ANNUAL REPORT 2021-2022

For the year ended March 31, 2022

Railway Technical Research Institute

Foreword

Ikuo WATANABE
President of the Railway Technical Research Institute

I am pleased to announce that RTRI Annual Report 2021-2022 is now available. This report outlines and introduces the organization of RTRI, our master plan, research and development and other activities and related data of many research fields. It would be our great pleasure if you could glance over our progress in fiscal 2021 and it helps deepen your understandings of RTRI.

Tough times also continued in fiscal 2021 for railway businesses. The demand for railway transport remained low due to lingering Covid-19 pandemic and a series of natural disasters caused serious damage to railway facilities in many places. Furthermore, as a law to promote global warming countermeasures was enacted in May 2021 in order to attain a carbon neutral society in 2050, decarbonization is now an urgent issue for railways to be addressed.

Under these difficult circumstances, however, we were able to steadily implement all the planned research and development projects and other activities according to the business plan for fiscal 2021, the second year of the 5-year master plan RESEARCH 2025. While activities continued to be restricted in all aspects of the society, due to the pandemic, we have raised efficiency of research work, improved our data and information infrastructure to facilitate working from home and remote working. Thanks to these efforts to prevent delays in our activities, 261 research and development projects were implemented and 75 of them were completed by the end of fiscal 2021.

In August 2021 and March 2022, a heavy rainfall and the earthquake in the coastal area of Fukushima prefecture caused damage to railway lines. As usual, the researchers at RTRI quickly conducted damage surveys and supported the restoration work by sending cross-sectoral teams.

In 2021, RTRI celebrated its 35th anniversary. Under the vision “we will develop innovative technologies to enhance the rail mode so that railways can contribute to the creation of a happier society”, we will continue to create quality research outcomes by fully utilizing our capacity as an institute covering all the fields of railway technologies, in order to meet expectations by railway operators and customers. Continued support and advice from all the rail-related people will be greatly appreciated.

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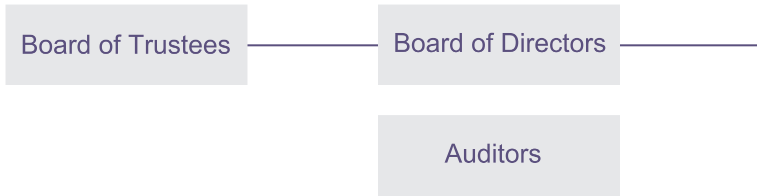
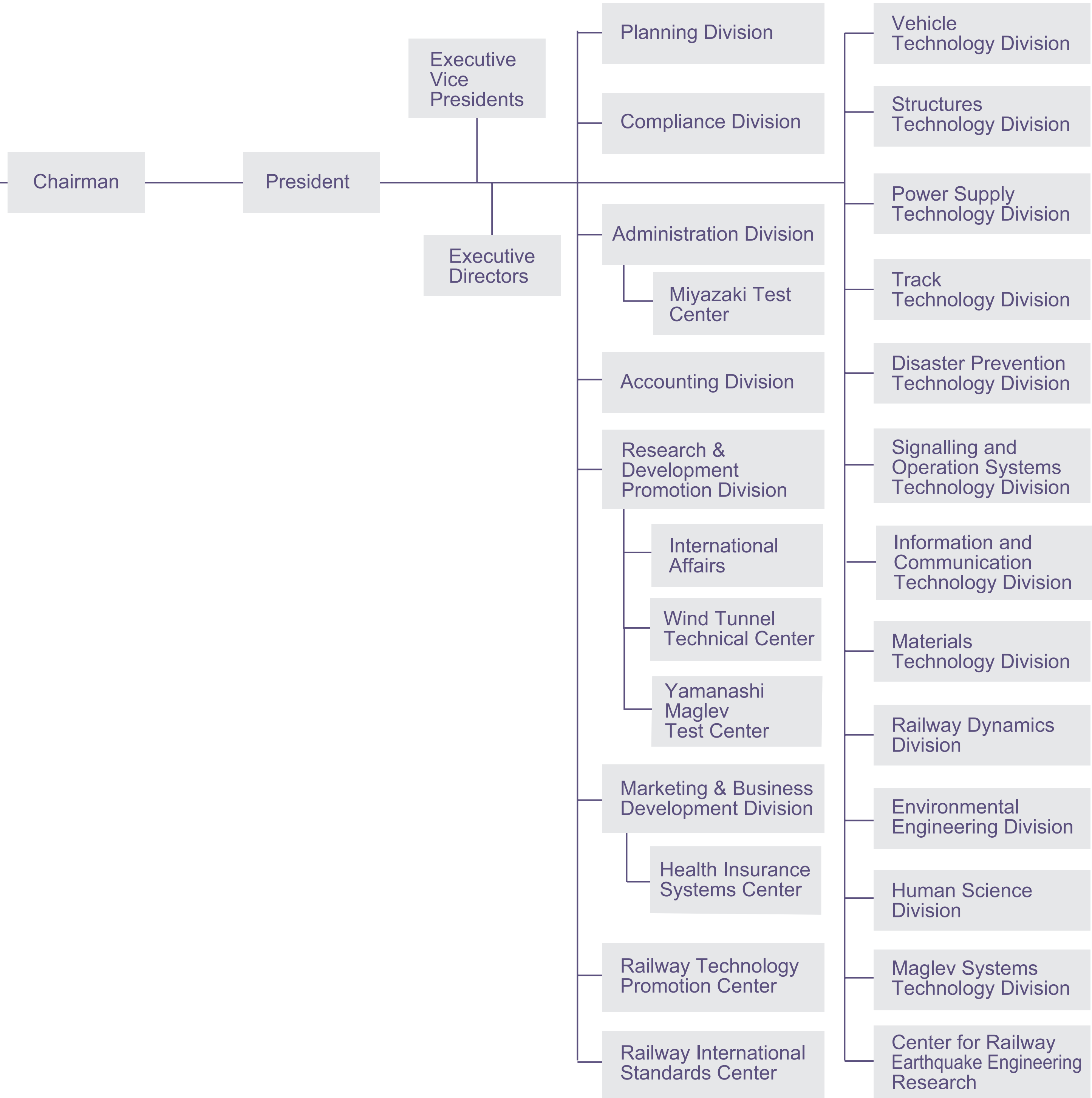
Overview

Organization





(As of April, 2022)

Major Results of Research and Development

IMPROVEMENT OF SAFETY

1. Earthquake early warning method for the earthquake source fault regions

- We developed an earthquake warning method that reflects the amplification characteristics of seismic motions at different locations and issues a warning when the P-wave exceeds a threshold specified.
- S-wave, which represents the principal motion, is predicted in real-time by multiplying the observed P-wave by the S-wave/P-wave amplitude ratio at various locations prepared in advance. A warning is issued when the ratio exceeds a threshold specified.
- A warning signal can be output in as little as one second or even less in the earthquake source fault regions.

With current P-wave warnings in railways, it takes at least one second to issue a warning after the earthquake is detected, because data for over one second is needed to estimate the epicentral distance and back azimuth. To improve the immediacy of alarms for the earthquake source fault regions, we developed a method capable of issuing a warning in less than one second after earthquake detection based on when a specified P-wave threshold is exceeded.

The proposed method determines whether an alarm is necessary based on a real-time prediction of the amplitude of the S-wave, which represents the principal motion. This prediction is multiplying the observed P-wave amplitude by the S/P-wave amplitude ratio in advance (Fig. 1). The S/P-wave amplitude ratio varies widely from station to station, however (Fig. 2). Thus, the proposed method improves warning accuracy by using the S/P-wave amplitude ratio determined from data at a variety of seismic observation stations. Furthermore, since the method relies only on P-wave amplitude at seismic observation stations and simple arithmetic processing, it enables more immediate and reliable earthquake early warnings in the earthquake source fault regions.

Application of the proposed method to the 2016 Kumamoto earthquake confirmed that the method is capable of issuing a warning faster than any other current P-wave warning system in the earthquake source fault region (Fig. 3). The adoption of this proposed P-wave “specified threshold exceeded” earthquake warning into warning systems along railway lines can significantly enhance railway safety near the earthquake source fault regions.

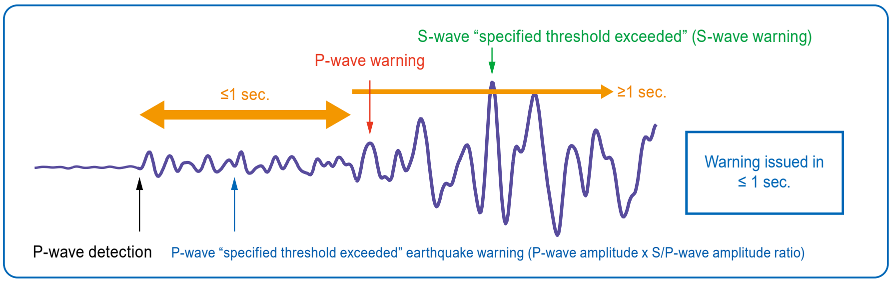


Fig. 1 P-wave “specified threshold exceeded” earthquake warning method

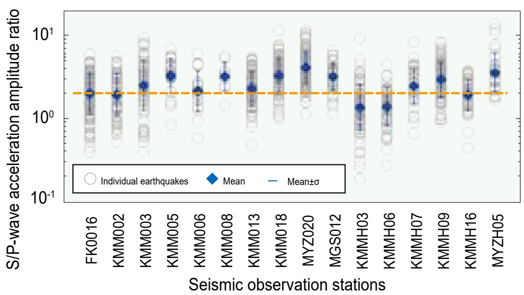


Fig. 2 S/P-wave amplitude ratio at seismic observation stations

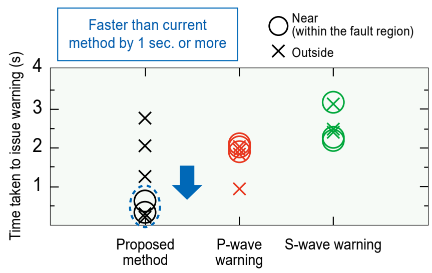


Fig. 3 Time taken to issue warning

2. Design method for bearing parts to control damage and improve restorability

- We proposed a design method for bearing parts that increases the precision of calculations of the strength of parts with embedded stoppers and limits damage to parts that are difficult to restore after an earthquake.
- The new method reduces construction costs of hard-to-restore damaged parts after an earthquake by 80%.

Stoppers are embedded in the bearings of concrete bridges to prevent bridge collapse.

Damage to bearing parts with embedded stoppers was observed after many recent earthquakes in Japan, even when there was no collapse or safety threat (Fig. 1). In such cases, when damage occurs as a result of concrete peeling at the area shown in Fig. 1 (2) (girder end), which is narrower than shown in Fig. 1 (1) (pier front), repairing the bridge is difficult. Therefore, controlling the damage to these difficult-to-restore areas is an effective way to shorten the time and cost of restoration work after an earthquake. In light of this, we proposed a method of calculating strength that is capable of assessing the influence of bending shape and configuration of rebar to improve the strength, without increasing the quantity of rebar in parts with embedded stoppers (Fig. 2). With the conventional method, the same strength is calculated regardless of rebar bending shape and configuration, despite the fact that loading tests and FEM analysis show that strength varies according to these factors. We therefore proposed a strength calculation method that takes into account the impact of rebar bending shape and configuration.

With the conventional design, damage may occur at the girder ends, which are difficult to repair, but we confirmed that the new method limits the damage to such hard-to-restore parts of a bridge to a minimal level, while at the same time ensuring equal or better strength than the conventional method (Fig. 3). By eliminating the need to use heavy machinery for chipping concrete and erecting scaffolding, which are essential for repairing earthquake-damaged parts of a bridge, construction costs can be cut by 80%.

These findings will be reflected in the upcoming revision of the Design Standards for Railway Structures and Commentary (Concrete Structures).

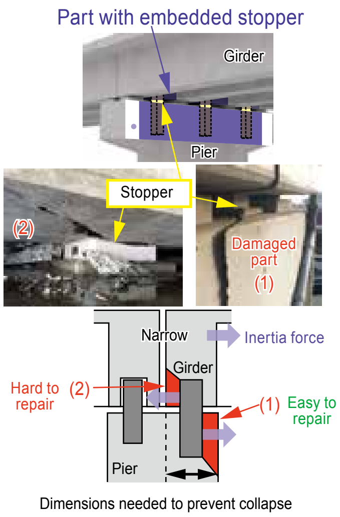


Fig. 1 Example of earthquake damage

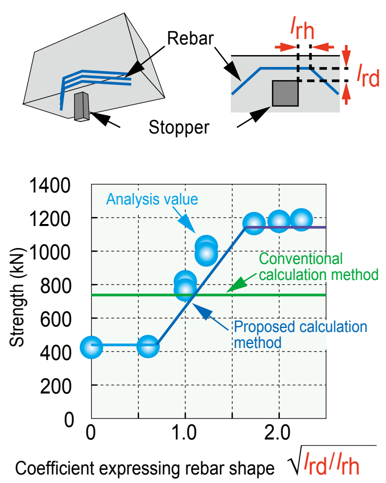


Fig. 2 Shape and strength of rebar in parts with embedded stoppers

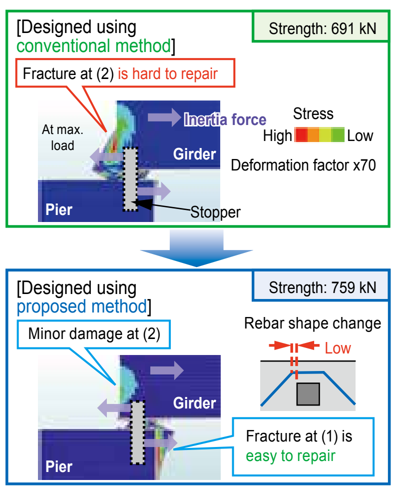


Fig. 3 Comparison of damage in parts with embedded stoppers

3. Method for verifying the restorability of railway structures considering small- and medium-scale earthquakes

- We proposed a method for verifying the restorability of railway structures considering small- and medium-scale earthquakes as well as large-scale earthquakes (Level 2 seismic motion)
- With the method, the number of days needed for restoration after an earthquake is used as a verification index in the design of new structures and the assessment of existing structures, making it possible to construct structures that are easier to restore.

Current seismic design of railway structures requires that damage resulting from a large-scale earthquake of seismic intensity 7 (Level 2 seismic motion) is rapidly repairable. However, the structural performance against medium-scale earthquakes of seismic intensities “6 lower” and “6 upper,” which are occurring frequently in recent years, is not clearly defined. As a result, some issues have emerged in relation to “rapid” restoration. For example, it took a long time to resume operation after the 2018 northern Osaka Prefecture earthquake and the 2021 northern Chiba Prefecture earthquake.

To solve this problem, we proposed a method for verifying the restorability of structures taking into consideration the effects of small- and medium-scale earthquakes. A feature of the design flow of the proposed method (Fig. 1) is that it applies to “all seismic motions including small- and medium-scale earthquakes” and that “the number of days required for restoration is used as a verification index.” This method can be directly adopted into frameworks of current seismic design.

To make the design with the proposed method more practicable, a nomogram (Fig. 2) for the required strength (yield seismic intensity) of structures was developed for each of required restoration time, conditions (e.g., region, structural type), and damaged structural parts (e.g., foundation, column). The results show that to ensure the same level of restorability as a structure with prior column damage, a structure with prior foundation damage requires a higher yield seismic intensity. In past earthquakes, it takes many days to restore a structure whose foundation has been damaged. This trend is in accordance with the results in Fig. 2. Fig. 2 shows the yield seismic intensity necessary to make a structure restorable in five days, but it is possible to design in the same procedure as usual by selecting the nomogram corresponding to the required number of days for restoration.

The proposed method makes it possible to design new structures that are easier to restore after earthquake damage. Moreover this method can identify the parts of existing structures that require most time for restoration, so it is possible to shorten the time until operation resumes after an earthquake by applying focused proactive measures to these parts.

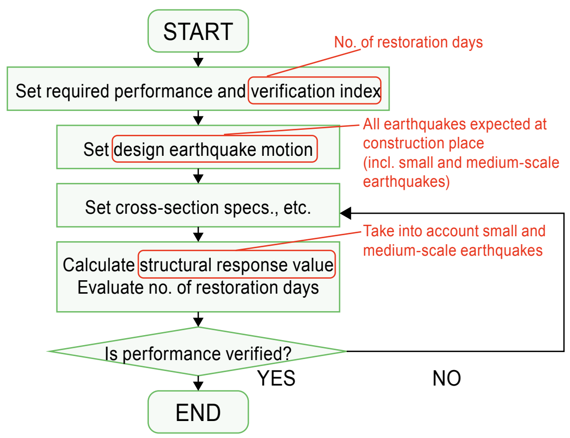


Fig. 1 Design flow with proposed method

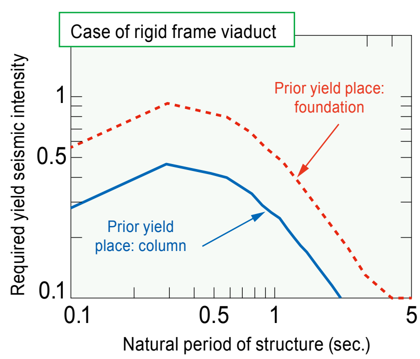


Fig. 2 Nomogram for restorability verification (example of five days for restoration)

4. Method for evaluating vehicle safety in strong winds using probabilistic risk assessment

- We proposed a method to evaluate the safety of vehicles based on the probability of external wind force exceeding the overturning resistance of vehicles to strong winds by expressing both the overturning resistance of vehicles to strong winds and external wind force as a probability distribution.
- The method can be used to set wind speed values for operation control in accordance with critical wind speeds of overturning for vehicles and actual wind conditions.

In recent years, as meteorological disasters have become increasingly severe, making railway services more resilient against strong wind disasters has become an urgent challenge. At the same time, tougher regulations relating to strong winds can lead to less stable and convenient transportation. In light of this, we introduced a probabilistic risk assessment method to the safety evaluation of vehicles operating under strong wind conditions and proposed a safety assessment method for preventing trains from overturning and for maintaining stable transportation services.
The lateral acceleration used for calculating the critical wind speed of overturning, which represents the overturning resistance of a vehicle to strong wind, is not constant; it varies depending on travel conditions. The wind speed values of the natural wind, which represents the external force that overturns the vehicle, also have variability. To assess the effects of the variation in the critical wind speed of overturning and wind speeds in windy conditions, each is expressed as a probability distribution (Fig. 1). By applying the concept of failure probability, the probability of a wind speed exceeding the critical wind speed of overturning is determined and used as a risk index Pf to express the possibility of the vehicle overturning (Fig. 2).
This risk index can be used to determine appropriate wind speed for operation control for the type of vehicle and wind conditions along the railway line. For example, a safe wind speed for operation control can be specified based on the risk index value determined under conditions where no accidents have occurred in the past. When a new type of vehicle with a different critical wind speed of overturning is deployed, the wind speed for operation control can be flexibly modified to match the different critical wind speed of overturning using a uniform risk index for that section of railway line (Fig. 3).

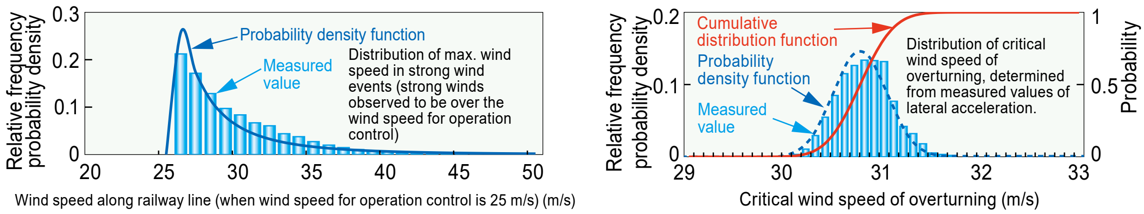


Fig. 1 Example of a probability distribution for wind speed along the railway line and critical wind speed of overturning

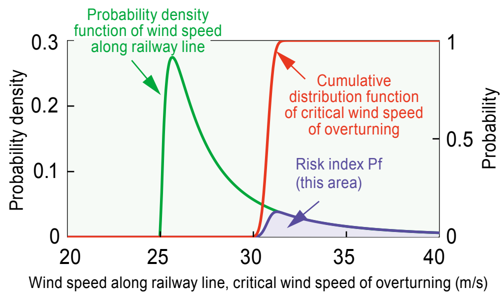


Fig. 2 Risk index Pf based on the concept of failure probability (for wind speed for operation control of 25 m/s)

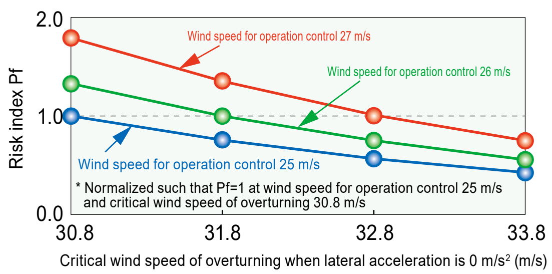


Fig. 3 Example of Pf comparison based on differences in wind speed for operation control and critical wind speed of overturning

5. Inspection of gaps by hammering slab track filling layers and prediction of deterioration

- We developed a method for detecting gaps between track slabs and filling layers by combining hammering tests and machine learning, as well as a test device capable of inspecting one track slab every five minutes.
- We also developed a method for predicting strength loss in filling layers and gaps between track slabs and filling layers due to frost damage and other causes, by means of a coupling analysis of heat conduction and structure.

In cold regions, frost damage tends to reduce the compressive strength of the filling layers of slab tracks. Train loads can also cause gaps between the track slab and filling layer. To quantitatively and efficiently detect the extent of such gaps, we proposed a method of detection that combines a hammering test and machine learning. Application of this method to slab tracks confirmed that gaps can be detected with 90% accuracy (Fig. 1). To inspect a large number of track slabs in a short time, we developed a continuous hammering test device with 11 hammering units (Fig. 2). This device makes it possible to inspect a single track slab in approximately five minutes.

When intensive repairs are conducted to extend the service life of slab track in cold regions, it is necessary to predict deterioration of filling layers in order to select which areas of the laid slab track will require repairs. Through experiments, we confirmed that the compressive strength of filling layers decreases with the number of freezing and thawing cycles and that the amount of plastic deformation due to repeated loading increases as the ratio of compressive stress to compressive strength increases. Through a coupling of unsteady heat conduction analysis and structural analysis, we identified a mechanism by which the compressive stress and the amount of plastic deformation at the outside of a filling layer increases when a track slab is subjected to train loads under upward convex warping caused by rising temperatures during the day (Fig. 3). Based on these findings, we developed a method for predicting deterioration capable of determining the loss of strength in a filling layer and the gap between track slab and filling layer (Fig. 4).

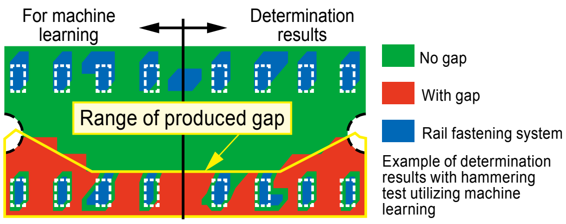


Fig. 1 Determining gaps using hammering test and machine learning

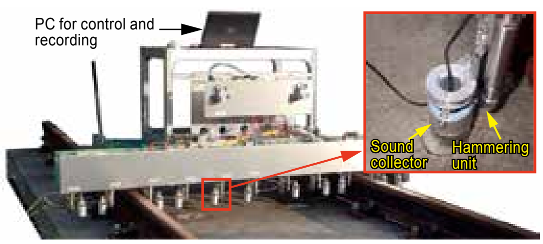


Fig. 2 Continuous hammering test device

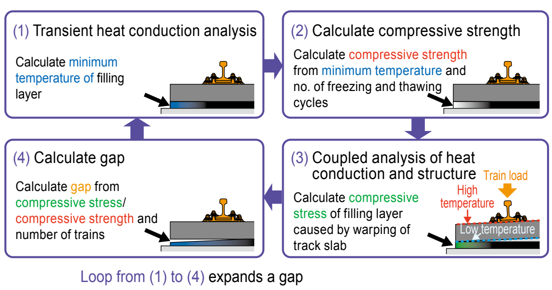


Fig. 3 Flow of deterioration prediction

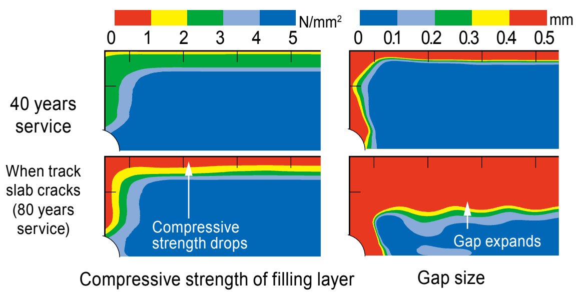


Fig. 4 Example of predicting filling layer deterioration

6. Method for estimating snow accretion and snow dropping of a train vehicle for investigating countermeasures against snow dropping

- The amount of snow that accumulates on a bogie and the locations where snow drops off from it can be estimated in real time from weather information along the line.
- The growth of snow accretion on the cover plate of a bogie can be estimated within an error of approximately 3 cm, and sections of line where snow dropping occurs frequently can be estimated within an error of approximately 2 km.
- This method can be used to determine whether snow removal work is necessary and to examine sections where measures against snow dropping are needed.

In snowy areas, snow thrown up by moving vehicles can settle on cover plates of bogies and the accumulated snow can drop off while the train is moving, possibly damaging ground equipment. To efficiently and effectively implement measures against snow accretion and dropping, we developed a method for estimating the snow accretion and snow dropping of a train vehicle. This method can be used to estimate the amount of accumulated snow and the location where snow drops off in real time, based on information about train operation and weather along the line.

Previous methods did not take into account snow dropping except in long tunnels. This method can calculate the amount of snow accretion on the cover plate of a bogie in open sections using the snow accretion rate determined in advance by an already developed snow accretion simulator, based on information about weather along the line. In addition, it can take into account the loss of snow when snow drops off in warmer environments such as tunnels. The method is therefore capable of estimating the rate of snow accretion in real time (Fig. 1).

We confirmed that this method is able to estimate the snow accretion rate on arrival at a station with an error of approximately 3 cm (Fig. 2) and to estimate the sections in tunnels where snow drops off frequently with an error of approximately 2 km (Fig. 3).

The estimated amount of snow accretion on arrival at a station can be used to determine whether snow removal work is necessary or not. Estimation of sections where snow drops off frequently can be useful in planning equipment inspections and prioritizing countermeasures against snow dropping.

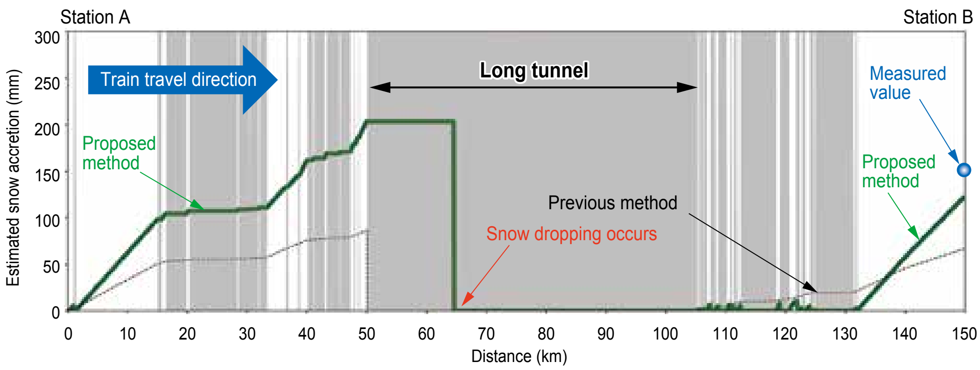


Fig. 1 Example of calculation of method for estimating snow accretion and dropping of a train (the gray shaded areas are tunnel sections)

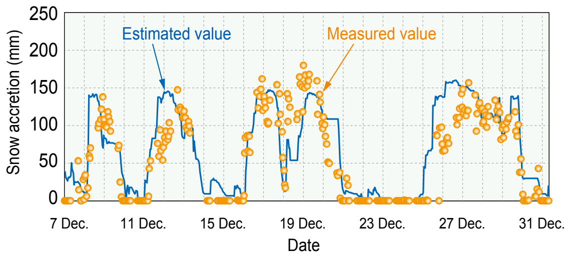


Fig. 2 Comparison of estimated and measured values of snow accretion rate on arrival at Station B

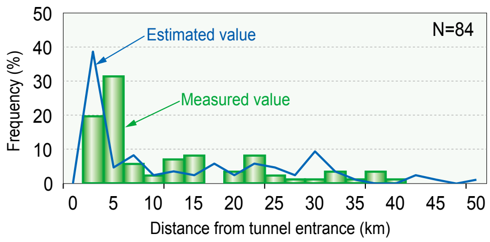


Fig. 3 Comparison of snow dropping locations in a long tunnel (frequency at intervals of 2.5 km)

7. Method of applying image processing-based object detection and obstacle determination to safety applications

- We developed a method of self-diagnosing camera and image processing unit failures.
- Applying this method to an abnormality detection equipment at level crossings, we confirmed that it is capable of fault diagnosing at 0.1-second intervals.
- This method enables the implementation of image processing-based object detection and obstacle determination functions in safety-related equipment.

Since image processing units that use cameras and general-purpose processors cannot diagnose failures by themselves, they cannot ensure sufficient safety in the event of a failure. Therefore, they cannot be used in safety-related equipment. One way to address this issue of image processing unit failures might be to perform image processing using a current signalling computer which is specially designed for safety-related applications (fail-safe components). Due to slow processing speed, however, this is not a practicable solution. And since image processing uses machine learning and random numbers, conventional diagnostic methods that utilize multiple image processing units to check for bit-perfect matches of processed data cannot be used either.

To solve this problem, we developed a method that works in combination with a fail-safe component to perform high-speed self-diagnosis of failures in image processing units and cameras (Fig. 1). The method diagnoses image processing errors in image processing units by focusing on the similarity of processing results. Specifically, the processing contents of the image processing unit are compressed in the diagnostic image and the similarities are then determined in the fail-safe component as “differences of the diagnostic image = similarities.” In addition, by adding a function to the camera that embeds diagnostic data in the image data and outputs a test pattern, we proposed a method to diagnose image freezing and other issues using a fail-safe component (Table 1).

We trial manufactured a detection equipment that implements the proposed method, to serve as an abnormality detection equipment at level crossings. By means of an artificial fault test, we verified that the method works and is capable of fault diagnosing the operational status of the equipment at 0.1-second intervals.

The proposed method can detect large differences that influence determinations, while still allowing differences in processing results in multiple image processing units arising from machine learning (e.g., background images updated every cycle). It can therefore be applied as a fail-safe configuration in AI and general-purpose processors that handle non-image data. This approach to camera diagnosis can also be applied to other general-purpose sensors for LiDAR, millimeter wave radar, etc.

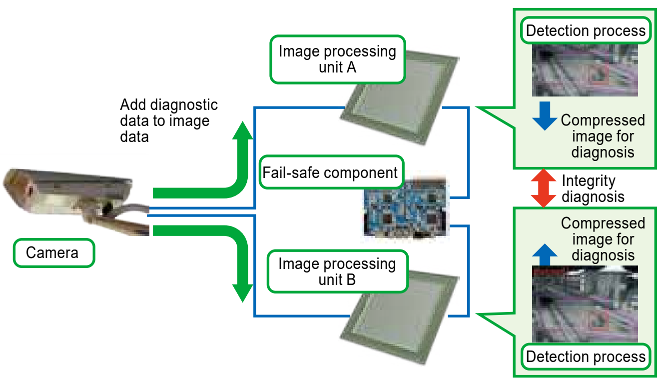


Fig. 1 Configuration and diagnostic procedure

Table 1 Failure modes and diagnostic methods

Device	Failure mode	Diagnostic method	
Image processing unit	Machine learning processing error	Comparison of compressed image for diagnosis	
	Image processing error		
	Object detection error	Output comparison	
Camera	Image is frozen; it is not updated	Diagnostic data	Inspection codes
	Image dropped frames		Frame count
	Image capture cycle shift/ error		Clock count
	Diagnostic data error	Test pattern	
	Pixel failure (blocked shadows, blown highlights)	Level analysis	

8. Support system for preventing a decline in alertness level of drivers

- We developed a system that detects the alertness level of drivers with images and issues an alarm.
- It can estimate alertness level with an accuracy of 80% or higher, even when the driver is wearing a mask.
- With the proposed alarm presentation method, 90% of people with reduced alertness level reported that they felt “awakened.”

As part of the efforts of railway operators to ensure safe and stable transport services, preventing a decline in the alertness level of train drivers is an important challenge. While methods for estimating the alertness level of drivers have been implemented in automobiles, in the case of trains, there is an issue with ensuring accuracy due to the wide variety of driver behaviors. This study attempted to address this problem by developing a system that estimates a driver’s alertness level based solely on information from images of the driver’s face while driving and issues an alarm sound when the alertness level drops by a specified amount (Fig. 1, left).

The system captures facial images using a fixed camera in the train, without any sensors contacting the driver’s body. Deep learning is used to evaluate alertness on a scale of six levels. In an experiment with 112 general test subjects, we confirmed that the system is capable of accurately gaging the alertness with an estimation accuracy of 80% or higher, even when masks are worn (Fig. 1, right).

For the alarm that is issued when a drop in alertness level is detected, we developed a sound that is highly rated for its functionality (strong arousing effect), perceptibility (easy to hear), and its distinguishability (not mistaken for other sounds). When test subjects in a laboratory experiment suffered a drop in alertness, their reaction time in a simple reaction task recovered when exposed to this alarm sound (Fig. 2), with approximately 90% of subjects responding “I felt awakened” in a questionnaire.

After the system was trialed on a commercial train, the results confirmed that the system accurately captures facial images, even under diverse lighting conditions, and that it is capable of estimating the alertness level of drivers in real time. Three drivers (including a conductor) rated the arousal effect of the alarm sound, giving it a score of 5 or more out of 6 points (Fig. 3).

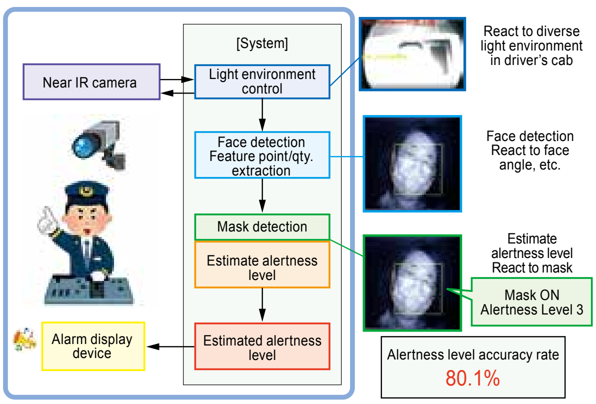


Fig. 1 Configuration of support system for preventing a decline in alertness level

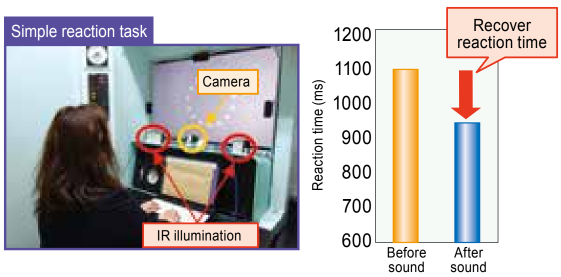


Fig. 2 Arousal effect of alarm sound in a laboratory experiment

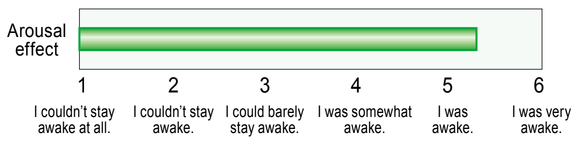


Fig. 3 Arousal effect of alarm sound in an on-track test

9. Phased array ultrasonic testing method for easy detection of flaws in bogie frame welds

- We formulated an ultrasonic testing method and procedure for bogie frames based on the phased array method that can easily detect flaws in welds.
- The method easily distinguishes between flaw signals and noise, and effectively detects inclined flaws and flaws in coatings.
- Detection sensitivity is equal to or better than that of conventional ultrasonic testing methods.

Since the bogie frames of railway vehicles are fabricated with numerous welds, any flaws within welds can pose risks of serious damage. Conventional inspection methods require a high level of skill to detect flaws, however. In light of this, we formulated a method and procedure for detecting flaws in bogie frames based on the phased array ultrasonic testing (PAUT) method. The method is capable of easily detecting any flaws inside welds.

Unlike conventional ultrasonic testing methods, which transmit and receive ultrasonic waves at a fixed angle (conventional UT method), the PAUT method transmits and receives waves at various angles to obtain cross-sectional images that enable visualization of flaw detection results (Fig. 1). Since images are used to discern flaws, distinguishing flaw signals from noise due to the shape of welds is easy, greatly reducing the chances of missing flaws. And since ultrasonic waves can be directed at flaws from various angles, this method is also effective in detecting inclined flaws with an inclination of 30° or more, which are typically difficult to detect using the conventional UT method (Fig. 2). Although detecting flaws in bogie frames is usually performed after removing the coating, our analysis has shown that even when this inspection method is applied without removing the coating, detection sensitivity is reduced by no more than 20% for coating thicknesses up to 1 mm.

With the conventional UT method, the flaw detection procedure is based on the Japanese Industrial Standard (JIS) "Method for ultrasonic testing for welds of ferritic steel." In the newly developed PAUT method procedure, a sensitivity adjustment procedure based on the same standard flaw as used in the JIS method, enables a flaw detection sensitivity equal to or better than the conventional UT method. Since flaw detection results with the new PAUT method are comparable to those of the conventional UT method, transition to the new method is easy.

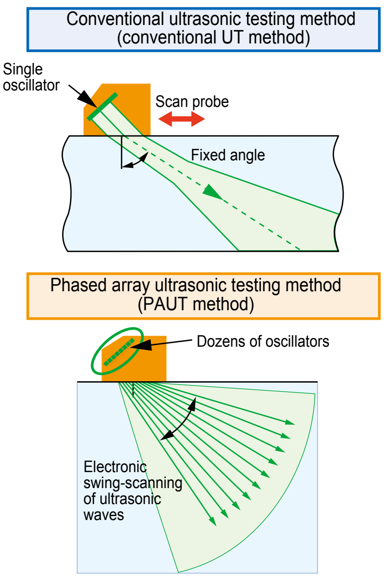


Fig. 1 Outline of phased array ultrasonic testing method (PAUT method)

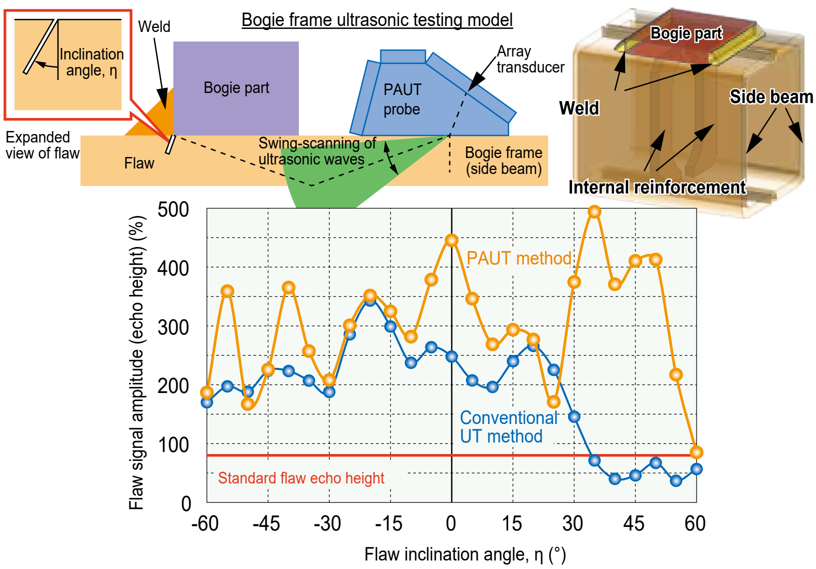


Fig. 2 Comparison of detection sensitivity for inclined flaws between conventional UT and PAUT methods

10. Oil for axle-box for Shinkansen with excellent low-temperature performance and maintainability

- With the expansion of the Shinkansen network into extremely cold regions of Japan, we developed a lubricating oil for axle journal bearings of Shinkansen train that retains its fluidity even at temperatures below -40°C and that prevents reddening over time.
- The lubricant has been confirmed to have excellent durability in a bench test on actual axle journal bearings for the equivalent of 800,000 km of travel.

Currently, only one brand of oil is used to lubricate the axle journal bearings of Shinkansen trains. However, there were concerns that this oil would not cope when the Shinkansen network was expanded into extremely cold regions, due to a lack of low-temperature performance. The lubricating oil developed by the RTRI in the past ("Axlube"), made using synthetic oil for enhanced low-temperature performance, has not been adopted because it turns red over time, making it difficult to distinguish this color change from the presence of abrasion debris, which is a problem for maintenance. To solve these problems, we developed a new oil for axle-box for Shinkansen (developed oil) that offers both excellent low-temperature performance and maintainability.

The developed oil utilizes a highly refined mineral oil as a base oil and includes additive substances that inhibit reddening. The developed oil has a lower pour point than the current oil and is verified to retain its fluidity even at temperatures below -40°C (Fig. 1).

Outdoor exposure tests have also confirmed that the developed oil is capable of inhibiting reddening caused by using Axlube (Fig. 2).

We verified the durability of the developed oil by conducting a bench test with real axle journal bearings operating for the equivalent of 800,000 km of travel. At the end of testing under these conditions, no abnormalities were found in the properties of the oil or the test bearings, confirming the oil's outstanding durability (Fig. 3). The base oil and additives that make up the developed oil are general-purpose products that are employed widely in oils for other applications. This helps to keep costs down and ensure a stable supply of raw materials.

The developed oil is expected to be deployed on Shinkansen vehicles that use oil bath lubrication after its durability is confirmed on operational vehicles.

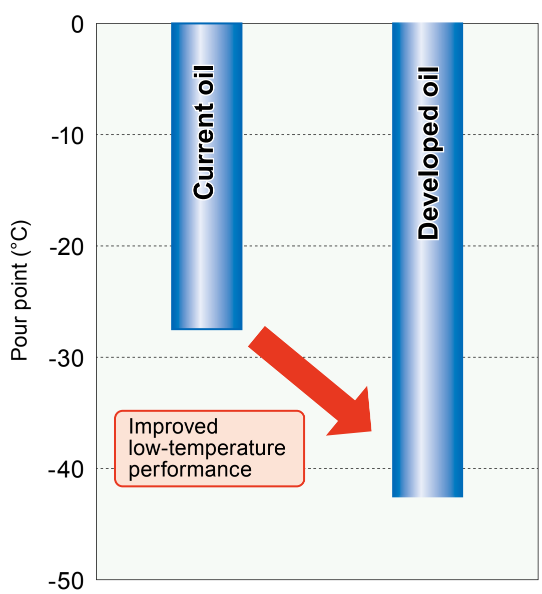


Fig. 1 Pour point* of current oil and developed oil
* The lowest temperature at which the oil flows

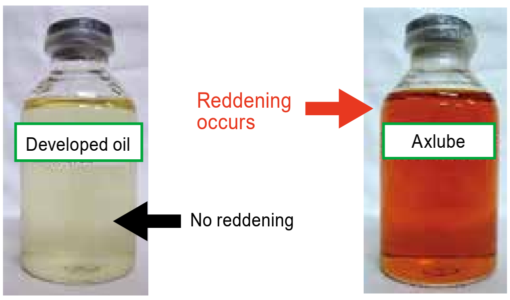


Fig. 2 Results of outdoor exposure test

Fig. 3 Test bearing after bench test (equiv. of 800,000 km)

11. Seat surfaces for minimizing injuries to passengers in the event of a collision

- We developed a seat surface for walkover seat that minimize injuries to passengers in the event of a collision.
- To ensure comfort, a cushioning structure is incorporated into the seat surface. No major design changes to current seats are required, since the cushioning effect is achieved by the seat surface alone.
- In the event of a railway crossing accident, the new seat surface can reduce lower limb injuries in passengers by 60% compared to the previous one.

When passengers are seated on seats arranged laterally (in the direction of sleepers), e.g., on the walkover seat fitted in suburban vehicles, they can suffer lower limb injuries if they are thrown forward into the seat in front of them by the impact of a train collision. This risk has been highlighted in past railway accident investigation reports. In Europe and the U.S., there are regulations aimed at limiting the severity of injuries, and in some cases seats are even fixed in a non-convertible structure to help minimize injury severity. Up to now in Japan, however, the severity of injuries has not been assessed in this context. In light of this, we developed a seat surface capable of reducing the severity of lower limb injury in the event of a collision.
In the seat surface structure of a conventional seat, the cushioning is typically supported from below by a top plate surrounded by highly rigid steel pipe (Fig. 1). This structure is a factor that tends to worsen severity of injuries that occur when a passenger's lower limbs collide with the seat in front of them. Therefore, after subjectively evaluating the structure to ensure that there is no loss of sitting comfort, we devised a cushioning structure such that the part where a passenger's lower limbs would impact is made of aluminum angle and supported by urethane at both ends (Fig. 2). To confirm the effectiveness of this structure in reducing injuries, we fabricated a prototype seat surface and conducted a sled test under a hypothetical level crossing accident (Fig. 3). Our findings confirmed that the new seat reduced the severity of lower limb injury by about 60% compared to conventional seating surfaces. This is even lower than the injury severity limit stipulated in the technical report of the European Rail Supply Industry Association (UNIFE), which is widely referenced for evaluations in Europe and other countries (Fig. 4).
Since a substantial shock-absorbing effect can be achieved with only the seat surface, when railway operators develop seats aimed at mitigating injury risks in the event of a collision, this new design can be introduced without any major change to existing seat designs.

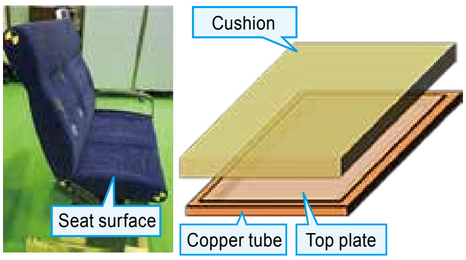


Fig. 1 Seat surface structure of conventional seats

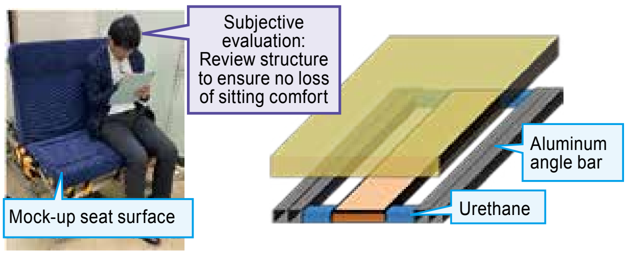


Fig. 2 Seat surface with embedded cushioning structure for sitting comfort

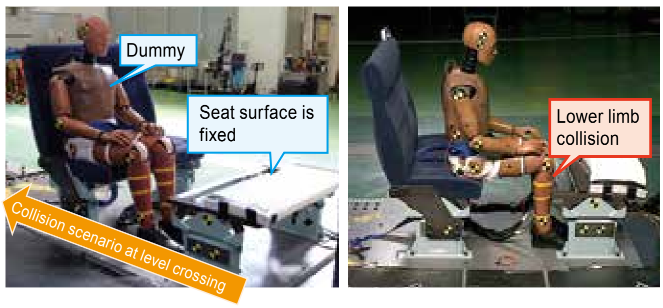


Fig. 3 Confirming effectiveness in a sled test

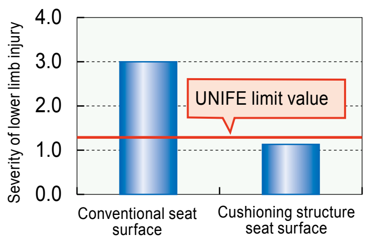


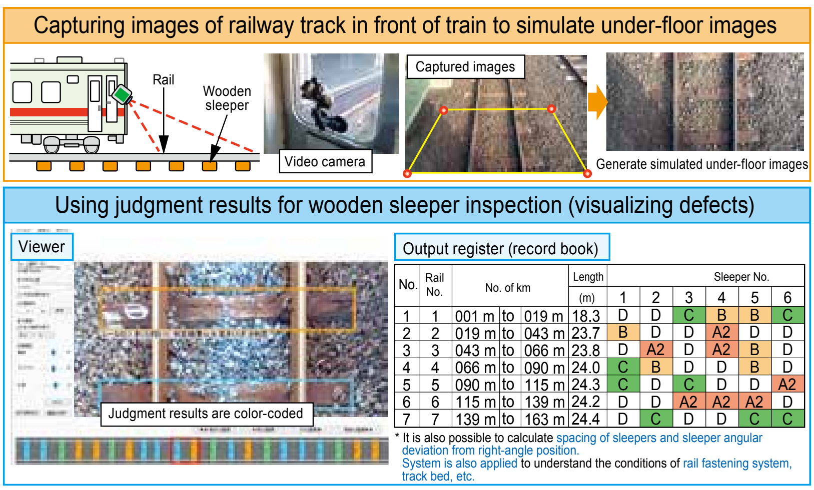
Fig. 4 Effectiveness in reducing lower limb injury

12. System for determining the degree of deterioration of wooden sleepers using images of railway tracks in front of trains

- We developed a low-cost system for determining the degree of deterioration of wooden sleepers based on a deep learning technique that uses images of the view in front of a train captured with an off-the-shelf video camera.
- The system can automatically judge the degree of wooden sleeper deterioration, according to a four-level classification scheme, with an accuracy of 90% or higher.
- Since the system displays the rated degree of deterioration directly on images, defective sleepers can be visualized easily using a viewer.

On sections of railway lines constructed mainly of wooden sleepers, there is a risk of "derailment by gauge widening" due to inadequately fastened rails caused by the decay of wooden sleepers. For this reason, the number of defective wooden sleepers and the state of individual sleepers needs to be continuously controlled, particularly along curving track. However, visual inspections of huge numbers of sleepers requires enormous labor. To solve this problem, we developed a system that uses video captured with an off-the-shelf video camera to automatically detect and judge the degree of deterioration of wooden sleepers by applying image processing and deep learning techniques to a simulated under-floor image, which is a projective transformation of images of railway track in front of the train (Fig. 1). This system can be installed on any train in less than ten minutes, by just setting up a video camera. It is also less expensive than the under-floor image capture systems currently used by JR companies.

When we applied this system to images of approximately 16,000 wooden sleepers taken from above a train on a commercial line, we confirmed a sleeper detection rate of 99.5% (100% except when the sleeper surface is covered by a significant amount of ballast or other material). A comparison of the degree of deterioration determined by this system and that determined from images (4 levels) by a track maintenance engineer also confirmed that the system is capable of automatically assessing deterioration with an accuracy of 90% or more (Table 1). In this case, the rate at which bad sleepers (A2, B) were mistaken for good sleepers (C, D) was 7%, but the probability of missing successive defects, which increases the risk of derailment by gauge widening, was considered sufficiently low. With this system, each sleeper is output in a color-coded format to denote the degree of deterioration, both to a viewer that displays the results and to a tabular inspection record book, making it easy to identify areas where there are successive defects in wooden sleepers.



No.	Rail No.	No. of km			Length (m)	Sleeper No. 1	2	3	4	5	6
1	1	001 m	to	019 m	18.3	D	D	C	B	B	C
2	2	019 m	to	043 m	23.7	B	D	D	A2	D	D
3	3	043 m	to	066 m	23.8	D	A2	D	A2	B	D
4	4	066 m	to	090 m	24.0	C	B	D	D	B	D
5	5	090 m	to	115 m	24.3	C	D	C	D	D	A2
6	6	115 m	to	139 m	24.2	D	D	A2	A2	A2	D
7	7	139 m	to	163 m	24.4	D	C	D	D	C	C

* It is also possible to calculate spacing of sleepers and sleeper angular deviation from right-angle position. System is also applied to understand the conditions of rail fastening system, track bed, etc.

Fig. 1 Restoration method of embankments using the dehydration effect of lime and the increase in the strength of soil due to compaction

Table 1 Sleeper detection rate and deterioration rating precision

Wooden sleeper detection rate 99.5%

	Deterioration level	Rating criteria	Rating precision
Poor	A2	Decline in gauge retention function	92.2%
	B	Decline in sleeper function	88.6%
	C	Minor damage	91.2%
Good	D	Good	94.1%

* No. of rated wooden sleepers: 16,033

13. A method for constructing communication-based train control systems using public communication network

- We proposed a design procedure for creating train control systems using public communication network such as 5G and a method for integrating information security functions in safety equipment.
- The method enables a reduction of up to 50% in the total number of ground equipment that make up the system and promises to achieve labor-saving in tasks related to facility design and maintenance.

The increasing deployment of communication-based train control systems is helping to increase the efficiency of train operations and reduce the need for ground equipment. In the coming years, use of public communication network such as 5G is expected to further reduce the number of equipment that railway operators need to self-manage, thereby enabling significant savings in design and maintenance work. However, in conventional systems, safety is guaranteed by functions that rely on equipment of private communication network that restrict information transmission. When public communication network is used, on the other hand, there is no specific method for implementing the information security measures necessary to ensure safety.

To address the above issue, we proposed a system configuration that makes information transmission functions, such as base stations, independent of safety-related security control functions of ground and on-board equipment and formulated a procedure for designing a communication-based train control system based on this configuration (Fig. 1). We also defined the safety and information security requirements that such safety equipment must meet to withstand external cyber-attacks on the communication network by third parties. As a specific implementation method, we proposed a method for integrating cryptography-based security functions in non-fail-safe modules and diagnosing the normal operation of these functions using test data from each message (Fig. 2). We also conducted a functional verification on a prototype module using a single-board microcontroller. By designing a system based on these methods it becomes easy to make use of public communication network. And by making safety equipment independent of update timing, hardware can be replaced with the latest communications technology and functions can be improved at any time, without compromising security. Depending on operational conditions and system configuration, the total number of ground equipment can be cut by around 50% by eliminating the need for base stations of private communication network and other radio equipment.

The findings of this study were adopted as a basic configuration to future communication-based train control systems by the “Study Group on Communication-Based Train Control Systems” established by the Ministry of Land, Infrastructure, Transport and Tourism and reflected in published guidelines.

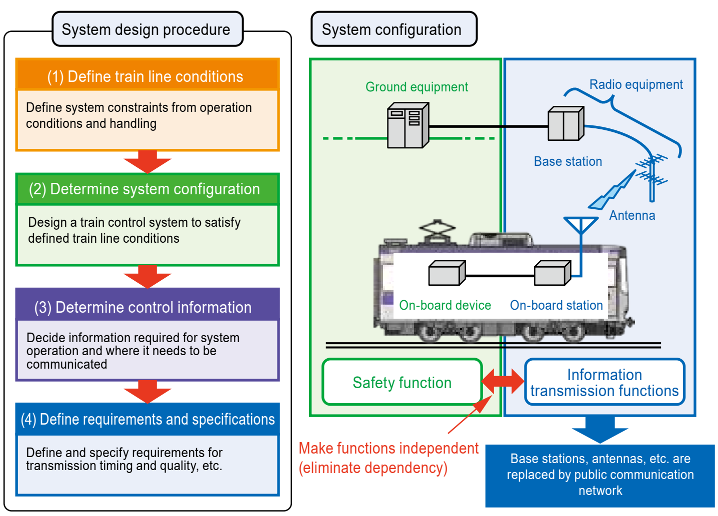


Fig. 1 Design procedure for communication-based train control system

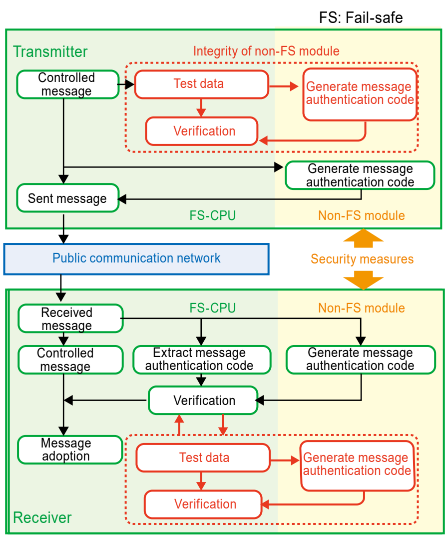


Fig. 2 Information security measures

14. Automatic anomaly detection using vehicle condition monitoring data without additional sensors

- We proposed a method for automatically detecting anomalies in vehicle equipment in operations without additional sensors using data from vehicle condition monitoring devices and machine learning driven by neural networks.
- We confirmed that the method is capable of promptly detecting actual failures occurred in operational vehicles.

In recent years, more and more systems for recording and summarizing the operating conditions of vehicle equipment have been adopted, enabling the accumulation of large quantities of vehicle condition monitoring data. This data can be used to promptly detect anomalies in vehicle equipment in operations without additional sensors, thereby improving the operational reliability further. However, due to complex changes in vehicle equipment conditions, it can be difficult to detect anomalies using only simple criteria, such as “when a threshold value is exceeded.”

We therefore proposed a method for extracting the characteristics of vehicle equipment conditions from vehicle condition monitoring data using a neural networks-based machine learning technique to determine the degree of anomaly (anomaly score) of the vehicle equipment (Fig. 1). (1) Firstly, a neural network is trained with vehicle condition monitoring data when vehicle equipment operates in normal conditions and a model is created to estimate item A, which expresses equipment conditions that would be affected by anomalies, from other items. (2) Next, the model and data not used for training are utilized to obtain the frequency distribution of differences between the estimated values and the actual measured values (estimation error distribution) of item A in normal conditions. (3) Finally, based on the estimation error of item A for the data in an actual operation and the estimation error distribution in normal conditions, the anomaly score—defined such that the lower the probability that the estimation error occurs, the higher its value—is calculated for each time period.

When we applied the proposed method to vehicle condition monitoring data acquired from operational vehicles, we verified that it is capable of promptly detecting anomalies, such as an engine overheating or a decline in air conditioning unit performance, based on increases in anomaly scores. By applying the proposed method to a condition monitoring system as in Fig. 2, crew and traffic controller are able to promptly ascertain the occurrence of anomalies in vehicle equipment. This enables them to take appropriate action, such as repairing the equipment before a serious breakdown occurs.

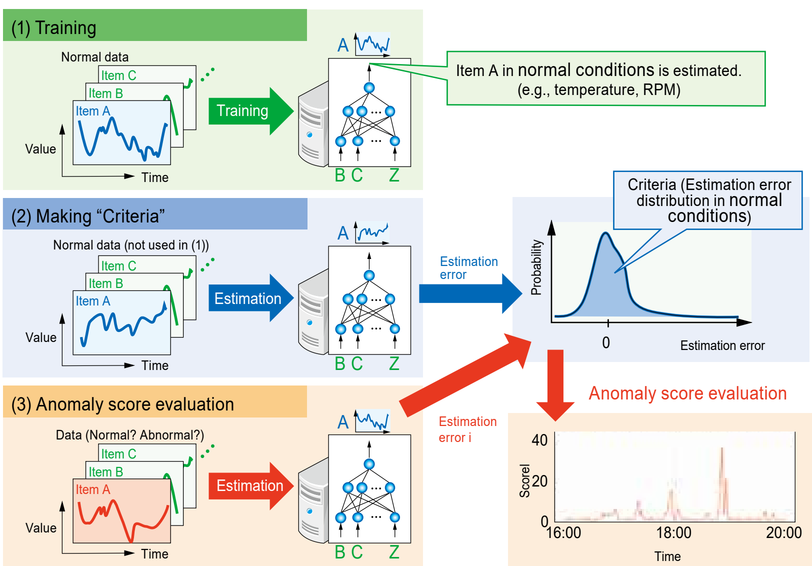


Fig. 1 Flow of anomaly detection

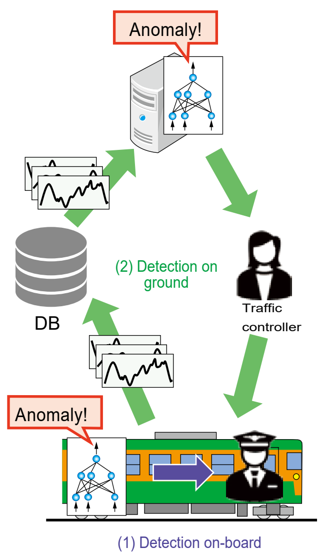


Fig. 2 Example of use

15. An soundness evaluation index and method for dealing with ballasted track that is contaminated with soil

- We proposed an index for evaluating the soundness of ballast includes with soil.
- The proposed index can be applied both to ballast that has fouling over time and ballast contaminated with soil due to heavy rain.
- We developed a Low-strength stabilization to limit the subsidence of ballasted track bed containing soil. Construction costs can be reduced by 90% compared to ballast replacement.

Ballasted track bed that has degraded over time or that has been contaminated with soil due to flooding and landslide after heavy rains is more likely to subside rapidly under train loads. The ballast is usually replaced in this case, but high repair costs have been an issue. In particular, there is typically a need to resume operation through the affected section as quickly as possible without ballast replacement, by reducing the train speed. To address this issue, we assessed the settlement characteristics of ballasted track bed by conducting repeated loading tests on ballast with different fine particles. Using the Fouling Index FI (sum of the proportions of ballast containing particle sizes of 75 μm or less and 4.75 mm or less) as an indicator of the soundness of the ballast, we demonstrated that the risk of rapid subsidence can be determined. The higher the value of FI, the greater the amount of subsidence (Fig. 1). To control the subsidence of ballasted track bed with a high soil content, we developed a low-strength stabilization (stabilized to a strength that allows re-tamping repair) that mixes ultra-fast hardening cement and polymeric materials to enable repair by tamping. We confirmed in full-scale tests that the method is effective in limiting subsidence of ballast with an FI of 20% or more, which is likely to suffer rapid subsidence. With this method, the ballast can even be re-tamped and repaired again after construction (Fig. 2). Trial constructions using multiple tie tampers on sections that had degraded over time and using ballast tampers on damaged sections demonstrated the effectiveness of subsidence control (Fig. 3). This method can reduce construction costs by 90% compared to ballast replacement. In April 2022, we commercialized a method for evaluating the soundness of ballast and a low-strength stabilization We also created manuals for the methods.

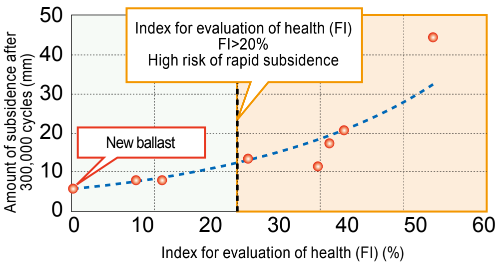


Fig. 1 Relationship between soundness index (FI) and amount of subsidence

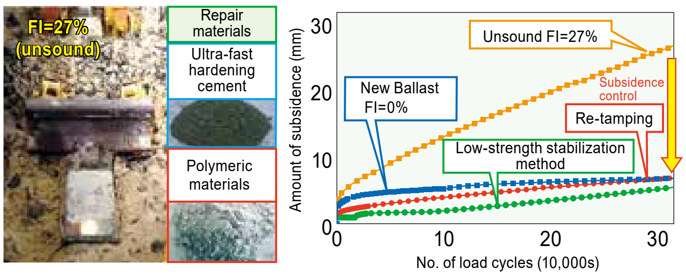


Fig. 2 Full-scale test of low-strength stabilization method

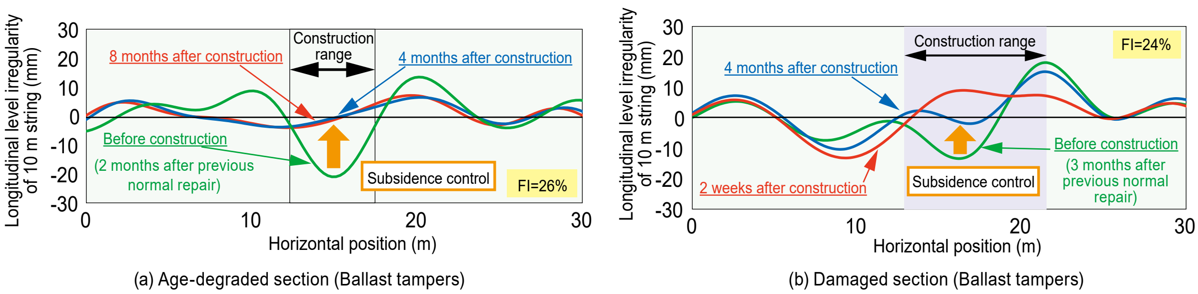


Fig. 3 Verifying the repair effectiveness of the low-strength stabilization method

16. Method for reducing the frequency of maintenance on standard longitudinal sleepers at boundaries with structures

- We proposed a method and standard structure for laying longitudinal sleepers at structure boundaries and verified the effectiveness of longitudinal sleepers in reducing longitudinal level irregularity in a test installation on a commercial line.
- We confirmed that the method reduced the progression of longitudinal level irregularity to about 20% of that with conventional sleepers, making it unnecessary to perform track maintenance three to four times a year.

Due to the sudden change in track support conditions, maintenance frequency tends to be higher at boundaries with structures, such as open channels that cross railway tracks and transitions from embankments to girders, than at other sections of line. The use of longitudinal sleepers is an effective way of reducing the labor required to maintain ballasted track. However, since such sleepers have hardly ever been used at structure boundaries, their effectiveness for this purpose remained unverified. In light of this, we conducted numerical analysis and full-scale testing to design a method of laying longitudinal sleepers at boundaries with structures, as well as to devise standard longitudinal sleeper structures to suit a variety of conditions (Fig. 1). At the same time, we verified the effectiveness of longitudinal sleepers in reducing longitudinal level irregularity in a test installation on a commercial line (Fig. 2).

More specifically, we proposed three laying methods—laying longitudinal sleepers before and after an open channel (Method 1); laying them across an open channel (Method 2); and positioning the end of longitudinal sleepers on an abutment (Method 3)—and designed a standard longitudinal sleeper structure for each method. In this way, once the laying method is determined, the appropriate kind of longitudinal sleeper can be selected without the need for any special design. The results from a test installation on a commercial line using Method 1 and measurements of longitudinal level irregularity proved that the rate of increase of longitudinal level irregularity with longitudinal sleepers is five times lower than with conventional sleepers, thereby making track maintenance unnecessary for 22 months (track maintenance was omitted six times in two years). Previously, track maintenance with conventional sleepers was necessary three to four times a year. Thus, installing longitudinal sleepers in sections that require frequent track maintenance makes it possible to significantly reduce track maintenance costs.

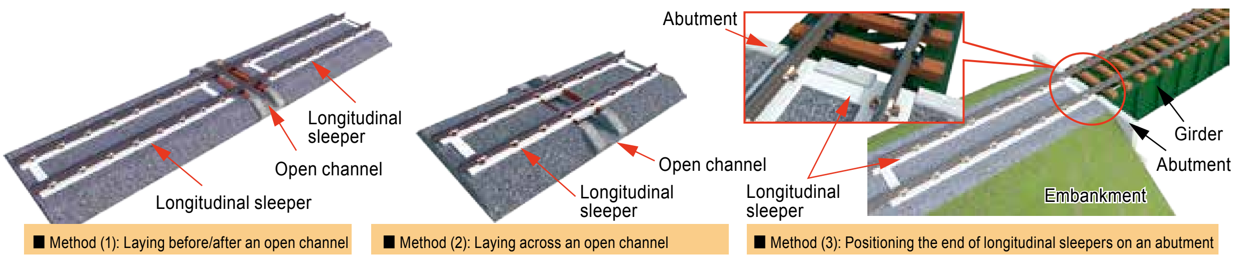


Fig. 1 Method of laying longitudinal sleepers at boundaries with structures

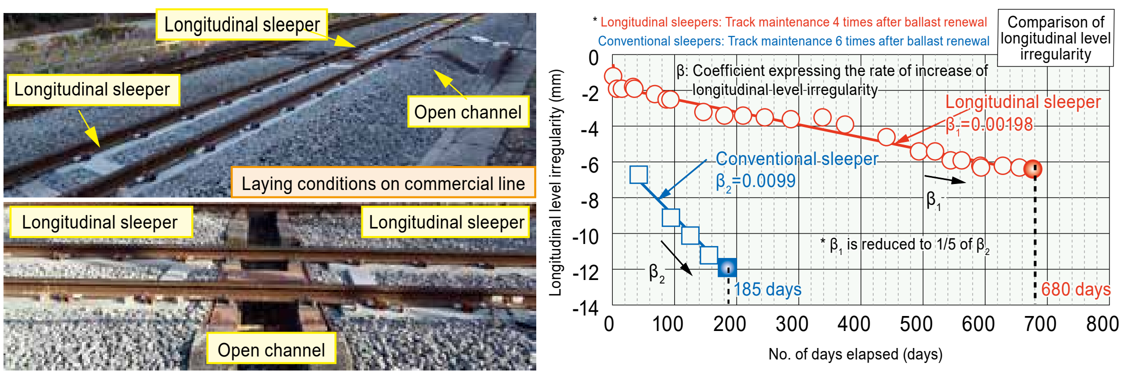


Fig. 2 Effectiveness of longitudinal sleepers in controlling longitudinal level irregularity
(Method (1), laying before/after an open channel)

17. Method for evaluating the effect of impact load on fatigue of steel bridges at rail joints

- The high-frequency vibration of members caused by the impact load of wheels passing over a rail joint contributes significantly to the initiation of fatigue cracks in steel bridges.
- We developed an analytical method for evaluating cumulative fatigue that takes into account high-frequency vibration.
- The method makes it possible to identify areas of high accumulated fatigue, thereby increasing the efficiency of inspection and reinforcement.

Fatigue cracks tend to occur frequently in the vicinity of rail joints on steel bridges (Fig. 1). The low-frequency vibrations arising from wheel movement are known to cause fatigue cracks. However, at rail joints, this is worsened by the impact loads generated when train wheels roll over the joint, causing high-frequency vibrations of several hundred Hz in steel bridge members. Measurements on existing bridges and analysis have proven that stresses caused by these high-frequency vibrations contribute significantly to the initiation of fatigue cracks (Fig. 2). Since these high-frequency vibrations are localized, it is necessary to check every bridge member for the presence of fatigue cracks during inspections; a significant burden.

In light of this, we developed an analytical method that estimates the stresses caused by high-frequency vibrations and evaluates the accumulated fatigue in the members of steel bridges. A feature of this method is that the impact load at rail joints is calculated from measured stress at one or two locations by inverse analysis and then the stress at any location is estimated, using the impact load as an input (Fig. 3). The method can be used to identify areas where accumulated fatigue is large (Fig. 4), to define the areas that require concentrated attention during inspections, thereby increasing inspection efficiency. Since the method identifies the propagation paths of high-frequency vibration and vibration characteristics, it can also be useful in selecting more effective reinforcement methods and enabling more efficient maintenance and management of steel bridges.

Fig. 1 Fatigue cracks in the vicinity of rail joints

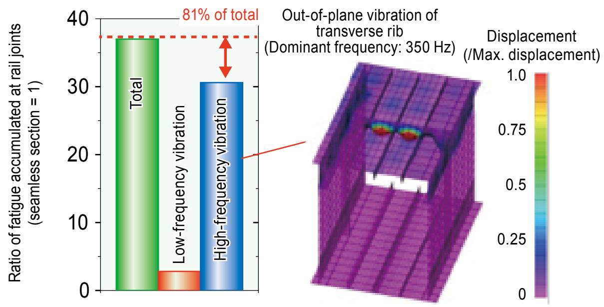


Fig. 2 Contribution of high-frequency vibrations to fatigue

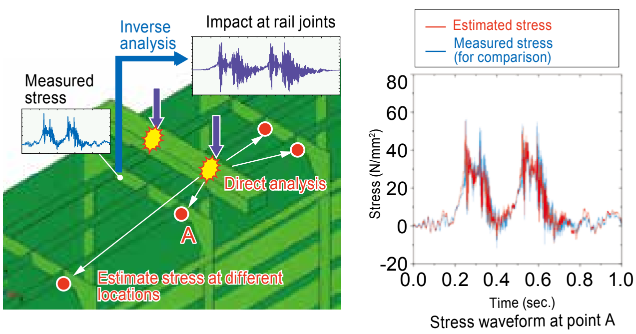


Fig. 3 Estimating stresses at different locations using measured stress

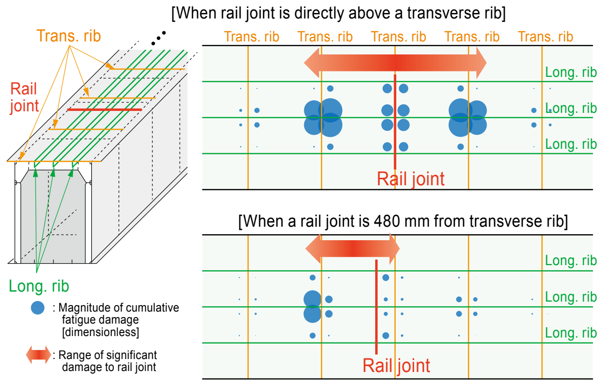


Fig. 4 Results of evaluating accumulated fatigue

18. Efficient method for adjusting openings in large tunnel entrance hoods

- We proposed an efficient method for uniformly adjusting the area of windows arranged consecutively in a tunnel entrance hood.
- Compared to the conventional method of adjusting the position of openings, the new method makes it possible to reduce micro-pressure waves by the same degree, using 80% fewer trials for adjustment.

To fully demonstrate the performance of tunnel entrance hoods as a measure for reducing micro-pressure waves in railway tunnels, it is important to optimize the shape, position, and size of openings arranged along the sides of the structure. As Shinkansen trains continue to get faster, tunnel entrance hoods are getting longer and including more “openings.” It is therefore becoming more difficult to optimize the conditions of the openings (open/closed) to achieve maximum effectiveness. In this study, we proposed an optimization method for uniformly adjusting the degree of opening (height or width) of all windows (Fig. 1), as opposed to the conventional approach in which the windows are either fully open or closed and optimization is performed by deciding which windows to open and close (Fig. 1) The new method of adjusting the degree of opening can reduce the magnitude of micro-pressure waves, which depends on the maximum pressure gradient in the tunnel, by the same degree as the conventional method (Fig. 2). Additionally, the new method can reduce the number of trials required for optimization by about 80% for long tunnel entrance hoods of 30 m or more (Fig. 3).

When only a limited number of trials can be performed to optimize actual tunnel entrance hood openings, it is essential to make the structure longer than necessary when using the conventional method, because it is not possible to achieve the full performance potential of the tunnel entrance hood. This new method can help to reduce the length of tunnel entrance hoods at the design stage because it is possible to achieve the maximum micro-pressure wave reduction effect (or close to it) even with only a small number of trials.

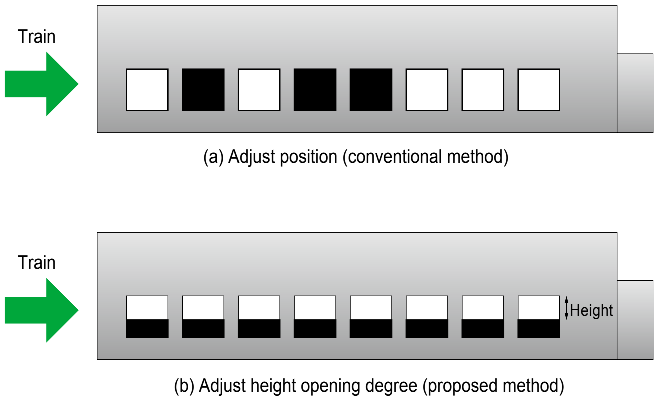


Fig. 1 Opening adjustment method

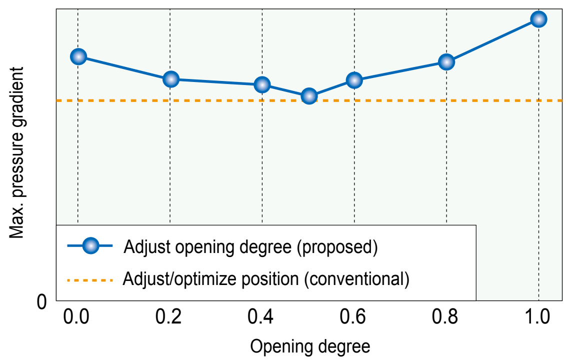


Fig. 2 Relationship between opening degree and max. pressure gradient(on-site test)

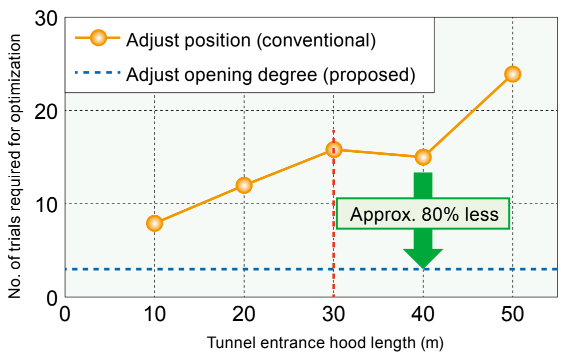


Fig. 3 Comparison of no. of trials required for optimization(model experiment)

19. High-resolution sound source identification method for way-side noise reduction measures

- The adoption of a new specially designed two-dimensional spiral array system and the application of a cutting-edge signal processing method for moving sound sources make it possible to increase the spatial resolution of sound source distribution around vehicles by a factor of about nine.
- Since the new system is capable of visualizing sound source distribution with a spatial resolution of about the size of a wheel, it can be used to analyze sound sources in bogies, pantographs, and other parts in detail. It is also useful for verifying the effectiveness of noise reduction measures.

When examining ways to reduce noise along Shinkansen lines, which is increasing as Shinkansen trains continue to get faster, it is necessary to understand the relevant sound sources distributed around vehicles. For this purpose, we created a portable two-dimensional spiral array system with a microphone array specially designed for measuring sound source distribution along railway lines (Fig. 1). This array system has enough spatial resolution to distinguish sound sources near the wheels of each axle when targeting a bogie. We also utilized a method of converting data recorded by the system, by analyzing it with a general-purpose signal processing program and then storing it in a database. This enables high-resolution identification of moving sound sources using a deconvolution method to remove sound source "fuzziness" caused by the geometric microphone array. This is the first attempt of its kind in the railway field in Japan. The sound source identification method is proven to increase the spatial resolution of sound source distribution by a factor of approx. nine (three times higher in the railway line direction and three times higher in the vertical direction) compared to the conventional signal processing method, which utilizes the delay and sum method. At this higher resolution, the sound sources around vehicles can be determined in excellent detail. For example, sound sources in and around the wheels of each axle of a fast-moving Shinkansen bogie and in the gaps between its vehicles can be clearly discerned (Fig. 2). The method makes it possible to investigate noise reduction measures for sound sources identified in bogies and pantographs and to demonstrate their effectiveness.

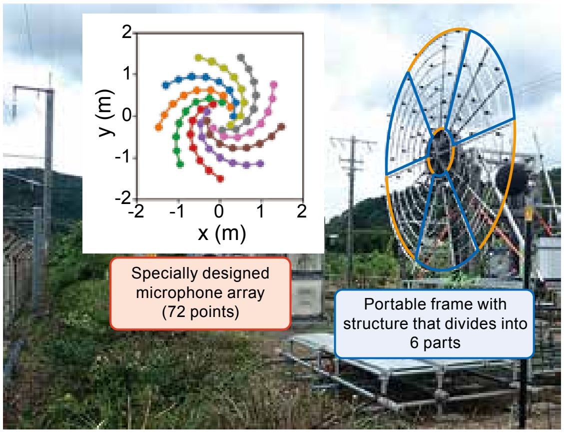


Fig. 1 A two-dimensional spiral array system used for measuring noise along railway lines
(9.1 m from the center of the nearest track)

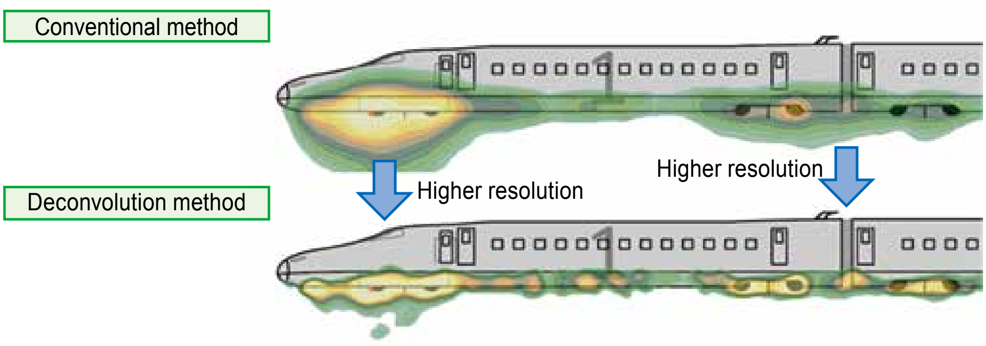


Fig. 2 Comparison of sound identification between conventional and new deconvolution-based methods for high-speed vehicles

20. Method of evaluating the effectiveness of investing in disaster countermeasures for freight transport

- We developed a method for quantitatively evaluating the effectiveness of investments in disaster countermeasures, using the volume of freight traffic and the costs to operators during periods when services are partially interrupted due to a disaster as indices for evaluation.
- The method can be used for formulating disaster countermeasures and identifying investment priorities, i.e., the areas that most need countermeasures.

As natural disasters become more severe and frequent, effective disaster countermeasures are required to improve the disaster resilience of rail freight transport. However, quantitatively evaluating the effectiveness of such investments has been difficult. To solve this problem, we considered periods when the railway network is partially interrupted due to a disaster. We first developed a method for quantitatively determining the volume of freight traffic Q (hereafter, “disaster transported volume”), including detour transport and substitute truck transport, and the cost to rail freight operators L (hereafter, “disaster cost”). When we verified the validity of the developed method using actual freight transport data from past disasters, assuming no change in freight transport demand after the disaster, we confirmed that this method is capable of accurately estimating disaster transported volume, with the exception of periods when demand drops temporarily due to long consecutive holiday periods (Fig. 1).

Next, to evaluate the effectiveness of investments in disaster countermeasures, we developed a method focusing on disaster transported volume and the sum of disaster period costs L and disaster investment costs I (total disaster cost). We calculated the difference in the disaster transported volume, ΔQ (Index 1) and the difference in the total disaster cost Δ(L+I) (Index 2), between the two cases in which disaster countermeasures are implemented and not implemented on railway networks. The disaster transported volume Q and disaster period cost L are calculated using the quantification method described earlier. This method is used to obtain Index 1 and Index 2 for each disaster countermeasure and to evaluate the effectiveness of each investment (Fig. 2).

This method can be used to formulate various disaster countermeasures, such as improving disaster resilience by enhancing facilities at freight stations (“hard” measures) and expanding truck substitution routes (“soft” measures), as well as to identify the areas of the railway network where it is most beneficial to apply measures. By replacing volume of freight traffic with that of passenger traffic, the method can be similarly used to evaluate the effectiveness of investments in disaster countermeasures for passenger transport on the same railway network.

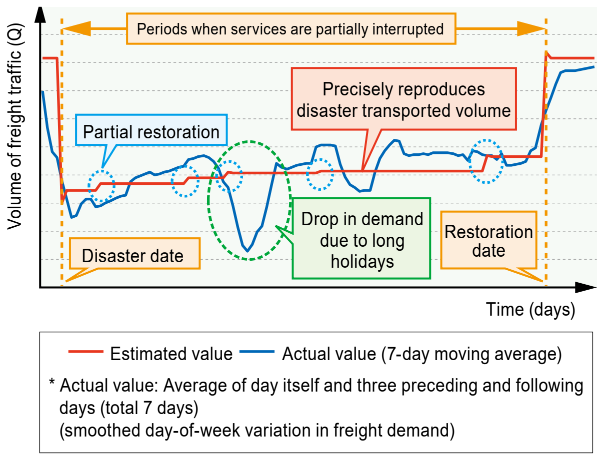


Fig. 1 Results of verification using actual freight transport data in past disasters

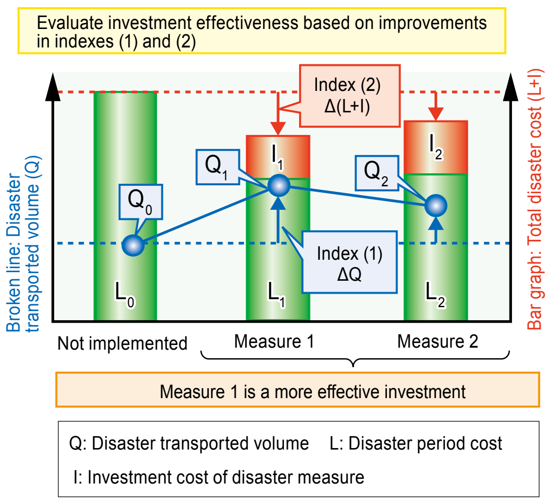


Fig. 2 Evaluation of the effectiveness of investments in disaster countermeasures based on the difference between volume of freight traffic and total disaster cost

21. Method of evaluating thermal comfort of solar radiation environments in commuter trains

- We proposed a method for evaluating the comfort of thermal environments in commuter trains, taking into account the effects of solar radiation.
- We conducted an experiment with participants by simulating a solar radiation environment inside a train, to confirm that the predictions generated by the proposed method correspond closely to actual experience.

Passengers often express their opinions about the thermal environment inside commuter trains, claiming they are too hot, or too cold.

A variety of factors affect thermal comfort in trains, including air temperature, humidity, air velocity, and solar radiation. One of these, solar radiation, which varies significantly with the position and direction of the running train (Fig. 1), has a big impact on passenger thermal comfort, but up to now it has not been possible to quantitatively evaluate thermal comfort in a way that takes this factor into account. To understand the physiological and psychological effects of this factor, we conducted an experiment with participants by simulating a solar radiation environment inside a train (Fig. 2). Based on our findings, we then proposed a method for evaluating thermal comfort that takes the effects of solar radiation into account (Fig. 3).

Using solar radiation, air velocity, and other parameters that define the thermal environment inside the train as inputs, the proposed method uses a thermos physiological model with an integrated thermoregulatory function to calculate the sensible temperature of each body part, thereby reflecting the physiological state of a passenger. Next, the average, maximum, and minimum sensible temperatures of the whole body and a statistical model based on a past experimental data with participants were used to predict the proportion of passengers that feel unsatisfied with a particular thermal environment ("dissatisfaction rate"). Since the model takes into account both local bodily sensations and the average sensation over the whole body, it can be applied to complex environments in which a part of the body is exposed to solar radiation. The coefficient of correlation between the predicted and measured dissatisfaction rates was 0.90, confirming that the method is sufficiently reproducible (Fig. 4).

The proposed method can be used to make a variety of quantitative evaluations from the thermal comfort point of view, for example to assess the effectiveness of measures such as improving air conditioning control and reducing solar transmittance through windows, or to examine the influence of opening windows for ventilation.

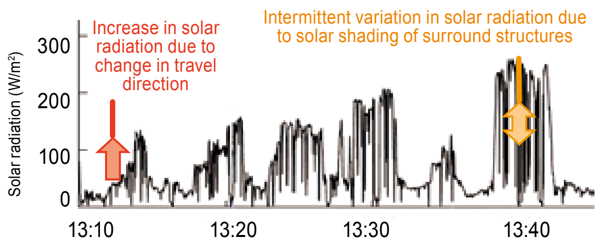


Fig. 1 Example of measured solar radiation in a train

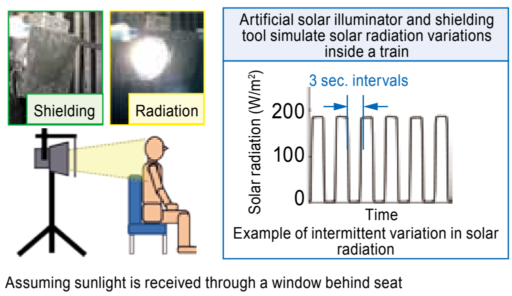


Fig. 2 Outline of an experiment with participants

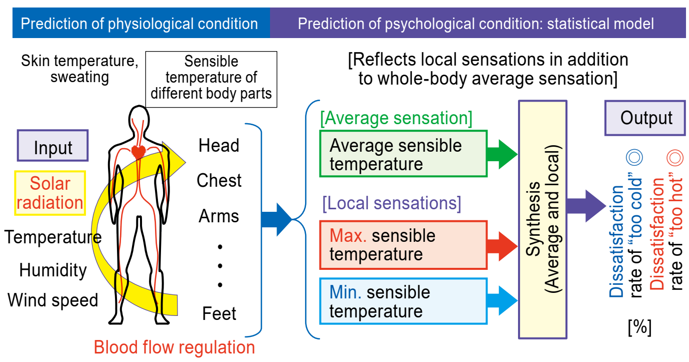


Fig. 3 Overview of proposed method

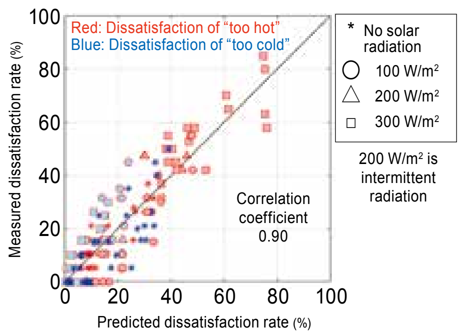


Fig. 4 Prediction based on proposed method and measurements

22. Earthquake early detection method based on deep learning of seismic motion

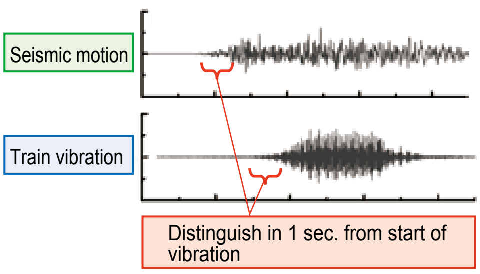
- We developed an earthquake early detection method based on deep learning of seismic motions.
- The method improves the ability to discriminate between seismic motion and noise from approximately 90% to 99% and enhances the estimation precision of all seismic parameters, including epicentral distance and magnitude.
- We confirmed that the method is capable of processing estimates in real time.

Earthquake early detection methods need to distinguish between seismic motion and noise from sources such as train vibration, estimate epicentral distance, magnitude, and other seismic parameters, and to determine the risk of damage to railways as soon as possible after detecting vibration. To accomplish all this, it is important to increase (1) the precision of discrimination between seismic motion and noise and (2) the precision of seismic parameter estimation. In view of this, we developed an earthquake early detection method featuring integrated deep learning and evaluated its precision.

Previously observed seismic motions and train vibrations are used as training data for identifying noise. Even when the number of train vibration records at a seismic observation station is small, it is still possible to achieve a high identification rate by increasing the volume of training data by means of a data generation process. Current methods have a noise identification rate of approximately 90%, but we have confirmed that with deep learning, this figure can be increased to approximately 99% (Fig. 1).

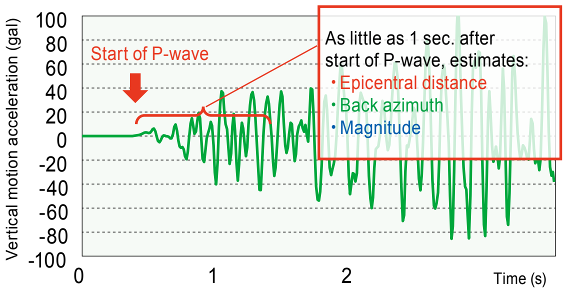
To estimate seismic parameters, we used approximately 20,000 observed seismic motions as the training data, confirming that the proposed method, compared to the current methods, is capable of significantly improving the estimation precision of current methods for all parameters (Fig. 2). We also showed that even with a general-purpose CPU, it is possible to complete all processing, from noise identification to seismic parameter estimation, in as little as 0.7 seconds, proving that the method is practicable for real-time applications.

In the coming years, the development of deep learning-based seismograph of early warning system for railway that incorporate noise identification and seismic parameter estimation will significantly enhance earthquake resilience.



	Current method	Deep learning
Identification rate of seismic motion	89.8%	99.9%
Identification rate of train vibration	90.0%	98.5%

Fig. 1 Discriminating between seismic motion and train vibration in an earthquake early detection system



Seismic parameters element	Improvement in estimation precision when using deep learning, compared to current method
Epicentral distance	Up 39%
Back azimuth	Up 4%
Magnitude	Up 27%

Fig. 2 Estimating seismic parameters in an earthquake early detection system

23. HILS for the current collection systems using a High-Speed Test Facility for Pantograph/OCL Systems

- Using a High-Speed Test Facility for Pantograph/OCL Systems, we developed a HILS for the current collection systems that takes into account the effects of overhead contact line (OCL) vibration, sliding due to travel, stagger of the OCL, environmental temperature, humidity, and energization.
- The HILS for the current collection systems enables comprehensive evaluation of pantograph performance based on a bench test, making it possible to develop higher-performance pantographs more efficiently and inexpensively.

To evaluate pantograph performance, it is important to conduct evaluation in an environment with overhead contact line (OCL) vibration, as well as sliding due to travel and stagger of the OCL. We previously developed a system capable of evaluating pantograph performance under the influence of OCL vibration up to high frequencies, as a HILS (Hardware-In-the-Loop Simulation) for the current collection systems. However, the method was unable to take into account the effects of sliding or stagger of the OCL. To resolve this issue, we embedded a HILS for the current collection systems in a High-Speed Test Facility for Pantograph/OCL Systems (HiPaC). Although the OCL vibrations that can be considered with this HILS system are limited to low frequencies, the system can take into account the effects of sliding and stagger of the OCL, as well as temperature rises and component wear due to ambient temperature, humidity, and energization (Fig. 1). In the HiPaC, the mass of the moving part is large compared to that of the previously developed HILS for the current collection systems and the frequency characteristics are also more complex. For this reason, developing a HILS compensator suitable for the HiPaC makes it possible to take into account OCL vibrations up to the frequency at which the pantograph travels from one supporting point to another (approx. 2 Hz). As a result, evaluations of the uplift of the contact wire at the supporting points through which the pantograph passes, which is an important indicator for the safety of the OCL systems, as well as selection of an appropriate damper constant for the pantograph, can now be conducted based on a bench test (Fig. 2). Previously, such evaluations could only be made by on-track testing. This new method therefore makes it possible to develop higher-performance pantographs more efficiently and less expensively.

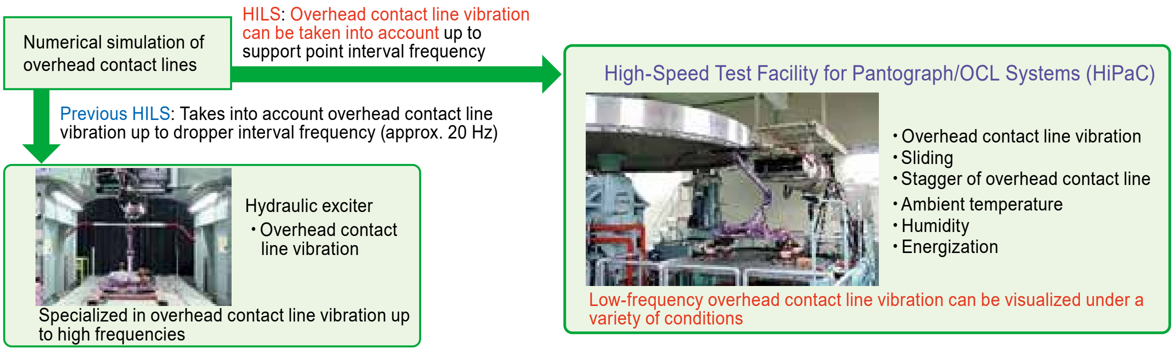


Fig. 1 Relationship between HILS using HiPaC and conventional method

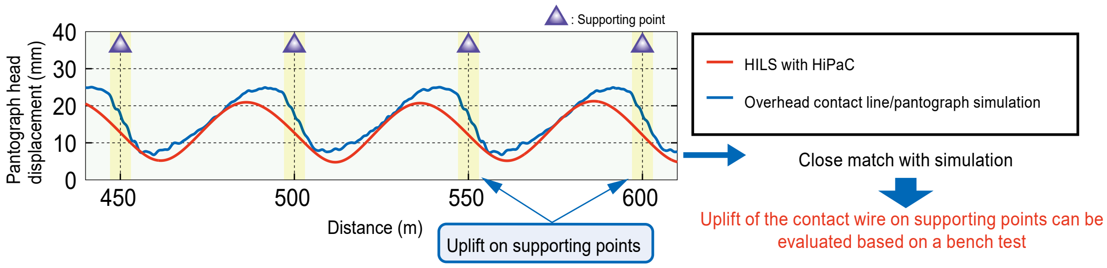


Fig. 2 Comparison of HILS test and simulation at a travelling velocity of 300 km/h
(Simulation is done under ideal conditions, without overhead contact line irregularities)

24. Mechanism of increasing wear rate of contact wires near pantograph stopping positions of Shinkansen

- An investigation within a Shinkansen station yard clarified the train-speed dependency of contact wire wear rate.
- The study revealed that the coefficient of friction increases at low speeds, thereby accelerating “delamination wear,” which is the cause of the high wear rate.
- We confirmed that the application of grease can reduce contact wire wear in low-speed sections of railway lines.

The wear rate of the contact wires of Shinkansen is high within station yards and other low-speed sections of track. For this reason, contact wires need to be replaced frequently, frustrating efforts to reduce maintenance costs. To understand why wear rate is high at low speeds, we examined the relationship between the wear rate of contact wires and travel speed, observed the cross-sectional structure of worn contact wires, and conducted sliding experiments over a wide range of speeds.

Data on the wear distribution of contact wires and train travel speed in a station yard revealed that the contact wire wear rate has the characteristic of increasing rapidly at low speeds (Fig. 1). Based on measurements in experiments to determine the train-speed dependency of the coefficient of friction (Fig. 2) and observations and analysis of the cross-sectional metallographic structure of actual contact wires using an electron microscope (Fig. 3), it is likely that wear rate increases at low speeds because an increase in coefficient of friction promotes a type of wear in the form of peeling known as “delamination wear.”

As a measure to limit delamination wear, we considered using lubrication to reduce the coefficient of friction. For this purpose, we fabricated a new laboratory test facility capable of simulating low-speed travel conditions (Fig. 4) and investigated the impact of grease on wear reduction. Our findings confirmed that the wear rate was reduced by 75% or more as long as the grease adhered to the contact wire (Fig. 5). We are now planning to verify the sustainability of the wear-reducing effect of external lubrication in operating trains.

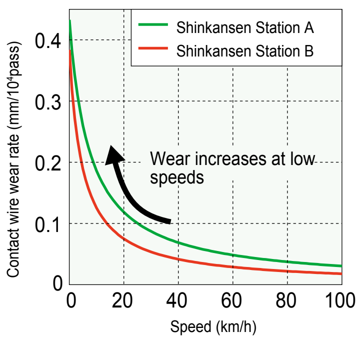


Fig. 1 Train-speed dependency of contact wire wear rate

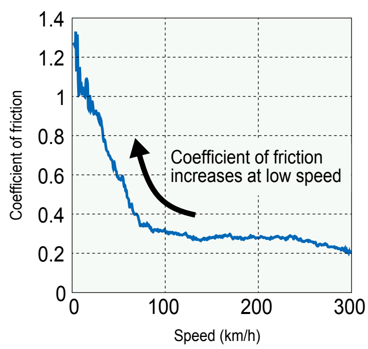


Fig. 2 Train-speed dependency of coefficient of friction

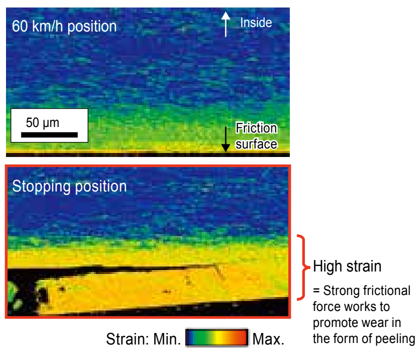


Fig. 3 Example of strain analysis of actual contact wire cross-section

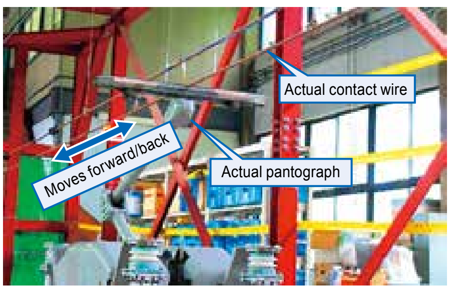


Fig. 4 New testing facility

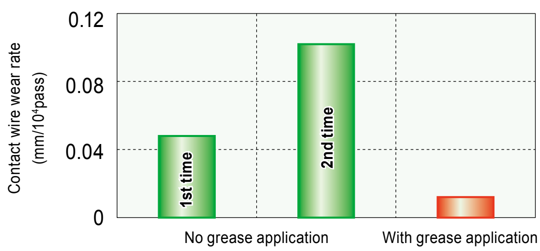


Fig. 5 Wear-reducing effect of contact wire by applying grease

25. Text analysis codes for human error analysis

- We created an algorithm (code) for text analysis to analyze work characteristics, psychological factors, and error behaviors described in risk information from accidents and potential incidents.
- The code can analyze 95% of approximately 4,000 items of the descriptive data of error behaviors in a few seconds, whereas it would take a human several months to classify them.

To utilize risk information about accidents or potential incidents for safety management purposes, it is necessary to organize and analyze collected information. However, although the number of railway accident reports is not large, there is a large volume of descriptive textual information due to the detailed investigations and analyses that are done for each incident. It is therefore a laborious task to organize all the information. At the same time, the number of voluntary reports about potential incident issues has risen in many organizations over the past decade, in line with growing safety awareness and the cultivation of a stronger workplace safety climate. This trend has made the burden of organizing risk information even heavier.

In light of this, we created an analysis algorithm (code) for applying text mining technology to the descriptive data of risk information. A notable feature of this algorithm is the creation of classification codes for identifying trends in the occurrence of human errors, including 162 work characteristics (scene, location, object, conditions, etc.), 18 psychological factors, and 4 error behaviors (Fig. 1).

Risk information analysis based on these classification codes revealed that the quality of reported error behavior varies according to the type of risk information—for example, accident or potential incidents (Fig. 2). Additionally, when work characteristics were summarized by reporting month, we were able to identify the environmental factors that required attention depending on the season (Fig. 3).

This method makes it possible to analyze 95% of 4,000 items of descriptive data in just seconds, compared to the several months it would take a human to classify the same error behaviors. We also confirmed that if the results of a human classification are assumed to be correct, the accuracy of the algorithm is in 83 to 94% (rate of matching).

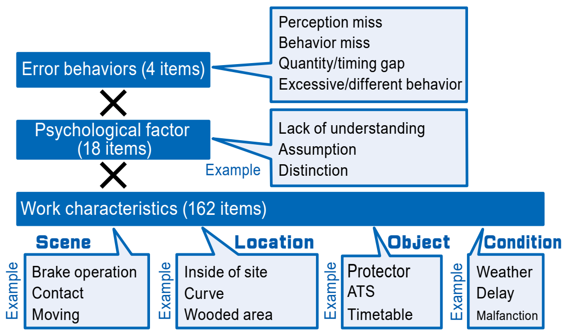


Fig. 1 Outline of text analysis codes

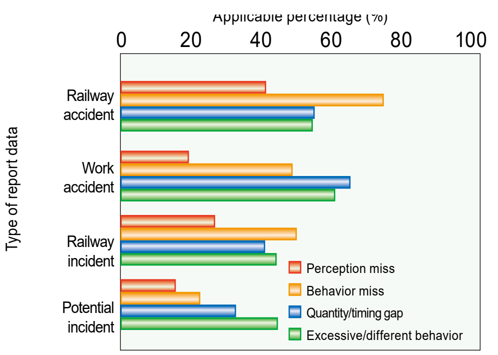


Fig. 2 Applicable percentage of error behavior (Usage example 1)

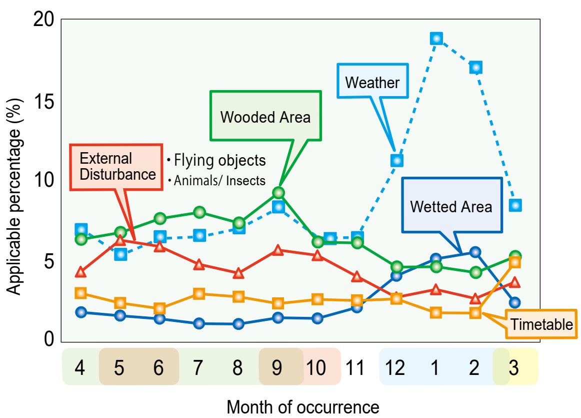


Fig. 3 Occurrence frequency of work characteristics items by reporting month (Usage example 2)

26. Method of visualizing sound wave propagation for clarification and prediction of railway noise

- We developed a measurement method for visualizing sound waves propagating through the air based on laser polarization and used it to visualize sound waves diffracting through sound barriers and the Doppler effect caused by a moving sound source.
- We developed a method for estimating the sound pressure distribution in a specific cross-section based on sound wave visualization results.
- The method can be used to shed light on the phenomenon of railway noise and increase the accuracy of noise prediction methods along railway lines.

Railway noise is characterized by the fact that sound sources move at high speed and by the presence of reflective objects such as vehicle bodies and sound barriers around the sound sources. So, to understand and predict this phenomenon, it is important to grasp the propagation of sound. We therefore developed a method for visualizing the propagation of sound emitted from a moving source through the air and the diffraction behavior of sound waves near a sound barrier.

To visualize sound waves, we used a parallel phase-shifting interferometer (Fig. 1). This device captures images of the interference fringes of laser light with a high-speed camera, making use of the fact that pressure fluctuations in the air caused by sound can be observed as phase changes in the light. We also developed a method for estimating the sound pressure distribution within a specific cross-section based on the theoretical equations for spherical waves.

By applying this method to a 1:80-scale model of a noise barrier, we confirmed that it is possible to visualize the reflection, interference, and diffraction attenuation of sound waves observed around the noise barrier (Fig. 2). Using a model launcher system to visualize the wavefronts of sound emitted from a moving sound source—a model train fitted with an ultrasonic transducer—we confirmed the ability to observe frequency modulation due to the Doppler effect (Fig. 3). This is the first time that the Doppler effect has been experimentally visualized in the air. With this method, we expect to be able to validate a physical model of multiple reflections between vehicle bodies and sound barriers and to evaluate the reflection, interference, and diffraction of sound waves under realistic railway structures. All this will be useful in further improving the accuracy of noise prediction methods along railway lines.

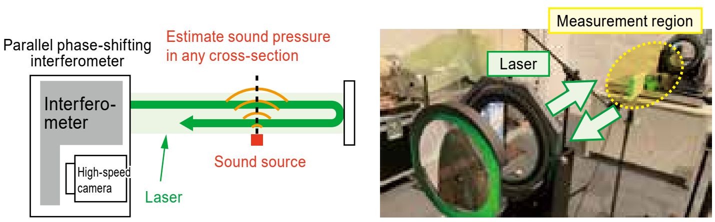


Fig. 1 Outline of sound wave visualization experiment

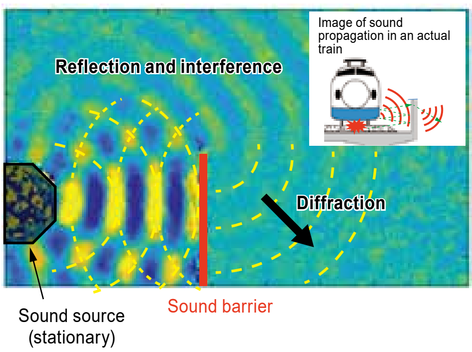


Fig. 2 Visualization of sound wave reflection, interference and diffraction with a sound barrier (model experiment)

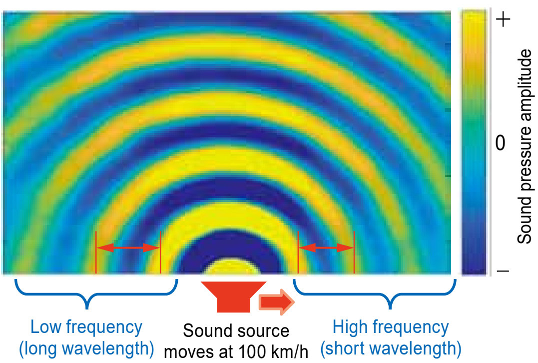


Fig. 3 Visualization of the Doppler effect and wavefronts of sound propagated from a moving source (model experiment)

1. Mr. Nakamura of RTRI Commended for his Contribution to Standardization Activities

Mr. Kazuki Nakamura of RTRI was given the Year 2020 Award for Contribution to Standardization by the Railway Technology Standardization Survey Committee. The award giving ceremony was held on March 31 in Tokyo.”

Award winner:
Mr. Kazuki Nakamura, Laboratory Head, Telecommunications and Networking, Signalling and Transport Information Technology Division

Award winning achievement:
Since 2017, Mr. Nakamura has contributed to the review activities in Japan as a member of the task force and panels for railway telecommunications of the International Telecommunication Union (ITU-R) and the Ministry of Internal Affairs and Communications. In addition, he participated in the International Special Committee on Radio Interference of the International Electrotechnical Commission (IEC/CISPR/SC B/WG 2) as an international expert for more than 10 years and contributed to domestic and international review activities.

He joined the Japanese delegation for the 2019 World Radiocommunication Conference (WRC-19) under ITU-R. He was given the award because he presented Japanese views at the conference with other members, succeeded in reflecting them in the resolutions and is expected to further contribute to the international standardization efforts.

* Award for Contribution to Standardization is given to persons who contribute to international and domestic standardization activities in the railway field. This award giving is started in 2007 by the Railway Technology Standardization Survey Committee (Chairperson: Hiroyuki Osaki, Prof. of the University of Tokyo Secretariat: Ministry of Land, Infrastructure, Transport and Tourism and RTRI) for the purpose of supporting the activities of award winners and raising the awareness of the importance of standardization among related people. In particular, the Award for Contribution to Standardization is given to a person who is expected to continue to contribute to standardization.

Mr. Kazuki Nakamura

2. High-Speed Wheelset Dynamic Load Test Facility Completed

On February 26, 2021, a new test facility was completed at RTRI. This test stand is capable of reproducing high-speed train running (maximum 500 km/h) and the load acting to the bogie (Fig.1 and 2), and, with this facility, durability and performance of Shinkansen's wheel and axle can be evaluated. It will be utilized to evaluate the durability of wheelset and bogie parts and to analyze the mechanism of wheelset damage development.

[Outline of the test facility]

•Instead of running a test bogie on a track, this facility is capable of reproducing 500 km/h running by rotating the wheelsets of a test bogie on its high-speed roller.

•Capable of reproducing vertical vibration of a track by shaking the roller vertically.

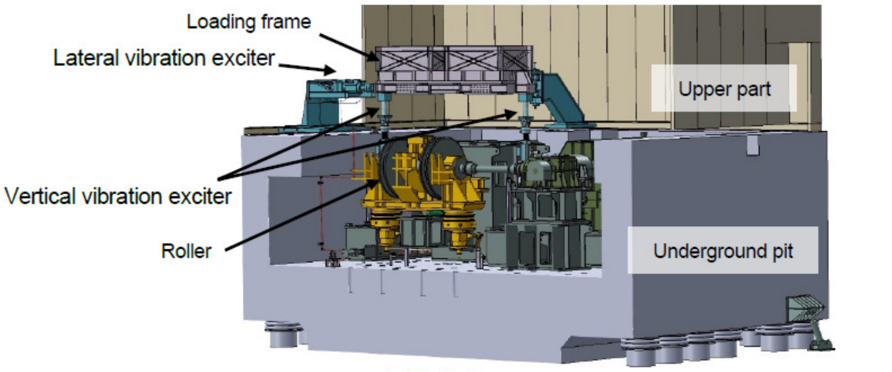
•The loading frame that simulates a carbody is shaken by the vibration exciters and reproduces vertical and lateral vibration of a running train carbody and the load acting to the bogie. (Fig. 2)

•Simulates the torque acting to the wheelset during acceleration and deceleration.*

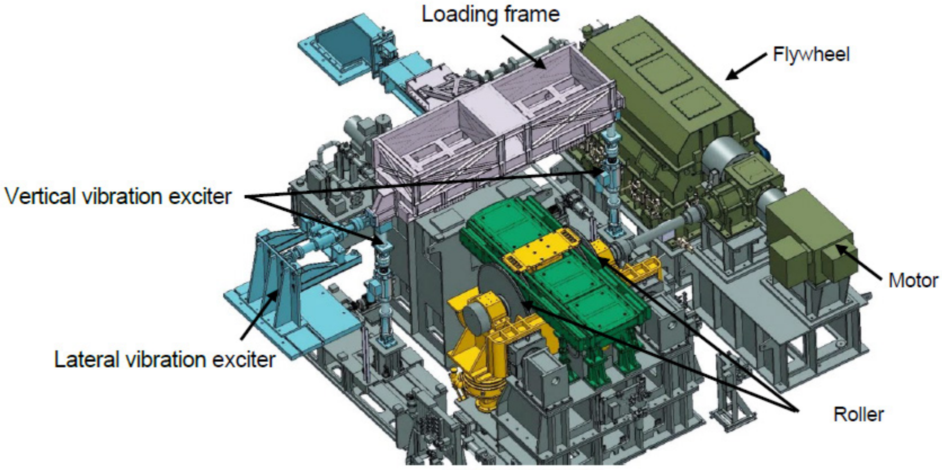
•Capable of testing bogies for different gauges as it has rollers of Shinkansen gauge and conventional gauge.

*Simulating the torque to move a carbody in the longitudinal direction with a flywheel.

Fig. 1 High-speed wheelset dynamic load test facility



(a) Entire image



(b) Components

Fig. 2 Configuration of high-speed wheelset dynamic load test facility

Table 1 Specification of high-speed wheelset dynamic load test facility

Component	Function	Specification
Roller	Simulating train running	・ Gauge: 1067mm and 1435mm ・ Maximum speed: 500km/h ・ Vertical vibration：-15 to +15mm
Loading frame	Applying vertical load	・ Static load: 80kN～200kN
Vertical vibration exciter	Simulating vibration by train running	・ 2 vertical and 1 lateral vibration exciters ・ Amplitude：-100 to +100mm ・ Load：-100 to +100kN per exciter ・ Different patterns of vibrations can be reproduced.
Lateral vibration exciter		
Flywheel	Applying the force by train motions during acceleration and deceleration	・ Under 300km/h: maximum 150kN ・ Over 300km/h: maximum 110kN
Others	Different-sized bogies can be tested.	・ Wheelbase: 1500～3000mm ・ Air suspension interval: 1750～2600mm

[Tests and evaluations using the test facility]

(1) Durability assessment

Using this test facility, durability of the components of a wheelset and a bogie can be evaluated under the conditions close to running tests with an actual vehicle. The results of the evaluation will be utilized in the research to assess the service life of these components and in extending inspection intervals for the purpose of achieving labor-efficient maintenance.

(2) Performance assessment

Vibration property and thermal property of the components of a wheelset and a bogie will be evaluated under the loading conditions simulating real train running or harder conditions. The results will be used to improve the bogie performance.

(3) Damage cause analysis

Through the tests on this facility under the conditions simulating the vehicle load and acceleration/deceleration torque, causes of damage to the components will be analyzed and effects of preventive measures will be verified.

3. Low-Noise Moving Model Test Facility Completed at RTRI

A low-noise moving model test facility was newly completed at RTRI. This testing facility, featuring the world's highest class performance, is capable of running a 1:20 scale model train at the maximum speed of 400 km/h and accurately reproducing the air flow and turbulence created by a running train. It was completed on July 10, 2020 and testing was started on October 29, 2020.

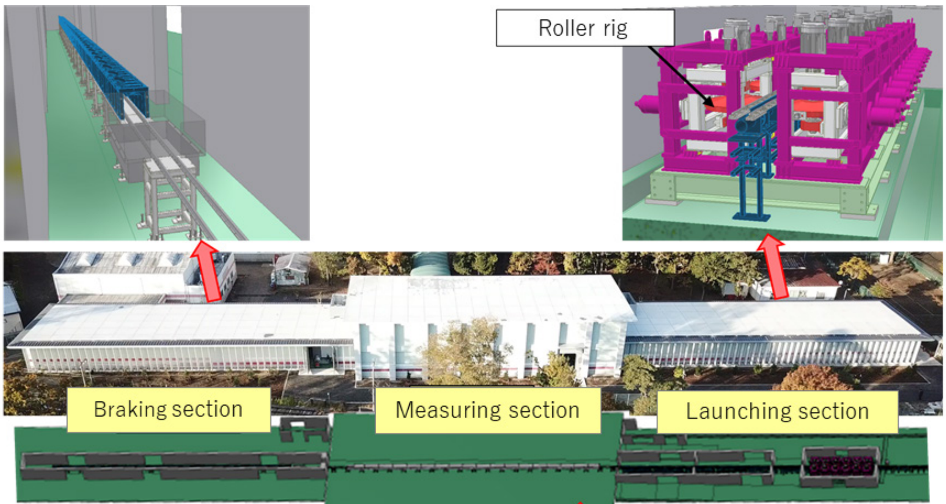
[Overview of low-noise moving model test facility]

This testing facility consists of three sections: launching section, measuring section, braking section (Fig.1)

In the launching section, a 1:20 scale model train is launched and accelerated to maximum 400 km/h by a roller rig. (upper right of Fig. 1) The model train has a streamline nose shape replicating an actual train's front shape (Fig. 2).

In the measuring section, the model train coasts in order to reduce background noise. This section is a semi-anechoic chamber and its walls and ceilings were covered with sound-absorbing material to reduce reflected sound (Fig.2). This semi-anechoic chamber enables measuring of pressure fluctuation in an open section of a tunnel (low-frequency-range aerodynamic noise generated by a train). In addition, by mounting a tunnel model in this chamber, micro-pressure waves propagating from tunnel ends and pressure and wind speed fluctuation in a tunnel can be reproduced.

In the braking section (upper left of Fig.1), the model train runs into foamed polystyrene beads placed in the 32 meter-long section and comes to a stop.



Maximum speed	400 km/h (length of model train 2.5 m) 360 km/h (length of model train 7.5 m)
Scale of model train	1/20
Length of model train	Maximum 7.5 m (corresponding to 150 m train)
Total length of facility	125 m (Launching section: 42 m Measuring section: 40 m Braking section: 43 m)

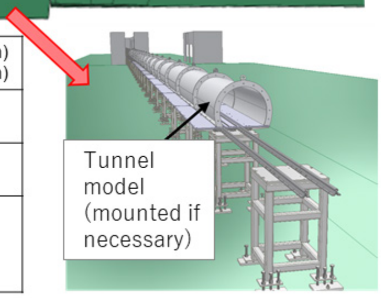


Fig. 1 Low-noise moving model test facility and basic specification

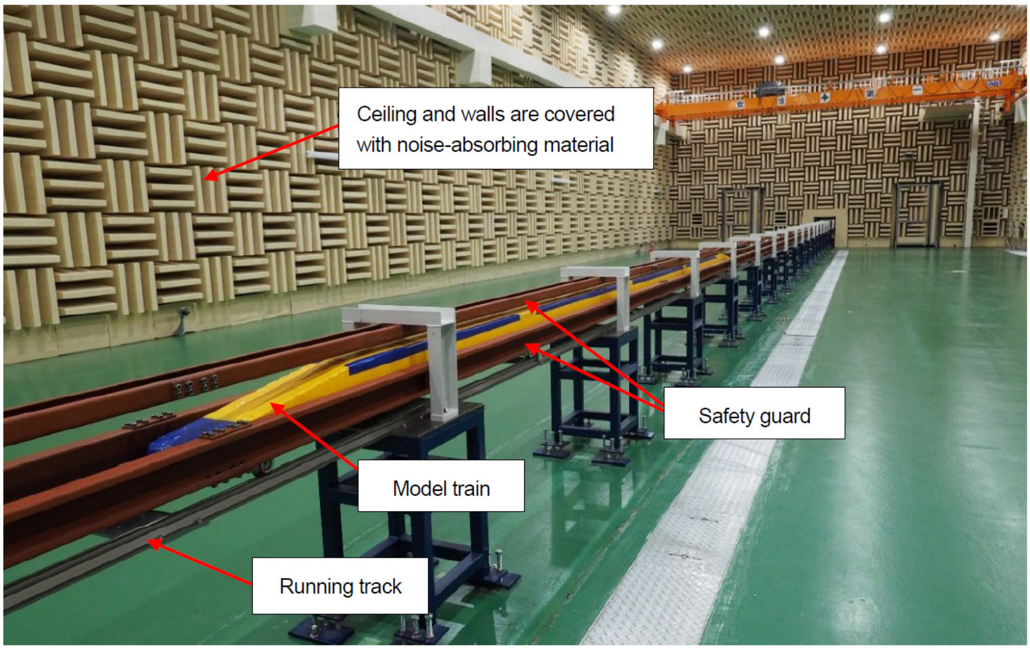


Fig. 2 Measuring section
Safety guard is tentatively mounted for speed-increase testing

[Planned testing and experiments]

High-speed trains generate turbulent air flow which causes aerodymnamic noise and the pressure fluctuations around the trains have impacts on insulating panels and tunnel walls. The low-noise moving model test facility will be used to analyze these phenomena and to develop measures to solve the problems.

(1) Experiments to analyze the phenomena caused by passing trains.

The research into the mechanism to generate low-frequency-range aerodynamic noise will be implemented and its results will be used to develop mitigating measures and to confirm their effects. By evaluating the impacts on structures including noise-insulating walls, tunnel walls and tunnel hoods, the data will be used for the strength design of structures.

(2) Experiments to reduce micro-pressure waves

When a train runs into a tunnel, micro-pressure waves radiate from the other end of the tunnel. Experiments will be conducted to improve the nose shape of a high-speed train in order to mitigate the micro-pressure wave radiation and to assess the performance of the mitigating hoods mounted to tunnel ends.

(3) Gathering data to develop numerical simulation methods

Using the test data accurately reproducing actual phenomena, we will develop numerical simulation methods to predict precisely the phenomena caused by train passing and radiation of tunnel micro-pressure waves. The simulation methods will be used for strength designs to ensure necessary strength of structures for higher-speed trains and new vehicles and to develop measures to mitigate micro-pressure waves.

[Reference]

RTRI has also had an older testing equipment for the similar purpose with the following performance:

Scale of a model train: 1/80 to 1/100

Maximum launching speed: 550 km/h

Shape of a model train: the model has circular cross-section shape, but the ratio of cross section area to vehicle length is equivalent to that of an actual car (Fig. 3)

Fig. 3 Model train of the older equipment

4. RTRI and the National Science and Technology Development Agency of Thailand Conclude Memorandum of Understanding on Technical Cooperation

On July 1, RTRI and the National Science and Technology Development Agency of Thailand (NSTDA) concluded Memorandum of Understanding on Technical Cooperation.

NSTDA is an independent institute under the Ministry of Science and Technology of Thailand which is responsible for research and development of overall technologies. Since 2011, RTRI and NSTDA have been sharing technical information and expertise through sending researchers for railway technical seminars in Bangkok and accepting visitors to RTRI from NSTDA. Since 2016, RTRI has been cooperating with NSTDA in organizing a railway technical tradeshow in Thailand. Furthermore, the two organizations have already started to build a cooperative relationship in the field of railway technical standards.

Since fostering a closer technical cooperation with NSTDA contributes to overseas development of Japanese railway technologies and further development of railway systems in both countries, RTRI concluded the memorandum with NSTDA.

Considering the current Covid-19 pandemic, Dr. Ikuo Watanabe, President of RTRI, and Dr. Narong Sirilertworakul, President of NSTDA, signed and exchanged the memorandum by postal mail and shared video messages.

This memorandum is the 10th agreement that RTRI has concluded with overseas institutions regarding technical cooperation.

Major activities under this memorandum are as follows. Further details will be discussed and determined later.

(1) Knowledge, information, skills and experience will be shared, developed and improved.

(2) In the process of preparing joint activities, both parties send researchers to each other and have meetings.

(3) Collaborative research, meetings, lectures, symposiums and research projects will be organized on the topics in which both sides are interested and/or which are beneficial for both sides.

(4) Information will be shared regarding the progress and future plans of activities in specific fields.

(5) Activities to strengthen the cooperative relationships will be encouraged as much as possible.

[Message by Dr. Ikuo Watanabe, President of RTRI]

I am very much pleased to be able to conclude the Memorandum of Understanding on Technical Cooperation with NSTDA. Since 2011, RTRI and NSTDA have been cooperating and sharing technical information and expertise through organizing "professional training course for railway engineering trainers" in Bangkok, participating in the Thailand Railway Industry Symposium and Expo (RISE) hosted by NSTDA, and accepting visitors to RTRI from NSTDA. Since Thailand is the most important country in the Southeast Asia and NSTDA leads railway research and development in Thailand, it is very much significant for both RTRI and NSTDA to conclude this memorandum of understanding on technical cooperation. In addition to the cooperation and exchanges we have continued so far, we would like to further cooperate with NSTDA in international railway standards development that ISO and IEC are addressing in order to include Asian railway technologies in the international standards.

I am very sorry that I am not able to talk directly with Dr. Narong Sirilertworakul at an in-person ceremony. Now vaccination has been accelerating both in Thailand and Japan, and I am looking forward to further promoting our cooperation and exchanges after Covid-19. I hope that Thailand railways will further develop and Japan and Thailand, RTRI and NSTDA will be having even closer relationships.

[Message by Dr. Narong Sirilertworakul, President of NSTDA]

On behalf of National Science and Technology Development Agency (NSTDA), Ministry of Higher Education, Science, Research and Innovation (MHESI), Thailand, I would like to thank all of you, viewing this video message. Although we could not be able to celebrate our MOU signing ceremony in-person under this difficult circumstances, we would like to do our best, in this manner, to carry on the establishment of our formal relationship and collaborative activities with our partner, Railway Technical Research Institute.

Our close relationship has started in 2011. NSTDA received great support from RTRI when we first organized "professional training course for railway engineering trainers" in Thailand. Since 2016, NSTDA and RTRI have continuously co-hosted the Thai Rail Industry Symposium and Exhibition (RISE) in Thailand. The RISE event is an academia-research-industry platform for sharing knowledge, know-how and experiences among Thai and international experts, researchers, engineers, and technicians. This kind of event is so important for Thailand to realize our goal to be a logistics hub in ASEAN.

Today, RTRI and NSTDA have come to conclude a 3-year MOU on Technical Cooperation in the field of railway technology. We are very much hoping that, through the exchange of information and know-how and this research collaboration, the two institutes will join hands to work and contribute to the advancement of railway systems and further strengthen the bilateral partnership between Thailand and Japan.

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Fig. 3 Model train of the older equipment

5. RTRI's Rolling Stock Test Plant constructed in 1959 designated as Mechanical Engineering Heritage

On August 7 this year, the Rolling Stock Test Plant (Fig.1) at RTRI was designated by the Japan Society of Mechanical Engineers(JSME) as Mechanical Engineering Heritage No. 108 because of its historical value as an existing mechanical and engineering asset.

[Overview of the facility]

・The facility was constructed in 1959 by the predecessor of the current Railway Technical Research Institute (RTRI), which was a research wing of the former Japanese National Railways. Its purpose was to modernize railway traction systems and increase running speeds. Testing was started in 1960.

・High-speed running can be reproduced as a bench test with an actual vehicle. The rail-shaped rollers rotate at high speeds and are capable of simulating train running. The rollers can also add vertical vibration.

(Reference)

Gauge of roller: adjustable between 1000 mm to 1676 mm

Speed: Up to 250 km/h with a vehicle, 350 km/h with a bogie

・It can be used for tests to confirm vehicle performance, including stability at high speeds.

・Test results were used to determine specifications for the test vehicle bogie prior to the opening of Tokaido Shinkansen. The Series 951 test vehicle for Sanyo Shinkansen was also tested at this facility (Fig.2) and this facility made a significant contribution to the development of Shinkansen.

・In 1990, RTRI constructed another high-speed vehicle test facility capable of testing at a maximum speed of 500 km/h in order to increase competitiveness of railways over other transport modes. Since then, vehicle running tests have been conducted at the new facility. The historical facility still serves for tests of inverters and other components.

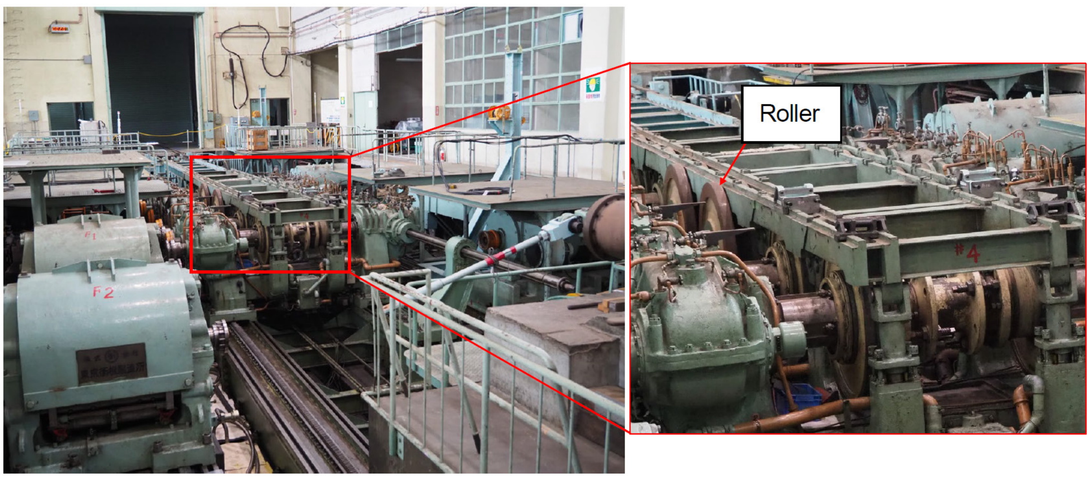


Fig. 1 Rolling Stock Test Plant

Fig.2 Sanyo Shinkansen test vehicle tested on this facility

[Note]

In 2007, JSME started to designate objects which are existing in Japan and have historical significance in the development of machine technology and engineering as Mechanical Engineering Heritage. This designation helps to preserve historical items and pass them on to the next generation as cultural heritage. JSME has designated 104 items prior to 2020.

JSME website
https://www.jsme.or.jp/kikaiisan/#section1

6. RTRI Develops Facility Gauge Measuring Equipment

RTRI developed a device to detect trackside facilities protruding into the track clearance (Fig. 1). This device is capable of checking continuously whether any trackside objects interrupt safe train running or not without manual measurement nor using a specialized measuring vehicle.

[Features of the device]

・By mounting this device to an existing track inspection car, the required track clearance can be checked in the regular track inspection without conducting additional inspections using a specialized vehicle.

・Using a laser sensor, this device enables continuous measurement of the clearance between train vehicles and trackside facilities and checking whether required clearance is maintained on the track both in the daylight and night time. The laser sensor measures the distance between vehicles and trackside facilities including signalling equipment and level crossings facilities by laser beam reflection time. Since the device can conduct measurement in 80 km/h running, quick detection is possible.

・Its data management unit (Fig. 2) automatically cross-checks the measured data with the facilities management registry and outputs the results confirming whether track clearance is blocked or not. It is capable of confirming the distance from selected trackside facilities as well.

・With this device, it is possible to confirm the sufficient clearance of 75% of the trackside facilities which have been checked manually by maintenance staff so far.

[Background]

In order to ensure safe train operation, building limits have been set for railway trackside facilities to keep sufficient clearance around a train. Railway operators build and maintain structures and facilities so that they do not block the required clearance.

The distance from a specific structure or facility has been measured manually by maintenance staff or by a specialized measuring vehicle so far. However, manual measurement requires a lot of time and labor, and for vehicle measurement, a specialized vehicle needs to be introduced.

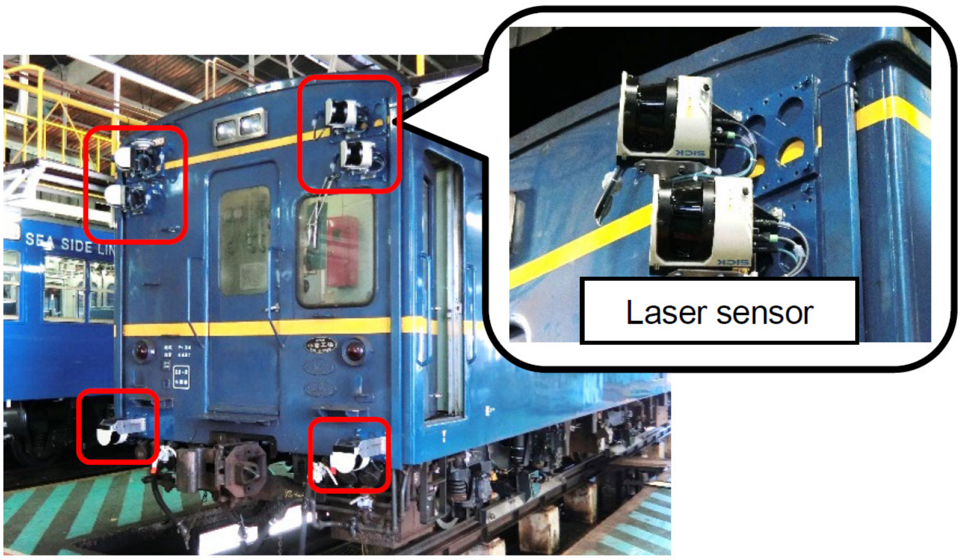
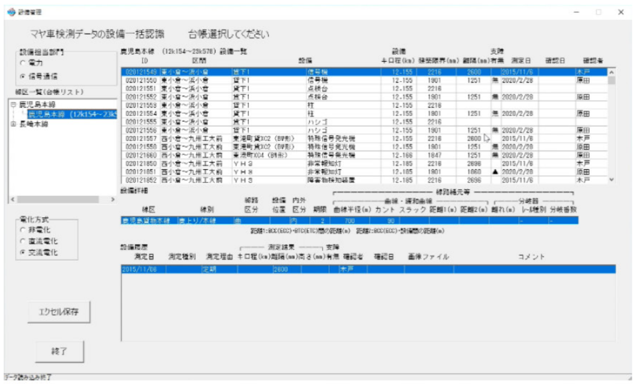
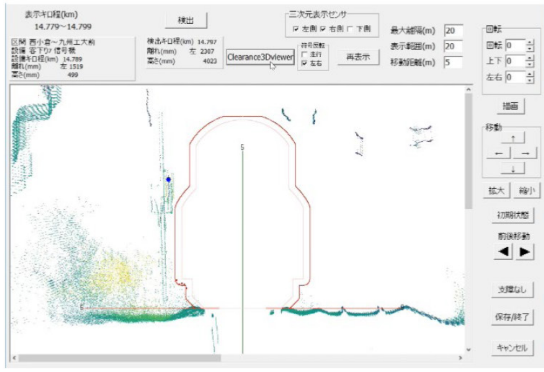


Fig. 1 Facility Gauge Measuring Equipment



(a) List of facilities



(b) Measured result of a facility

Fig.2 Screen display of the data management unit

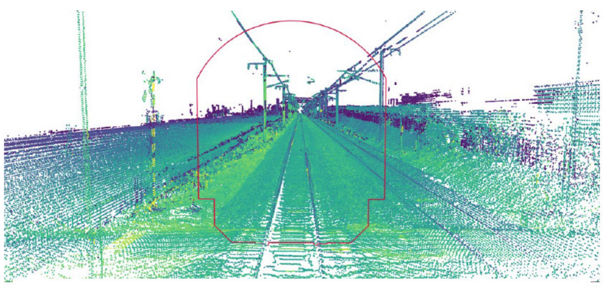
[Introduction to commercial operation]

Since trackside facilities are screened with this device in advance in order to identify those which do not need further measurement, 75% of the facilities do not require on-site manual measurement by maintenance staff.

In April, 2021, Kyushu Railway Company introduced this device to manage about 180 thousand items of ground facilities of conventional lines including signals, signs, tool boxes and power poles.

As the measurement data is 3-dimensional (Fig. 3) and cross-sectional shapes of tracks can be measured, RTRI is considering the possibility of using this system to measure distance between track centers.

(a) Image by ordinary camera



(b) Visualized image of 3-dimensioal data measured by the device
(Red line shows building limit)

Fig. 3 Example of data measured with this device

7. RTRI Develops Snow Accretion Simulator

RTRI developed the first snow accretion simulator in Japan. This simulator is capable of precisely reproducing the process of snow accretion onto train bogies by computing and the phenomenon can be analyzed under conditions close to actual train running including snowfall and wind intensity. This new device will be used to develop vehicles preventing snow accretion more effectively.

1. Background

While a train is running in snowy areas in winter, the snow on the track is blown off, is accreted onto the vehicle underfloor and bogies, and eventually grows into large chunks (Fig.1). Since it takes a lot of cost and manual work to remove the accreted snow, it has been required to develop vehicle shapes less likely to induce snow accretion. However, as the research on vehicle shapes has been implemented using actual vehicles so far, too much efforts have been required and the testing has been possible only in winter and snowy times. In the meantime, impacts by train running such as wheel rotation and winds cannot be accurately reflected on the testing in the snowfall wind tunnel using a model train. The snow accretion simulator has been developed in order to solve these issues and to reproduce the accretion process more precisely.

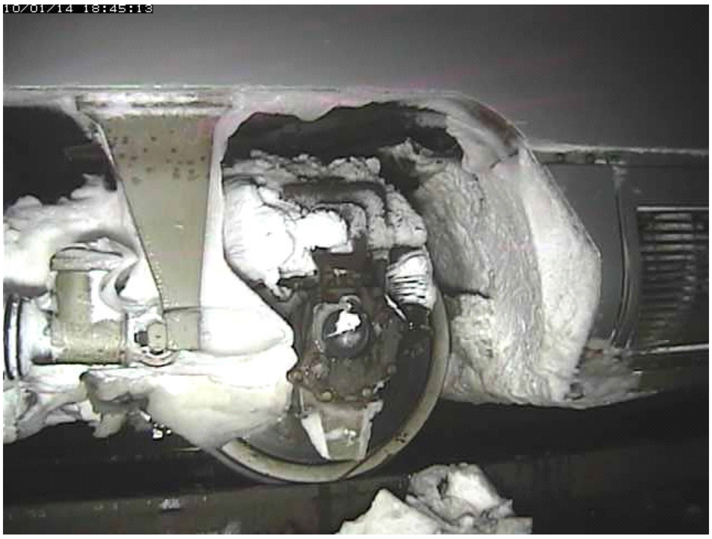


Fig. 1 Snow accretion found on an actual vehicle

2. Overview of the simulator

Using a super computer, this simulator has made possible high-speed calculation under different conditions (Fig. 2).

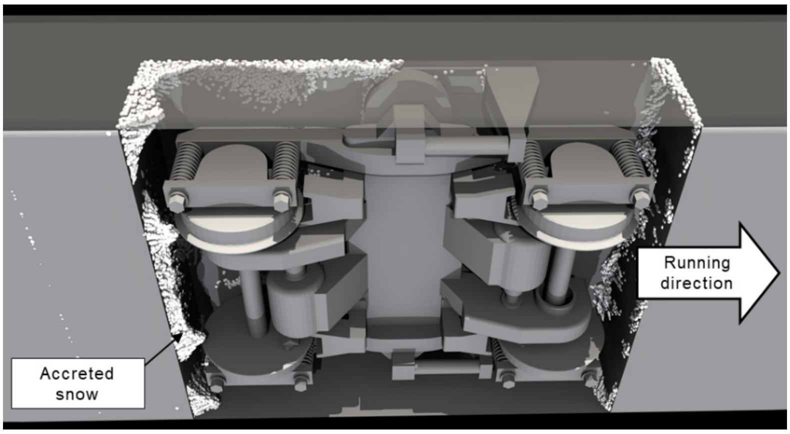


Fig. 2 Simulated snow accretion on a bogie

[Features of the simulator]

・Capable of calculating snow accretion under the impacts of train running such as wheel rotation and winds against a vehicle.

・Capable of simulating snow accretion onto objects with complicated shapes like train bogies.

・Capable of visualizing the accretion process including air flow, flying snow particles and snow accreted state and can be used to analyze the causes of snow accretion and to develop preventive measures.

・The simulator repeats three categories of calculations: calculations to analyze airflow around the object, to trace movements of flying snow particles and to assess the growth of snow accretion. With these calculations, it is capable of reflecting on the simulation the airflow around the object which changes depending upon surface shapes of the growing snow accretion and of reproducing the process more accurately (Fig.3) .

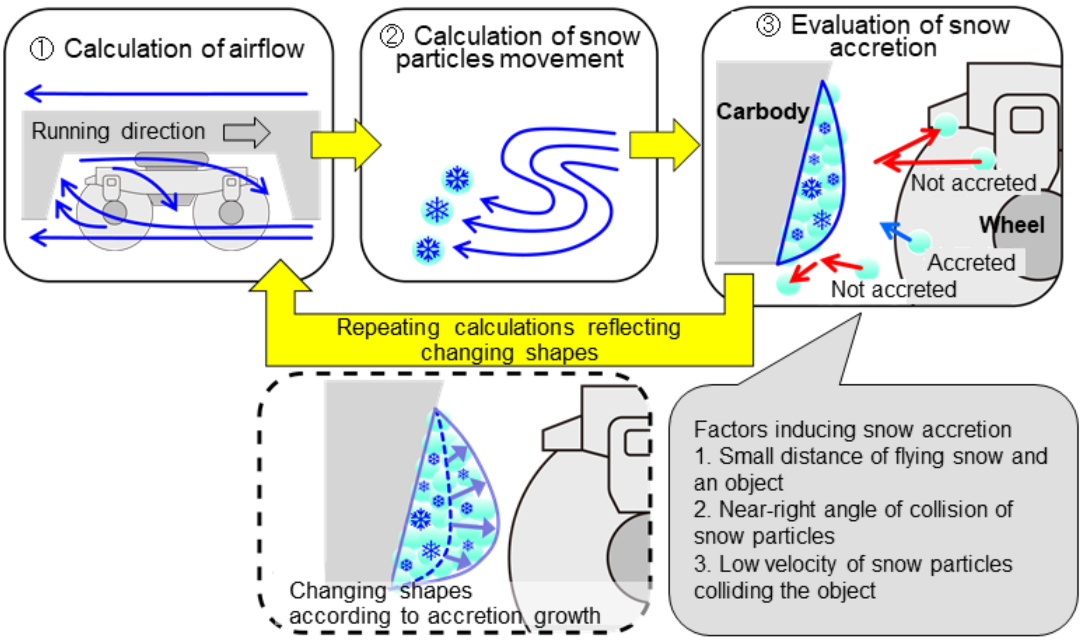
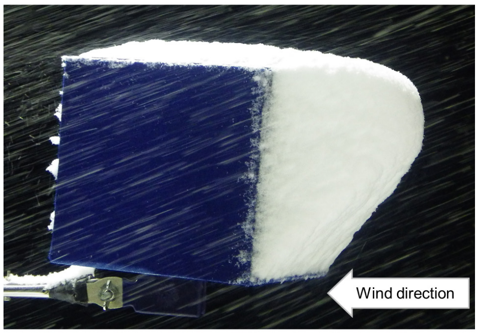


Fig. 3 Calculation system of the simulator

(a) Result of simulation



(b) Result of wind tunnel testing

Fig. 4 Snow accretion on a cubic object

・By comparing the results of this simulation and of the tests in the snowfall wind tunnel using a cubic test object, it has been confirmed that this simulator reproduces snow accretion with 6% error margin in terms of the area ratio from a lateral view (Fig. 4). In addition, the calculation results of the maximum thickness and weight of accreted snow on the complicated-shape bogie are almost consistent with those of wind tunnel tests (Fig. 5).

(The simulation is conducted without rotating the wheels in order to compare the results under the same conditions)

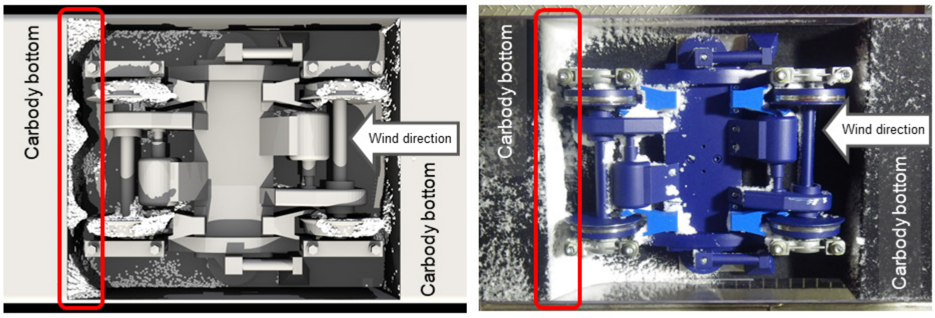


Fig. 5 Snow accretion on a train bogie

3. Research plan using the simulator

RTRI plans to use this simulator to improve vehicle shapes in order to reduce the snow accretion around bogies. Since the simulated snow accretion process can be incorporated in developing shapes of bogie areas, the efficiency of vehicle development can be raised.

8. RTRI Develops a Dynamic Gauge and Twist Measurement Device TRACK²er

RTRI Developed a dynamic gauge and twist measurement device TRACK²er. This device is capable of measuring track displacement caused by passing trains. Since this device can be mounted on a maintenance vehicle instead of using a track inspection car, it is possible to measure track displacement more easily, with lower cost.

[Background]

If track geometry is distorted, running safety and ride comfort of trains will be affected. Railway operators measure track irregularity (consisting of 5 items: longitudinal level irregularity; alignment; gauge; cross level; twist) and use the data in repair work and in maintaining adequate track conditions. Track irregularity includes “static irregularity” which occurs without train load and “dynamic irregularity” caused by the load of passing trains. Railway operators monitor and manage either of the irregularities. It is more effective, in terms of derailment prevention, to manage dynamic gauge and twist.

Dynamic track irregularity is mainly measured by a specialized track inspection car equipped with measuring devices. However, this method requires a specialized vehicle and a lot of careful preparation work to measure a number of tracks including service tracks.

[Features of TRACK²er]

・Since TRACK²er is a small-sized device (940×220×270 mm) and can be mounted on maintenance vehicles and commercial trains (Fig. 1), it is capable of measuring dynamic gauge and twist during maintenance work and commercial operation and makes the planning of measurement easier.

・Rail positions are measured by a 2-dimensional laser sensor. The tilt of the sensor toward the track is adjusted by an angle sensor (Fig. 2). The measurement error margin is 0.5 mm for gauge and 1.0 mm for twist, which means the same level accuracy as that of the measurement by a track inspection car.

・The measurement data is shown in tabular format. (Fig. 3 right) The points exceeding the preset standard value for replacement, repair and other maintenance necessities are shown in red color and oversights can be prevented.

・Rail profiles are shown as figures. (Fig. 3 left) The figure indicates measurement points on the rail used to calculate track displacement. In case an outlier is detected, it is possible to distinguish whether it is due to a measurement error or to track irregularities.

・The cost of TRACK²er is about one tenth of the previous on-board device developed by RTRI and this device can be mounted on or dismounted from a vehicle in an hour.

・By adding an optional remote controlling function, measuring with this device can be started and stopped from personal computers at the office.

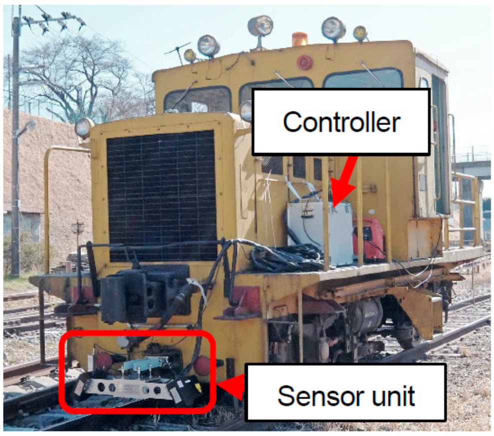


Fig. 1 TRACK²er mounted on a maintenance vehicle

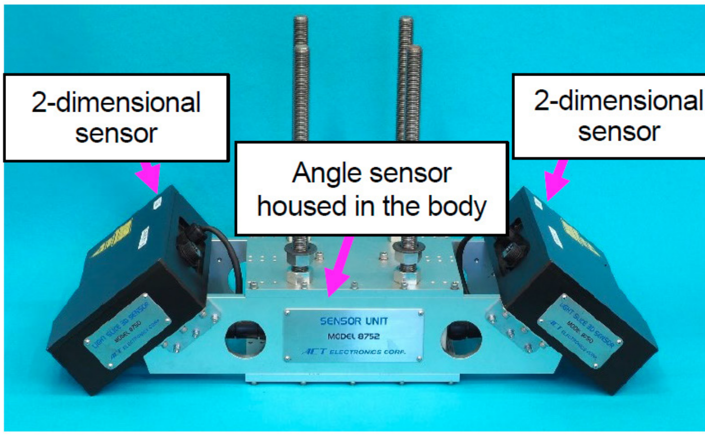


Fig. 2 Sensor unit

Fig. 3 Display of results

[Improving running safety]

TRACK²er enables dynamic measurement of gauge and twist without using conventional track inspection cars and contributes to improving running safety of trains.

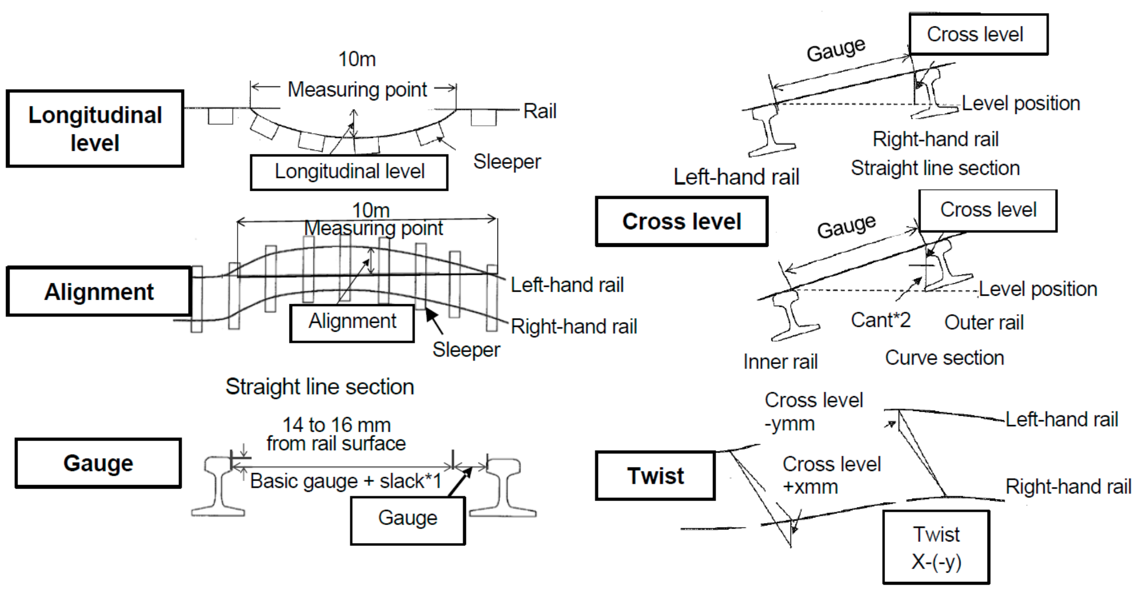
TRACK²er is a registered trademark of the Railway Technical Research Institute (registered trademark number 6442444).

[Reference]

Track irregularity:

Displacement and deformation of each part of railway tracks caused by repeated train passing and natural phenomena. Track irregularity includes following 5 factors.

	Items	Description	Item for TRACK²er measurement
Track irregularity	Longitudinal level	Vertical displacement of rails indicated by distance between top surface of rail and 10-meter line strained on the top surface. The distance is measured at the center of the line.	
	Alignment	Horizontal displacement of rails indicated by distance between inner side of rail and 10-meter line strained on the inner side. The distance is measured at the center of the line. For curves, design values depending on curvature radius are subtracted from the measured distance.	
	Gauge	Values obtained by subtracting rail-distance design value from distance between rail inner sides.	✓
	Cross level	Height difference between both rails. When cant is designated for curves, the cant is subtracted.	Measured to calculate Twist
	Twist	Level difference between both rails measured at two longitudinally distant points. The difference indicates distortion of track plane.	✓



*1 Slack: Gauge allowance designed to enable trains to pass curve sections smoothly

*2 Cant : Height difference between outer and inner rail in curve sections designed to enable trains to pass curve sections smoothly

9. Seismic Reinforcement Method for Deteriorated Steel Bridges Developed and Used on a Commercial Line

RTRI Developed an aseismic reinforcement method for steel bridges integrating steel girder, abutment and embankment (Fig. 1) and it has been applied to a commercial railway bridge. This method is particularly effective in reinforcing deteriorated steel bridges in urban areas where only little work space is available. Since this method does not require construction of a temporary track and only minimal under-bridge space is occupied during the reinforcement work, high seismic performance can be attained with a shorter construction period and smaller cost.

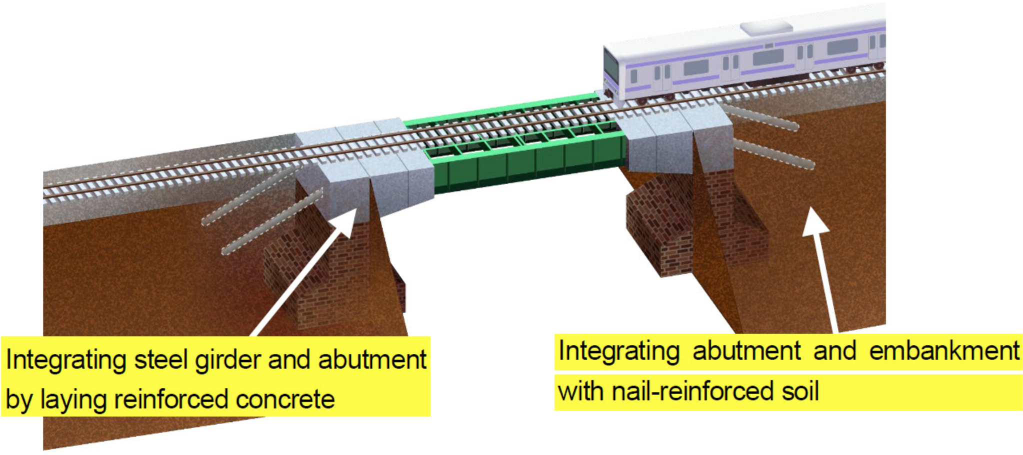


Fig. 1 Bridge reinforcement method integrating steel girder, abutment and embankment

[Background]

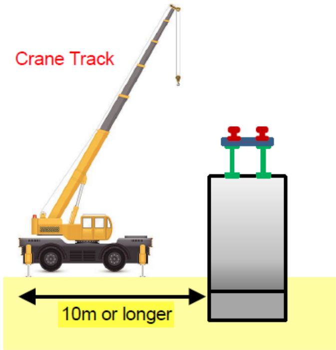
Some of the existing steel bridges constructed before 1970's need to be reinforced to improve their seismic stability, as seismic designs were not well introduced by before those past decades. When replacing a deteriorated bridge with a new one, the space for a crane track and a temporary track is necessary. (Fig. 2 (a)). Reinforcing abutment also requires a heavy construction machine to install ground anchors. (Fig. 2 (b)). Either of them takes a lot of work time and costs. In urban areas, in particular, it is difficult to transport and use large and heavy construction machines or to ensure adequate space for a temporary track. Furthermore, deteriorated steel bridges require a lot of maintenance work including corrosion measures for girders and supports.

[Outline of the method]

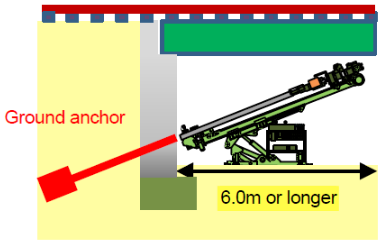
・The entire performance of a steel bridge is improved by integrating abutment and embankment with nail-reinforced soil, by connecting the steel girder and abutment with reinforced concrete.

・The entire stability of a bridge is enhanced by integrating abutment and embankment with nail-reinforced soil, those works can be handled with a small-sized machine. (Fig.2 (c)). In addition, the integrated bridge does not have the bearing connecting steel girder and abutment, the maintenance work for such section including corrosion measures becomes unnecessary.

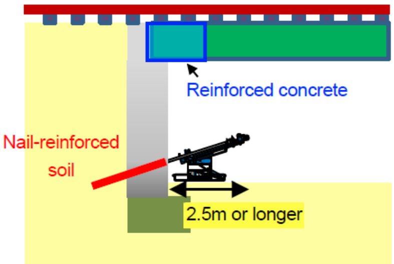
・As this method does not require any work with a large and heavy machine from the front side of abutment (from the under-bridge section), the time and space occupied during the work can be largely decreased and the work time and cost will be reduced up to 50 %.



(a) Existing method of bridge replacement



(b) Ground anchor installment



(c) Ground reinforcing with the new method

Fig. 2 Reinforcement work

[The bridge reinforced with this method]

This method was used for the first time to reinforce a commercial railway bridge on the line of the Odakyu Electric Railway Co., Ltd. As this steel bridge, constructed in 1927, is surrounded by roads and houses, this method was applied. (Fig. 3).

Part of this research was implemented with the railway technical development grants by the Ministry of Land, Infrastructure, Transport and Tourism.

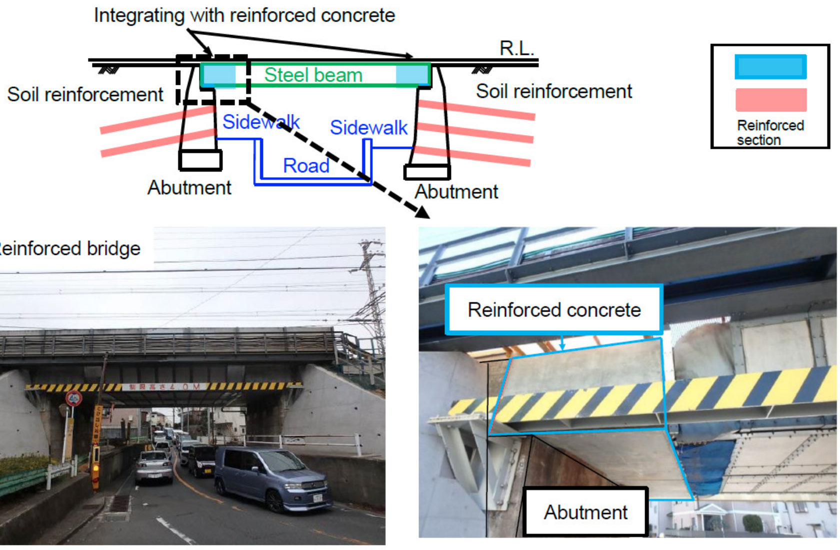


Fig. 3 A bridge on Odakyu Line reinforced with this method

10. New Embankment Repair Method Developed

RTRI Developed an early repair method and aseismic reinforcement method for the embankment damaged by rainfalls and earthquakes. By applying these methods, the performance of embankments will be improved, while work period and repair costs will be reduced.

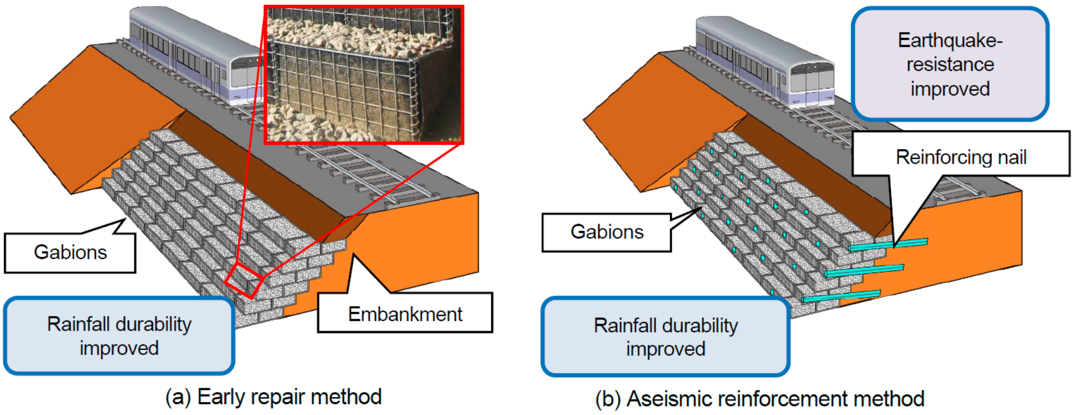


Fig. 1 Early repair and aseismic reinforcement method for damaged embankment

[Outline of the methods]

Previously, the embankment damaged by rainfalls and earthquakes (Supplementary fig. (a)) was temporarily sandbagged and train operation was resumed at slow speeds (supplementary figure (b)), then temporary retaining walls were installed (Supplementary figure (c)), sandbags were later removed and the embankment was reconstructed. (Supplementary figure (d)). This complicated process required long construction periods and high costs. (Table1). Since the repair work with the early repair method uses gabions instead of sandbags, it does not require such complicated work. It will reduce the construction period and cost, and at the same time, durability against rainfalls is improved.

In the aseismic reinforcement method, in addition to the work of the early repair method, the embankment is reinforced with soil reinforcing nails made of steel and soil cement. This method improves earthquake resistance as well as durability against rainfalls.

[Effects and characteristics]

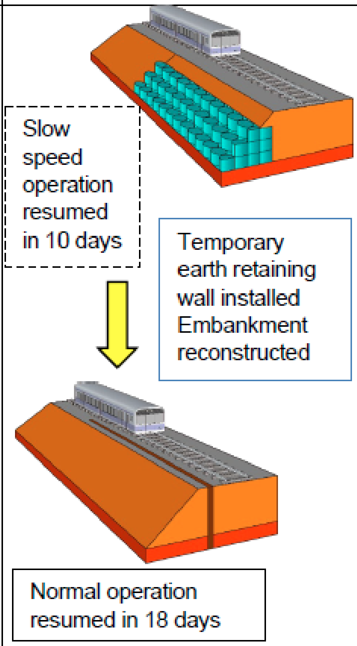
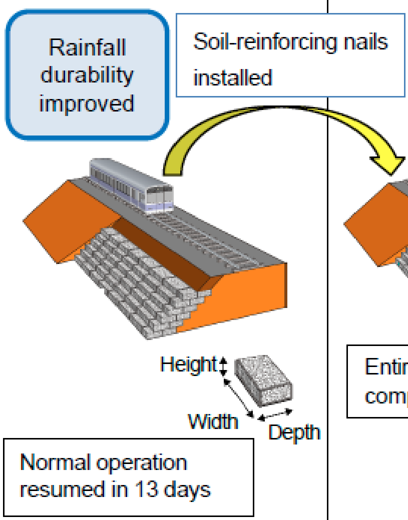
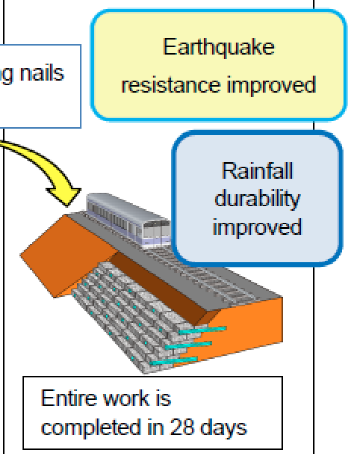
・In the early repair method, gabions are installed to the damaged section. Since the gabions are built with wire mesh sheets on site, the repair work can be done quickly and flexibly and the embankment can be repaired earlier.

・Since the gabions improve stability of embankments, it is confirmed by analysis that durability against rainfalls improves by about 70% compared to the existing repair method.

・With this method, train operation cannot be resumed at the stage of the temporary repair unlike the repair work with the existing method. However, the entire work period and cost are reduced by 30% and 60% respectively. (Table 1)

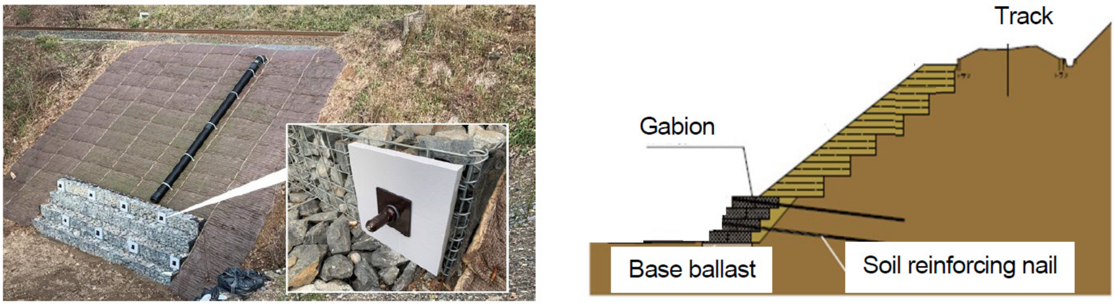
・In the aseismic reinforcement method, reinforcing nails are added to the early repair method. It is confirmed in model experiments that the embankment repaired with this method is capable of enduring 50%-stronger earthquakes compared to the one with the early repair method and the cost can be 30 % lower than the existing method. (Table 1)

Table 1 Comparison with the existing method and newly-developed methods
(5-meter high and 10-meter long embankment)

	Existing method using sandbags	Repair method using gabions	
		Early repair method	Aseismic reinforcement method
Images of the repair work			
Details	250 Large sandbags 50 type-III earth retaining walls	320 Gabions Width: 1.0 m Depth: 1.0 m Height: 0.5 m	320 Gabions Width: 1.0 m Depth: 1.0 m Height: 0.5 m 15 soil-reinforcing nails Diameter: 133 mm Length: 7.0 m
Repair cost ratio	1.0	0.4	0.7

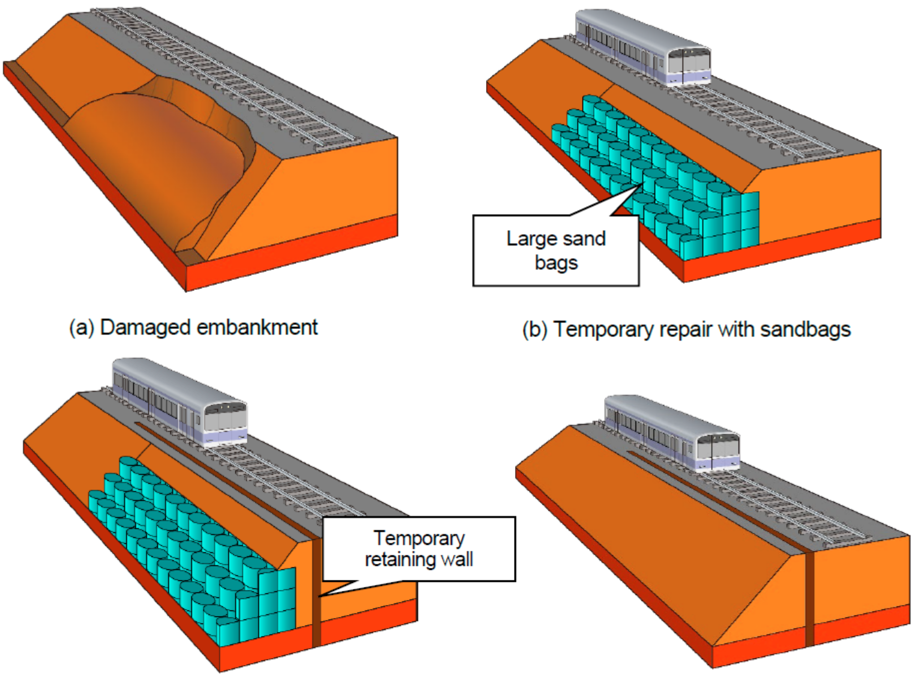
[Embankment reinforced with aseismic reinforcement method]

This method was used to repair the embankment of Sanriku Railways Rias Line damaged by the typhoon which hit the eastern part of Japan in 2019. (Fig. 2)



(a) View of the repaired embankment (b) Cross-section

Fig.2: The embankment repaired with the aseismic reinforcement method



(a) Damaged embankment (b) Temporary repair with sandbags

(c) Temporary retaining wall installed (d) Embankment repaired

Supplementary fig. The existing embankment repair method

Supplementary fig. The existing embankment repair method

11. RTRI's Researcher Given an Award for His Contribution to Railway Technology Standardization

Mr. Kazumasa KUMAZAWA, Assistant Senior Researcher, at RTRI, received the Year 2021 Award for Contribution to Standardization by the Railway Technology Standardization Survey Committee. The award ceremony took place on March 30 at Plaza F in Tokyo.

Award winner:

Mr. Kazumasa KUMAZAWA, Assistant Senior Researcher, Signalling Systems, Signalling and Operation Systems Technology Division

Award-winning contribution

Joining a domestic working group to deliberate international standards on railway timetabling since 2016, Mr. Kumazawa has contributed to working out the Japanese policy for international standardization. In particular, he has been a core person in preparing technical details of the international standard draft, ISO WD 24675 (Running time calculation for timetabling - Requirements). He has also served as an international expert of ISO/TC 269/SC 3/WG 3 (Railway timetabling), appointed by the Japanese Industrial Standards Committee, and is expected to further contribute to these activities. For all these contributions and accomplishments, the award was given to him.

* Award for Contribution to Standardization is given to persons who contribute to international and domestic standardization activities in the railway field. This award giving is started in 2007 by the Railway Technology Standardization Survey Committee (Chairperson: Hiroyuki Osaki, Prof. of the University of Tokyo Secretariat: Ministry of Land, Infrastructure, Transport and Tourism and RTRI) for the purpose of supporting the activities of award winners and raising the awareness of the importance of standardization among related people. The Encouragement Award has been given to those who are expected to keep contributing to these activities.

Mr. Kumazawa at the award ceremony

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