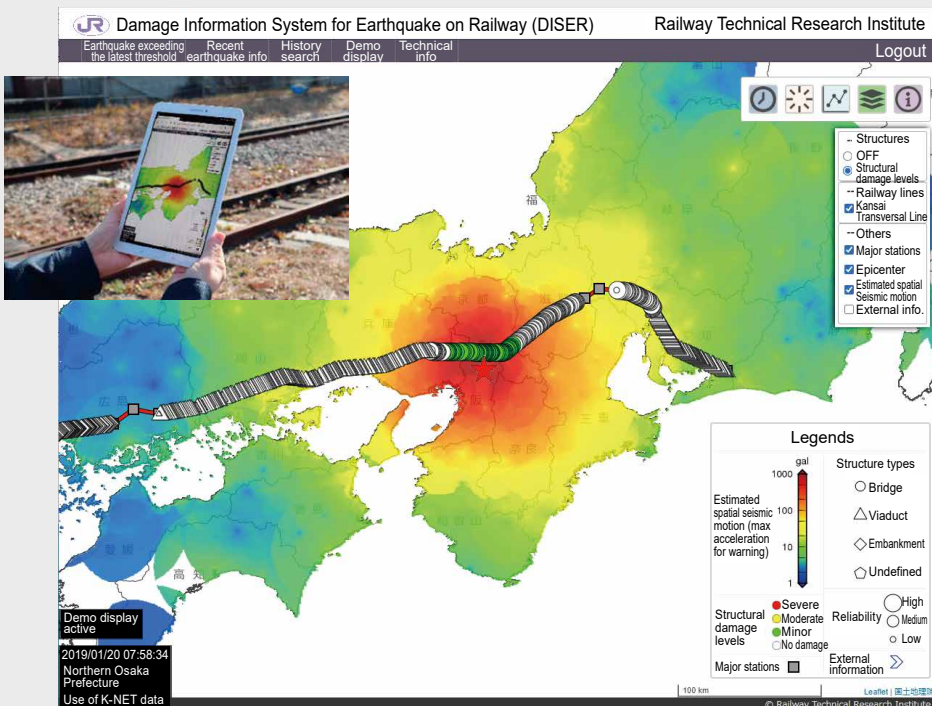
age Information System for Earthquake on Railway (DISER)<sup>4</sup>, a system that quickly provides information on earthquake shaking and the condition of structures along railway lines. The figure titled *Damage Information System for Earthquake on Railway (DISER)* shows an example of the system’s output. DISER utilizes the nationwide earthquake observation network operated by public institutions in Japan

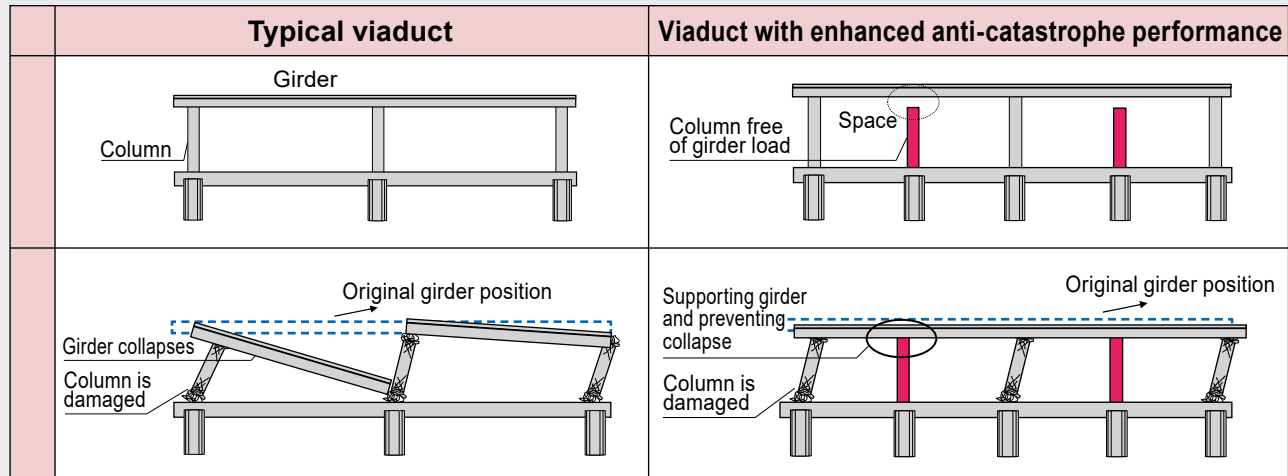
(approximately 1,000 observation points) to promptly deliver information on shaking along railway routes shortly after an earthquake occurs, thereby supporting efficient inspections and the resumption of train operations following train stoppages.

Even when structural reinforcement is implemented as a seismic countermeasure, the possibility of an earthquake exceeding the seismic motion assumed at the design stage cannot be completely ruled out. The Center is advancing studies aimed at enabling railway functions to recover as quickly as possible even in the event of unexpectedly large earthquakes and has been among the first in the railway field to adopt the concept of “anti-catastrophe performance<sup>5</sup>.” This concept involves taking measures to ensure that even if an earthquake beyond the assumed level occurs, it does not cause catastrophic damage.

The figure titled *Structure with enhanced anti-catastrophe performance* shows an example of measures to improve anti-catastrophe performance<sup>6</sup>. The viaduct on the left represents a typical structure, whereas the viaduct incorporates enhancements for anti-catastrophe performance. The upper section illustrates the normal condition, while the lower section depicts the anticipated scenario during an extraordinary massive earthquake exceeding design assumptions. Compared with a typical viaduct structure, the enhanced structure includes several red columns that are not connected to the girders. This design feature is the key point of this countermeasure method. Looking at the assumed situ-

### Damage Information System for Earthquake on Railway (DISER) (Note: The actual interface of DISER is in Japanese.)





**Structure with enhanced anti-catastrophe performance**

ation of a massive earthquake, the columns of a typical viaduct may be damaged, and the girders could potentially collapse. In contrast, although the columns of a viaduct with improved anti-catastrophe performance are damaged, the red columns support the girders and prevent collapse. In this way, anti-catastrophe performance prevents the collapse of viaducts, thereby reducing damage to vehicles, structures, and equipment beneath the viaduct. It also significantly reduces the time and cost required for restoration. Thus, the Center for Railway Earthquake Engineering Research is conducting R&D to enhance anti-catastrophe performance and prepare for worst-case scenarios, aiming to advance railway safety measures against massive earthquakes that exceed design assumptions and to enable the early restoration of railway functions.

### Conclusions

As examples of our R&D activities, we have introduced technologies for detecting earthquakes more quickly and stopping trains

safely, as well as technologies for restoring normal conditions as rapidly as possible. Since the Center strives to develop better solutions, these R&D efforts will never truly come to an end. In addition, the Center is engaged in various other initiatives to ensure safe and reliable railway systems against earthquakes. These include the development

of seismic performance evaluation methods, countermeasures for structures and ground, and damage prediction using simulations. For more details, please visit the Center for Railway Earthquake Engineering Research website: <https://www.rtri.or.jp/rd/division/rd61> (in Japanese).

### References

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