ANNUAL REPORT 2022-2023

For the year ended March 31, 2023

Railway Technical Research Institute

Foreword

Ikuo WATANABE
President of the Railway Technical Research Institute

I am pleased to announce that the RTRI Annual Report 2022 is now available. This annual report, first published in 2009 (the report on fiscal year 2008), outlines and introduces the organization and activities of the Railway Technical Research Institute (RTRI), its master plan, research and development efforts, and other activities while referring to visualized data on various fields. We have totally redesigned the layout for this fiscal 2022 issue to make it suitable for the integrated information source of RTRI and to provide high-quality information and faster and easier search experiences. It would be our great pleasure if you could take this opportunity to see our progress in fiscal 2022 and deepen your understanding of RTRI.

As many social and business activities were still restricted throughout the entire society due to the influence of COVID-19, tough times continued in fiscal 2022 for railway businesses. Meanwhile, it was also the year when we saw positive signs of recovery in transport demand, such as the inauguration of the West Kyushu Shinkansen and the resumed acceptance of inbound tourists.

Fiscal 2022 is the halfway point of our master plan, RESEARCH 2025, and the third year of our efforts to accumulate the fruits of our research and development. RTRI revised its organizational structure on April 1, 2022. This revision was intended to achieve research and development successes faster and more efficiently and to make our business operations more efficient. By taking advantage of the features of the new research divisions and new research structures and by increasing our research resources, we focused on improving safety, especially in enhancing resilience to natural disasters. We also concentrated on research and development for digital technology-based innovation in railway systems, one of the urgent issues for all railway operators. Moreover, we set up new research and development projects in a new field, decarbonization of railway transport, and focused on promoting the projects. As a result, a total of 273 research and development projects were implemented, and 114 of them were completed. For the heavy rainfall in August 2022, the researchers at RTRI set up a cross-disciplinary team, quickly conducted damage surveys, and provided technical support.

The Japanese railway, celebrating its 150th anniversary since its opening in 1872 between Shimbashi and Yokohama, has been contributing to society as the foundation of the state and a driving force of economic development. RTRI also has been dedicated to playing its part in society for 115 years while changing its name. 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, 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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    - Maglev Systems Technology Division
    - Center for Railway Earthquake Engineering Research

(As of June, 2022)

Major Results of Research and Development

IMPROVEMENT OF SAFETY

1. Rapid seismic damage estimation tool for large bridges

- We developed a preliminary estimation tool for evaluating seismic damage to large bridges within a few minutes of an earthquake event.
- The tool can be used to quickly determine if it is safe to resume operations along railway routes with large bridges.

After an earthquake, it is important to be able to assess the extent of damage to all railway structures in order to determine whether it is safe to resume operations. The Railway Technical Research Institute has previously developed a nomogram for rapid assessment of seismic damage to standard bridges and viaducts following an earthquake. However the nomogram is not able to accommodate the more complex behaviors of structures such as large bridges.

The Institute has now developed a preliminary estimation tool specifically for large bridges. The new tool (Figure 1) breaks down the complex behavior of large bridges into multiple motions (modes of vibration) and estimates the extent of motion (response value) for each mode of vibration. The previous nomogram, meanwhile, can be used to estimate response values for each mode of vibration, allowing us to quickly determine the overall extent of damage.

A comprehensive analysis of seismic damage to the 790-meter cable-stayed bridge shown in Figure 2 would take several hours, whereas the new tool can provide a comprehensive safety assessment in just a few minutes (see Figure 3). The tool can also be used to reliably estimate damage to individual structural members, such as bearings and supports, expressed as response values. In this way, the tool can be used to quickly determine if it is safe to resume operations along railway routes with large bridges.

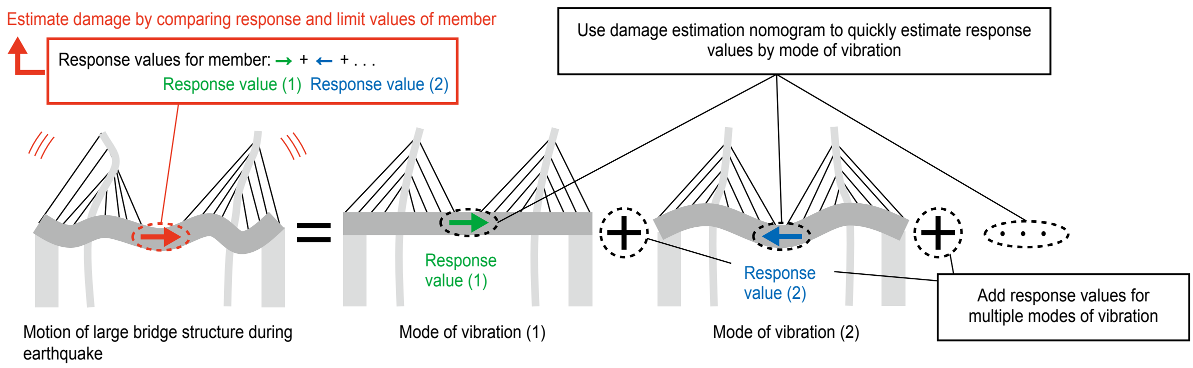


Figure 1 Seismic damage estimation tool for large bridges

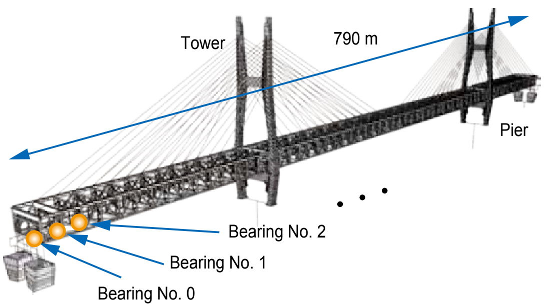


Figure 2 Cable-stayed bridge

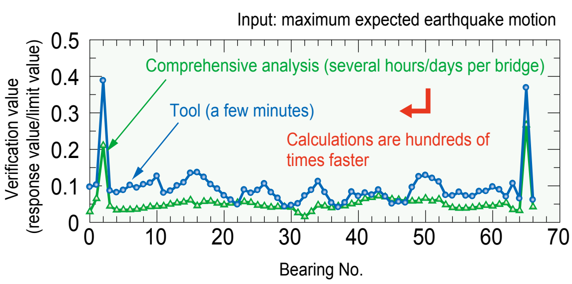


Figure 3 Seismic damage estimation

2. Seismic diagnostic for existing pile foundations affected by nearby excavation work

- We investigated the mechanism via which excavation work reduces the horizontal resistance of existing pile foundations nearby.
- We developed a seismic diagnostic for existing pile foundations that takes into account changes in ground resistance characteristics according to the separation distance between existing piles and excavated soil retaining walls as well as the resistance width of retaining walls.
- We demonstrated an approximately 20% reduction in overall construction costs by eliminating the need for large-scale works.

There are many railway projects currently underway in urban areas including building new lines, undergrounding existing lines, and removing level crossings by relocating the road under the railway line. Most of these projects involve construction of new underground structures in close proximity to existing railway structures, where retaining walls are put in place prior to deep excavation. As such, there is a need for a diagnostic tool for existing pile foundations that takes into account the impact of nearby excavation works (Figure 1). In particular, although it is known that excavation work impacts the horizontal resistance of existing pile foundations, to date we have not had a good understanding of the underlying mechanism, nor have we had a suitable diagnostic tool.

We used a combination of numerical analysis and large-scale model testing to investigate the mechanism through which excavation can affect the horizontal resistance of existing pile foundations in the vicinity. We also developed a structural analysis model for use in seismic diagnosis (Figure 2). This allows us to perform seismic diagnosis of existing pile foundations that takes into account the distance between the piles and the excavation retaining walls as well as the resistance width of the retaining walls. As a result, we can now determine the dimensions of retaining walls needed in order to provide the necessary seismic performance when excavating near to existing pile foundations. This approach is estimated to reduce overall construction costs by around 20%, since there is no need for large-scale works such as soil improvement.

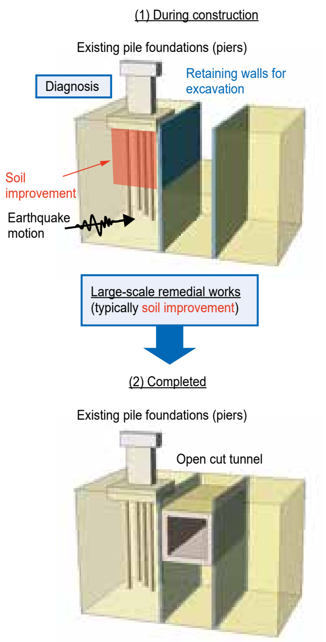


Figure 1 Excavation near to existing pile foundation

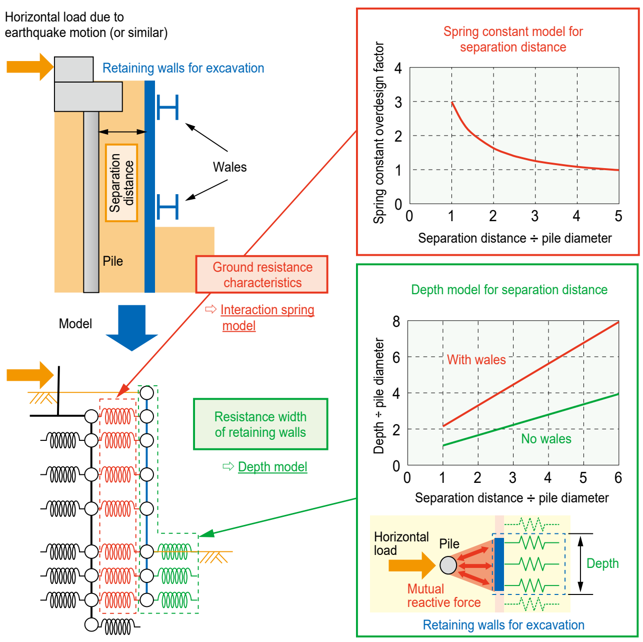


Figure 2 Seismic diagnostic tool

3. Earthquake countermeasure for poles on viaduct using stays and overhead wires

- We developed an earthquake countermeasure method involving a combination of stays and overhead wires that effectively reduces longitudinal vibration of poles on viaduct (in train direction) during an earthquake.
- This earthquake countermeasure method, when used together with portal structures, is faster and cheaper than conventional reinforcement or other solutions such as pole replacement.

Portal structures, with a beam connecting two poles on either side of the railway track, are often used for seismic reinforcement of poles on viaduct. Although portal structures have been shown to effectively reduce transverse vibration (perpendicular to track direction), the additional mass of the beam can extend the natural period in the track direction and lead to resonance with the viaduct itself. In the worst-case scenario, the portal structure may collapse. In combination with the stays, we have established that rigid connectors, which are attached to poles to prevent lightning damage to overhead wires, help to reduce the natural period of the poles, in turn suppressing resonance with the viaduct (see Figure 1).

We used full-scale tests to demonstrate the validity of our analysis model (see Figure 2). We also showed that the stays effectively reduce the natural period of the poles in the track direction, and that the rigid connectors allow for longer intervals between stays without affecting performance (see Figure 3). The shorter natural period of the poles effectively reduces pole vibration associated with L2 earthquake motion (see Figure 4).

In combination with portal structures that mitigate transverse vibration (perpendicular to train direction), this approach proves to be both faster and cheaper than conventional reinforcement or other solutions such as pole replacement.

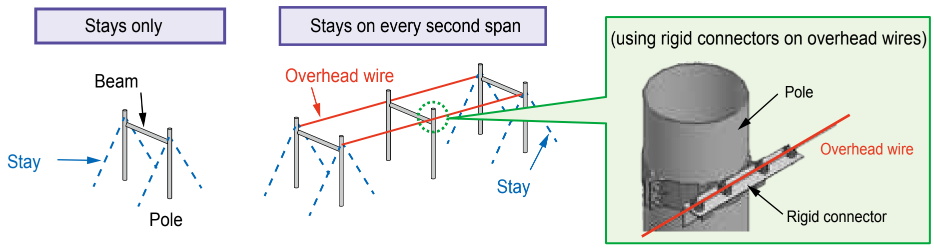


Figure 1 Earthquake countermeasure using stays and overhead wires

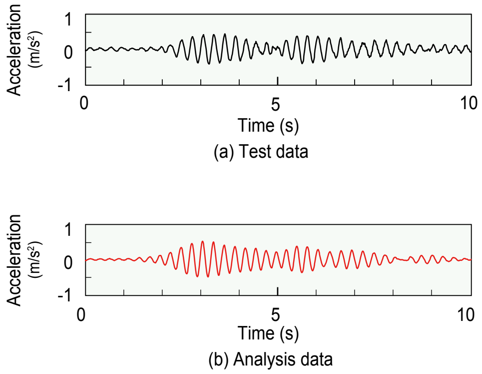


Figure 2 Verifying analysis accuracy (pole response waveform caused by earthquake motion)

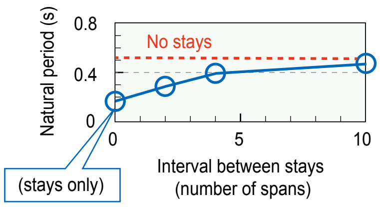


Figure 3 Reducing the natural period of poles

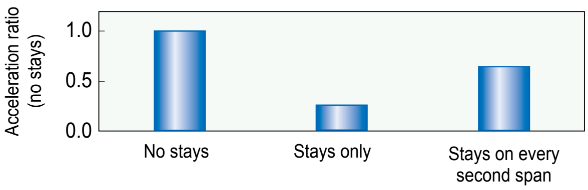


Figure 4 Pole vibration during L2 earthquake motion

4. Rainfall-damaged embankment safety assessment tool

- We developed a tool to assess rainfall-damaged embankments to determine whether it is safe to resume operations, and to help choose the best emergency repair structure.
- The tool simplifies the decision-making process around whether to conduct emergency repairs on a damaged embankment and the extent of emergency repairs required. This encourages the use of less complex repair structures, thereby facilitating the speedy resumption of train services.

In recent years, heavy rainfall events have been causing severe damage to railway embankments. The initial emergency response to resuming operations following embankment damage along rail lines typically involves the use of large sandbags and train operation at reduced speeds. In the absence of proper structural standards or criteria, this means that major repairs are often needlessly deployed on relatively minor instances of embankment damage.

We conducted a number of rainfall and load tests to evaluate the impact of resuming train operations on damaged embankments and embankments fortified with large sandbags. We used the findings to create a flowchart (see Figure 1) tool for deciding whether it is safe to resume operations when an embankment has been damaged by rainfall, and determining the most appropriate repair structure. The tool uses a nomogram (see Figure 2) to assess the damage to the embankment (the scale and angle of rupture) and determine whether train operations can be safely resumed without the need for emergency repairs. Where repairs are deemed necessary, the tool includes a handy selection table (see Figure 3) for choosing the required repair structure. Both the nomogram and the selection table are based on stability calculations predicated on the minimum required safety standard for damaged and repaired embankments, indicated by the blue arrows in Figure 1. Where circumstances allow for preliminary testing and/or site surveys of embankment strength and groundwater conditions, this information is incorporated into the nomogram and selection table. In some cases it may be determined that there is no need for emergency repair work on an embankment that has been declared unstable, or that a simpler approach can be used (see red arrows in Figure 1).

This tool can be used to quickly determine whether a rainfall-damaged embankment requires emergency repairs and, if so, the most appropriate structure. The tool facilitates speedy resumption of operations and also helps to reduce the number of sandbags deployed in emergency repairs.

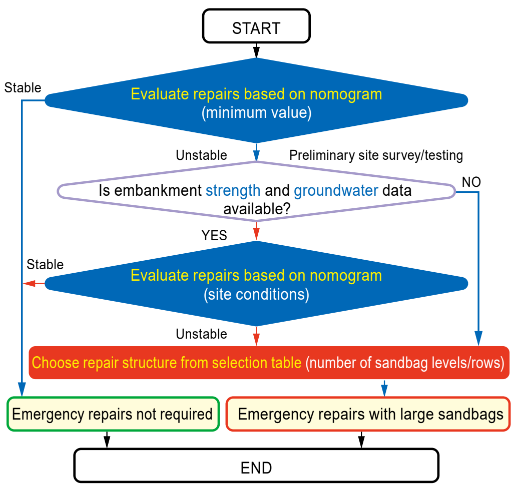


Figure 1 Embankment safety assessment tool

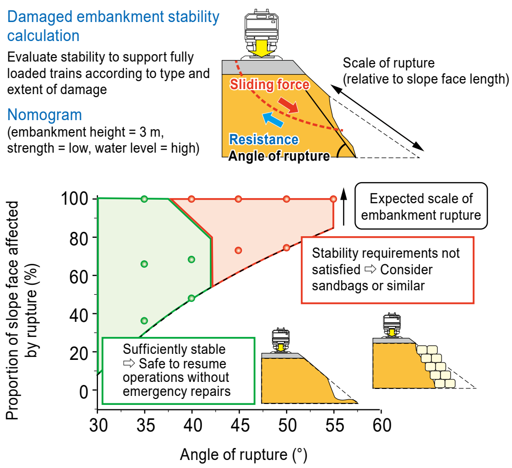


Figure 2 Nomogram for safe resumption of operations

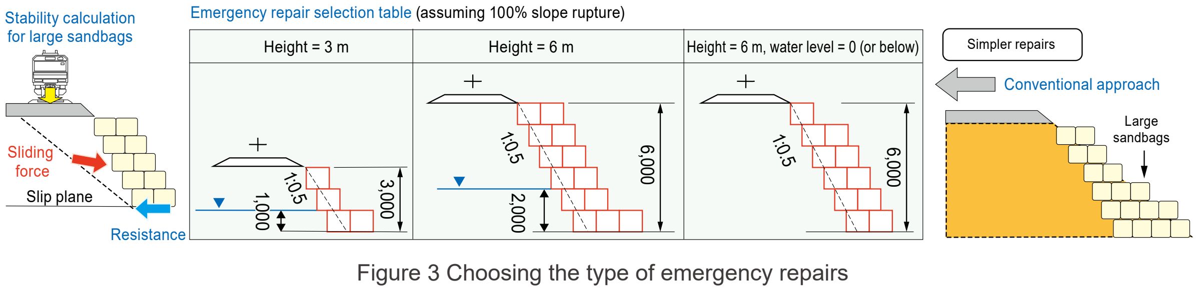


Figure 3 Choosing the type of emergency repairs

5. Creation of time-varying dynamic wind maps

- We have developed a method for creating dynamic wind speed maps that vary in time according to the update interval of the wind speed observed by an anemometer.
- This method can map wind speeds equivalent to instantaneous wind speeds with an error of approximately 5 m/s or less.
- This wind map can be used to monitor strong winds and determine operation controls for railway sections where anemometers have not yet been installed.

In light of the increasing intensity of typhoons in recent years, with stronger winds observaed over wider areas, there is a need to augment wind data observed by discretely installed anemometers. In order to realize low-cost, wide-area, and detailed monitoring of strong winds, we have developed a method to create dynamic wind speed maps that change with time by combining “point” wind speeds observed from time to time by anemometers and “surface” wind speed distributions obtained by CFD (Computational Fluid Dynamics).

First, CFD is performed for each of the 16 wind directions over an approximately 30 km x 30 km analysis domain (upper left of Figure 1) that includes the location of one or more anemometers. Next, using the results of CFD, the rate of increase or decrease of wind speed (hereafter, the rate of increase or decrease of wind speed is denoted as the wind speed maltipliers.) at each analysis grid point within the domain (bottom left of Figure 1) is calculated based on the wind speed at the analysis grid point where the anemometer is located. The wind speed multipliers take into account the average wind intensity at each analysis grid point relative to the entire domain, as well as the effect of local wind speed increases at each analysis grid point. By multiplying the wind speed observed by an anemometer (upper right of Figure 1) by the wind speed multipliers, the wind speed distribution over the surface (wind speed map, lower right of Figure 1) is obtained. When the wind speed observed by the anemometer is updated, the wind speed map is also automatically updated. In addition to anemometers owned by railway companies, the Japan Meteorological Agency’s AMeDAS can be used as anemometers to obtain wind speed data.

Verification with 14 cases of strong winds obtained with anemometers at six locations (Figure 2 upper) confirmed that the 10-minute maximum instantaneous wind speed can be evaluated with an error of approximately 5 m/s (Figure 2 lower).

This wind map can be used to monitor strong winds and determine operation controls for railway sections where anemometers have not yet been installed.

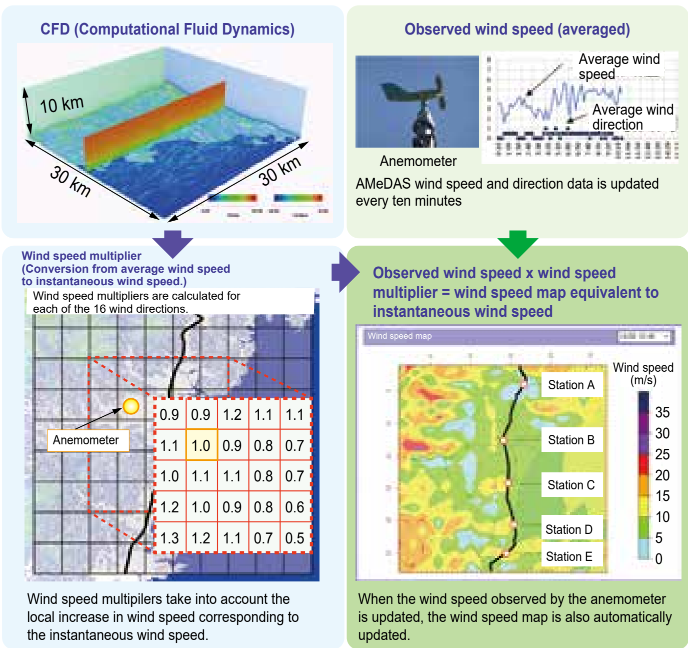


Figure 1 Procedure for creating a wind speed map

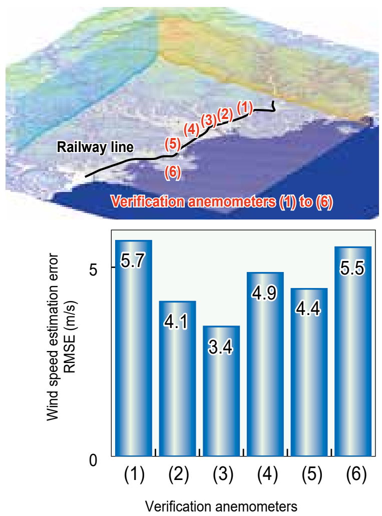


Figure 2 Margin of error in wind speed map for 14 strong wind events

6. Braking performance improvement under snow conditions by controlling wheel temperature using snowproof brake systems

- It is clarified that higher wheel temperatures increase the coefficient of friction of tread brake blocks in snow conditions.
- Management of wheel temperatures by setting appropriately the air pressure of snowproof brakes can lead to the improved braking performance with no adverse impact on the wheels.

Snow can affect the performance stability of tread brakes, sometimes causing trains to stop out of position at stations. We conducted bench tests to investigate the causes and mechanisms of the reduction in the friction coefficient of the brake blocks. We found that for certain brake block materials, under a mild pushing force higher wheel tread temperatures lead to an increase in the coefficient of friction in the presence of cold water (see Figure 1). This was found to be related to the pressure of the water entering the interface between the brake block and the wheel tread.

Snowproof brake systems that keep the brake blocks very lightly applied to the wheels during normal motion for the prevention of ingress of snow into the contact interface are implemented, but their potential influence on wheel temperature has not been considered. If snowproof brakes make the wheels warmer, then we can expect to see improved braking performance due to the higher coefficient of friction of the brake blocks. However this is true only up to a certain point—wheel temperatures in excess of 150°C can cause problems such as hollow wear on the wheel tread.

We designed a model for estimating wheel temperatures during snowproof braking operation with greater accuracy using the finite element method (FEM). The validity of this methodology was confirmed by our observations (see Figure 2). Using FEM, we showed that by adjusting the air pressure of the snowproof brake we can keep wheel temperatures at a level that increases the coefficient of friction on the brake blocks and improves braking performance in snow conditions without any adverse impact on the wheels.

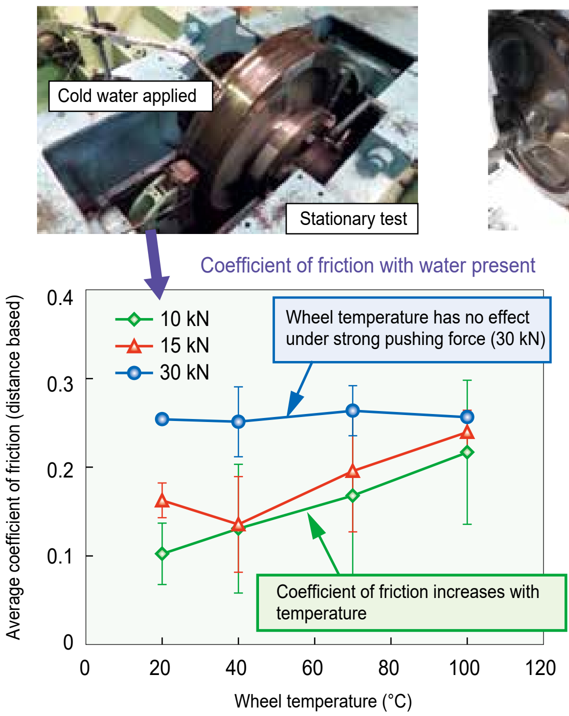


Figure 1 Wheel temperature and coefficient of friction

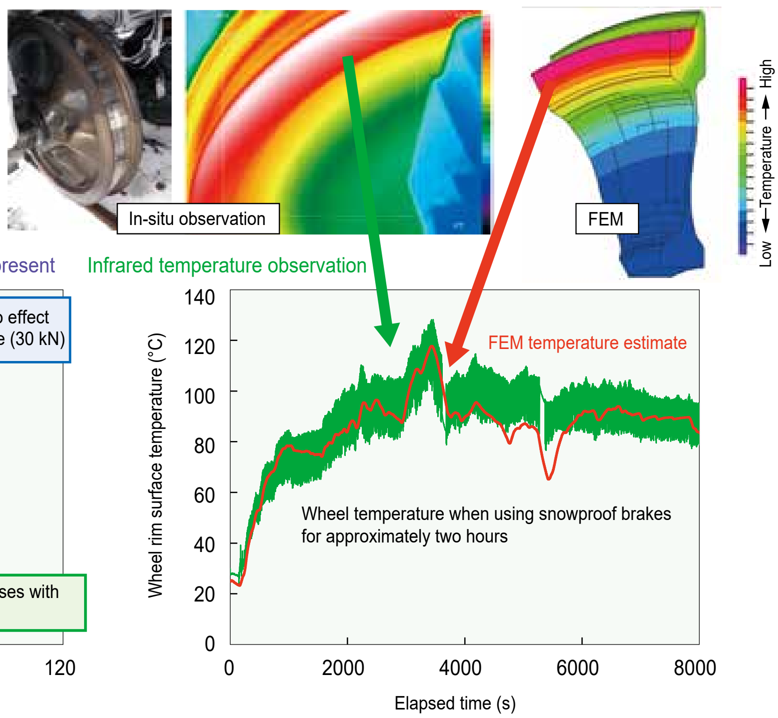


Figure 2 Observed vs estimated temperature on wheel rims

7. Platform safety support device using side-mounted cameras

- A system for checking platform safety using cameras mounted on the side of the rolling stock.
- Designed to detect passengers close to the train and alert the train operators accordingly. Can also recognize wheelchairs, baby strollers and white canes.
- Utilizes a high-speed AI model with 20 msec response time using only CPUs, specifically trained for the railway environment.

On one-person operated (OPO) trains, it is the responsibility of the train operator to ensure platform safety during departure. In recent years, these trains have been equipped with cameras on the sides of the vehicles, enabling operators to check the platform from the driver's seat. We have developed a platform safety support device that utilizes these side-mounted cameras to provide assistance for the train operators.

For training an AI model, we employed dedicated datasets tailored to the railway station environment, enabling it to recognize both the full body and head of approaching passengers, along with identifying objects such as wheelchairs, baby strollers, and white canes(see Figure 1). Our device comprises a high-speed AI model developed in-house and paired with a CPU. The AI implementation prioritizes processing speed while maintaining performance, resulting in effective real-time operation with a 20-millisecond response time, as illustrated in Figure 2. Notably, our device offers a cost-effective solution, as it omits expensive components such as GPUs and their associated image processing semiconductors. Furthermore, its design, lacking a dedicated cooling fan, results in a smaller, quieter, and less vibration-prone system (complies with JIS E4031 Rolling Stock Equipment - Vibration and Shock Tests). The device can be retrofitted to use the video feed from existing side-mounted cameras providing timely alerts to train operators regarding approaching passengers (see Figure 3).

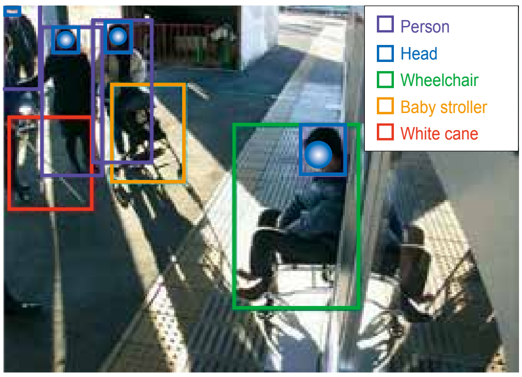


Figure 1 Recognizing human form and key objects

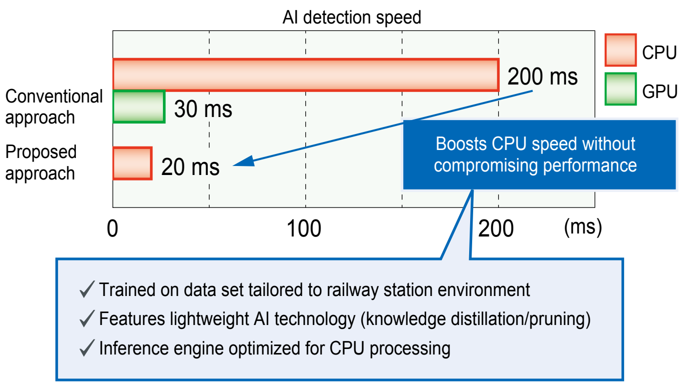


Figure 2 AI model optimization

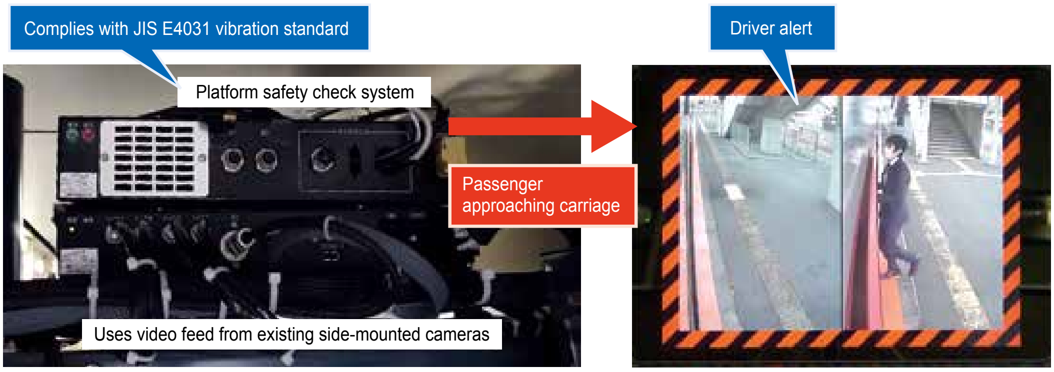


Figure 3 Platform safety check device using side-mounted cameras

8. Silicon buffers on passenger cars provide longitudinal ride comfort and improved safety in train breakdown operations

- We developed a silicon buffer for passenger cars designed to replace existing rubber buffers.
- Internal running tests showed that the silicon buffer reduces longitudinal vibration by up to 6.5 dB.
- A numerical simulation of a breakdown operation involving two 8-car trains found that the silicon buffer reduces the maximum coupler force on couplings at all points, and also helps to prevent car body floating.

Most rubber buffers currently in use on passenger cars are designed with no initial pressure, in order to maximize ride comfort. However, some initial pressure is needed during train breakdown operations so that the buffers can absorb more energy, which reduces the risk of trainset buckling. Buffers are thus required to perform two conflicting functions: maximizing ride comfort while minimizing the trainset buckling risk. We developed a silicon buffer unit for passenger cars (see Figure 1) that features an internal attenuating element designed to generate a measured level of attenuating force in response to longitudinal movement between cars.

We installed the new silicon buffer on a two-car train at the Railway Technical Research Institute and performed a running test with the brakes disconnected on one of the cars (car T). The test shows immediate attenuation in longitudinal vibration (see Figure 2). The silicon buffer was also found to improve the ride quality level, reducing longitudinal vibration by up to 6.5 dB compared to conventional rubber buffers. In a numerical simulation of a breakdown operation involving two 8-car trains, the longitudinal force (coupler force) acting on couplers was found to be lower at all points when rapid deceleration equivalent to emergency braking was applied at a speed of 10 km/h. There was no indication of car body floating (with associated risk of derailment) at any point. This indicates that train breakdown operations can be performed safely without needing to expel air from the air springs (see Figure 3). Thus we showed that replacing existing rubber buffers with the new silicon buffers will improve ride comfort in the longitudinal direction while also mitigating the risk of trainset buckling during breakdown operations.

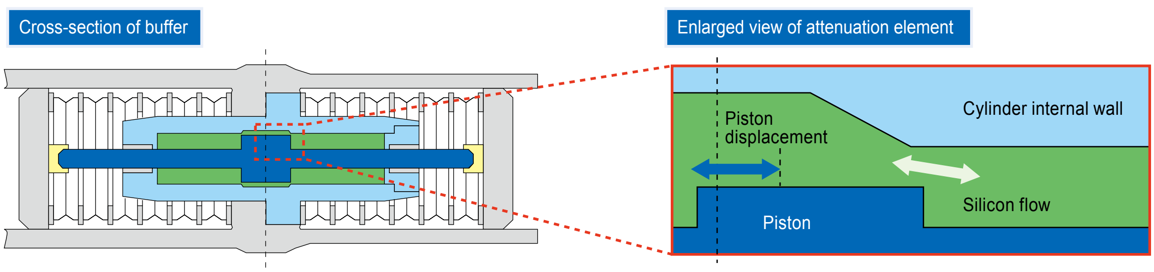


Figure 1 Schematic of silicon buffer

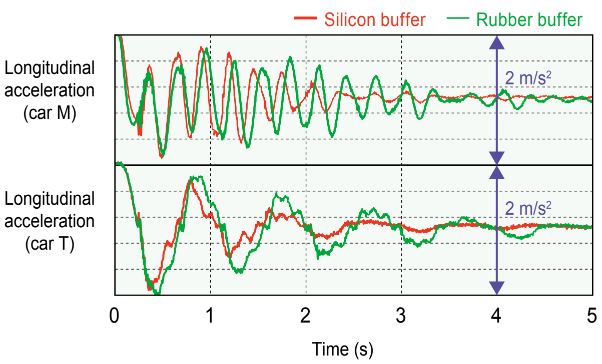


Figure 2 Acceleration damping in longitudinal direction (brakes on car M, no brakes on car T)

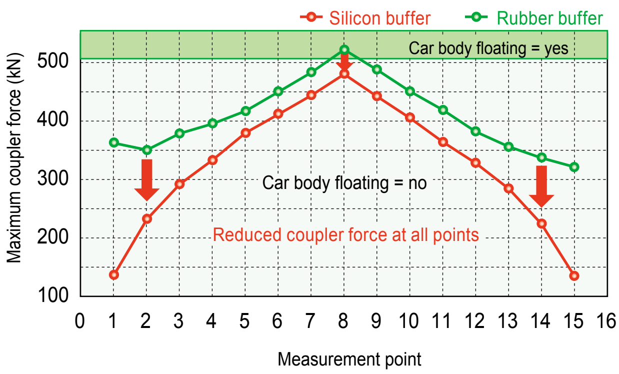


Figure 3 Using numerical simulation to reduce maximum coupler force (for breakdown operation involving two 8-car trains)

9. Integrated analytics platform for railways

- We have developed an integrated analytics platform that aggregates maintenance data from multiple systems and allows data sharing and analysis between systems.
- By aggregating observation data from different systems and supporting conversion of differing formats for location information, the platform supports integrated analytical projects involving multiple systems.

Maintenance data such as rolling stock, tracks and power systems is currently held in individual systems. As railways are systems where these are interrelated, cross-sectional analysis using data from other systems is expected to efficiently identify the root causes of harmful alterations and design appropriate remedial strategies. The problem has been, however, that different systems use differing data formats and measuring systems (particularly in terms of data precision and intervals between observations), not to mention different types of equipment and even different formats for expressing location information.

Our integrated analytics platform for railways aggregates and unifies maintenance data from differing systems to enable cross-sectional analytical studies across multiple systems. The platform uses a standardized kilometrage format that distinguishes between up/down lines and main lines/passing tracks, and also recognizes discontinuities associated with track works, in order to enable seamless conversion of differing location information formats used by different systems. We have also developed an analytical technique that uses multiple indicators to investigate relationships between different data sets. This technique can quickly and efficiently trawl through huge volumes of data aggregated from multiple systems to identify the location of any potential changes in equipment status.

In order to verify the functionality of the platform, we built a prototype system of the platform for use on the test track at the Institute (see Figure 1). Using the prototype system, we demonstrated how maintenance data from multiple systems is automatically forwarded to the mirror server on the platform and converted into a common format for aggregation. As an example, we set a simple scenario with one train and one substation, and demonstrated that data on current supplied by the substation and current collected in the train (in differing formats) could be successfully collated and used to detect an earth fault of approximately 100 A within just a few minutes.

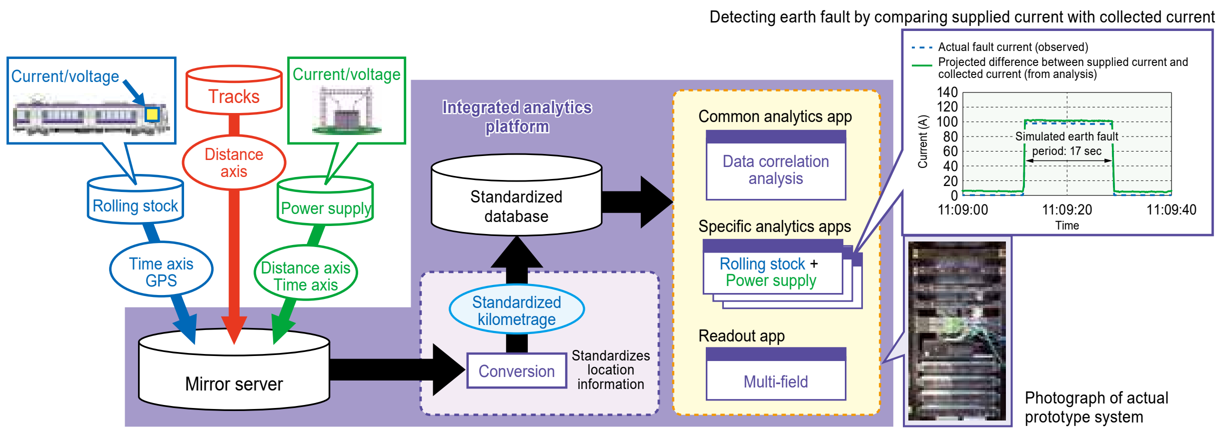


Figure 1 Prototype system of integrated analytics platform

10. On-board obstacle detection system suitable for low-light conditions

- An obstacle detection system that can be installed in the driver's cab. The system utilizes a combination of camera and LiDAR technology to identify objects on the railway tracks, even in low-light conditions.
- Achieved a detection success rate of over 90% for identifying the human form at distances of up to 400 meters under low-light nighttime conditions.
- The system and sensors can be configured to suit specific performance requirements.

Normally when a driver sees an obstacle on the railway tracks, they slow the train or stop altogether. Automatic detection of objects in front of the train will reduce the driver workload and boost operational safety. Our obstacle detection system can be used to assist drivers in spotting obstacles on the railway tracks both during the day and at night.

We have previously developed AI-based systems for the identification of the human form and other objects in video images. However, these systems achieved a success rate of 95% or higher only at distances of up to 300 meters in daylight and performed less effectively at night. In contrast, our newly developed system also utilizes AI for object identification in video images, but the incorporation of LiDAR data (laser reflections from objects) enables it to maintain performance in low-light conditions, including nighttime scenarios.

Figure 1 illustrates the functioning of our system for nighttime obstacle detection on railway tracks. It is evident that the LiDAR laser accurately identifies a person under conditions where a camera may fail. To assess the system's nighttime detection performance, we conducted tests using up to nine LiDAR units at different distances (see Figure 2).

Our findings indicate that when nine LiDAR units are connected, the system can identify individuals located 400 meters ahead with an accuracy exceeding 90%. Furthermore, increasing the number of LiDAR units enhances resolution, characterized by the number of laser points per unit area at the detection distance. With 14 units installed, the system can reliably detect individuals at distances of up to 500 meters during nighttime conditions, achieving close to 100% accuracy.

While our findings shown in Figure 2 are for distances of up to 500 meters, if newer LiDAR units with laser coverage beyond 500 meters were to become available, it will deliver further improvements in detection distances. Given that LiDAR units are compact (around 10 cm3) and relatively inexpensive (under ¥200,000), a system comprising ten or more LiDAR units is considered feasible in terms of size and cost. The obstacle detection system offers design flexibility, so that railway operators can choose the sensor configuration to suit their particular performance requirements.

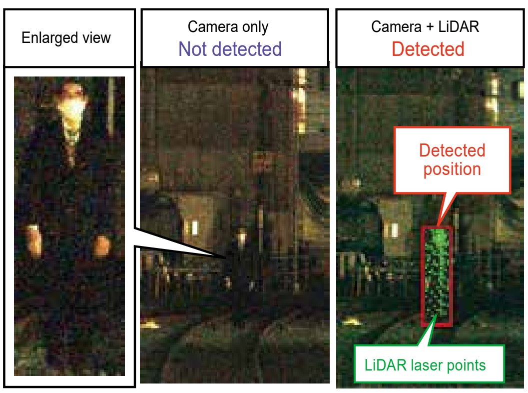


Figure 1 Detection performance: person on tracks

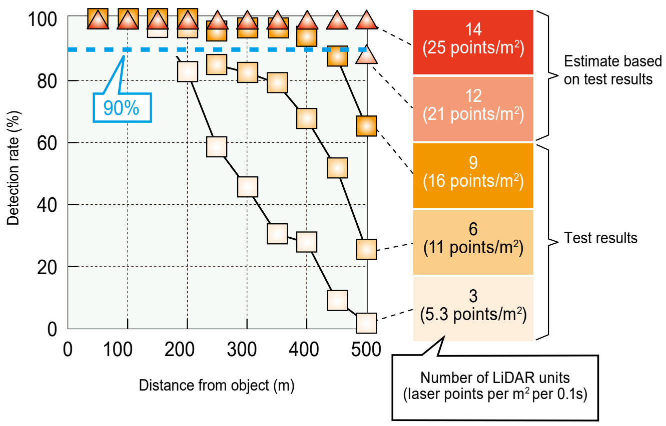


Figure 2 Number of LiDAR units vs detection rate

11. Tool for estimating bridge deflection from on-board track irregularity measurements

- We developed a tool that estimates the amount of bridge deflection by calculating the difference between track irregularities measured at the front and rear cars of the train set.
- At speeds of up to approximately 100 km/h, the tool is able to calculate bridge deflection with an error of no more than around 10% relative to on-site measurements.

Bridge deflection associated with passing trains is a key indicator used in bridge maintenance work. Traditionally, bridge deflection is measured using on-site instruments for each span in turn. This costly and time-consuming process has effectively prevented ongoing monitoring of bridges through regular measurements of bridge deflection. Our tool generates an estimate of bridge deflection by calculating the difference between track irregularities measured at the front and rear cars of a moving train set.

In order to estimate bridge deflection using observations taken from a moving train set, we need to determine the correlation between track irregularity and bridge deflection, which varies in accordance with train movement. We also need to isolate the bridge deflection component within track irregularity. To this end, we first established that bridge deflection is theoretically proportional to the difference in observed track irregularity between the front and rear cars of the train set. We used this to extract the bridge deflection component by eliminating static track irregularity from the difference, then multiplied by the conversion coefficient to produce an estimate for bridge deflection (see Figure 1). Our tool requires track measuring devices to be installed on the front and rear cars of the train set. As Figure 2 shows, trials on an in-service railway line indicate that the maximum bridge deflection estimated by the tool is accurate to within approximately 10% of standard on-site observations for train speeds of up to 100 km/h.

This tool can be used to identify bridges subject to significant bridge deflection along each route, and schedule repair work on the basis of ongoing monitoring of bridges.

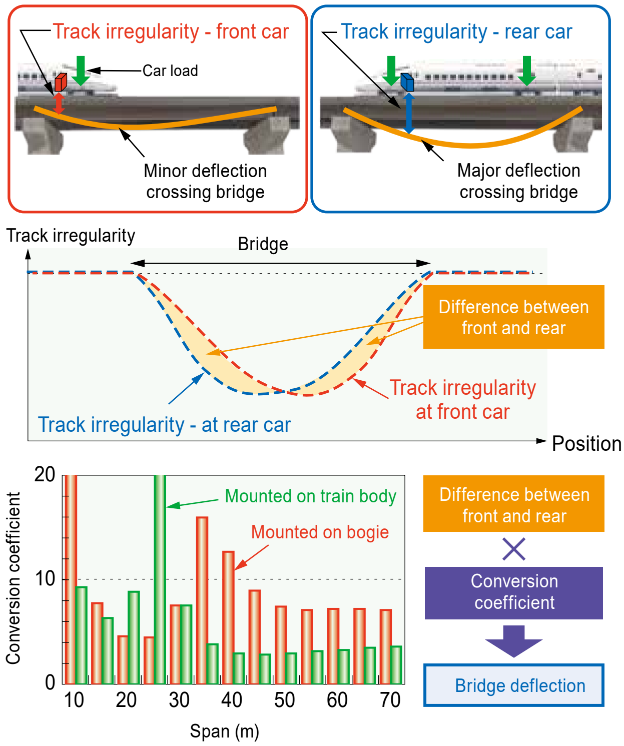


Figure 1 Bridge deflection calculated from difference in track irregularity between front and rear cars

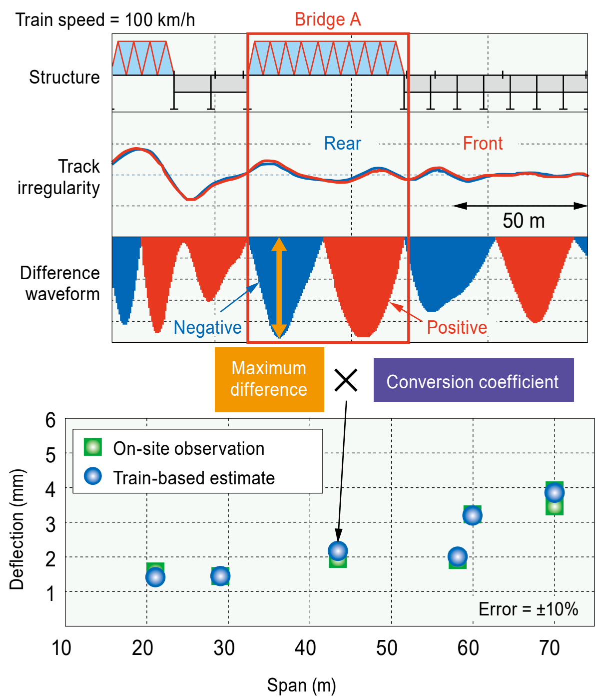


Figure 2 Evaluation of bridge deflection tool (train speed = 100 km/h)

12. Wear measuring apparatus for overhead conductor rail using light sectioning

- We designed a contactless measuring apparatus that uses light-sectioning to measure wear depth on various types of overhead conductor rail with an accuracy of 0.5 mm.
- The system can take measurements at 20-mm intervals from a maintenance car traveling at 30 km/h, thus providing an efficient and reliable source of data for maintenance.

Overhead conductor rail that employs rail-shaped conductors or deformed contact wires in confined spaces such as subways and narrow tunnels is subject to wear, yet the width of the contact surface does not change. For this reason, the standard approach used on overhead contact wires, which involves estimating wear depth based on the width of the contact surface, is unsuitable and manual fixed-point inspection is used instead.

Our apparatus uses contactless light-sectioning, via a slit laser and camera, to provide continuous contour measurements that can be used to evaluate wear depth on overhead conductor rail (see Figure 1). By overlaying the contour generated via light-sectioning onto the original profile of the rigid conductor equipment, the system measures the residual height of the conductor, and by extension the wear depth (see Figure 2). It can be used on conductors of all types and profiles. Stationary tests show that the system is accurate to within 0.5 mm irrespective of the type or profile of overhead conductor rail under measurement (see Figure 3).

The existing process for checking wear depth involves a maintenance worker conducting a preliminary inspection of high-wear sites for evidence of wear, then following up with manual measurement if necessary. Our system, which is installed on a maintenance car or similar and takes continuous measurements at 20-mm intervals at a speed of 30 km/h, is both more reliable and more efficient than the current approach. The system has already been adopted by the Tokyo Metropolitan Government Bureau of Transportation for use in measuring wear on rail-shaped conductors as part of maintenance operations on the Oedo subway line (see Figure 4).

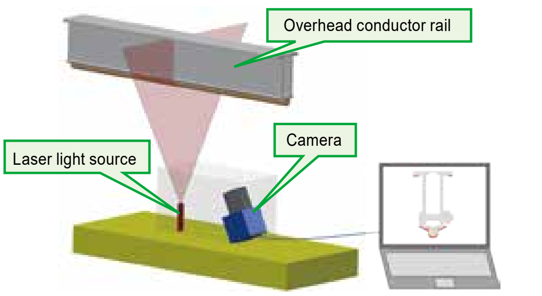


Figure 1 Overhead conductor rail wear depth measuring system

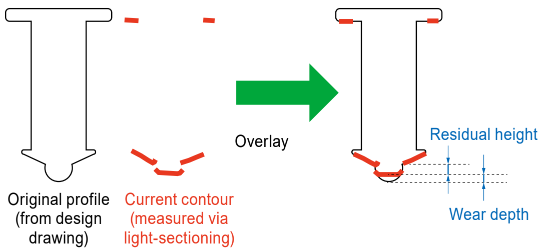


Figure 2 Wear depth algorithm

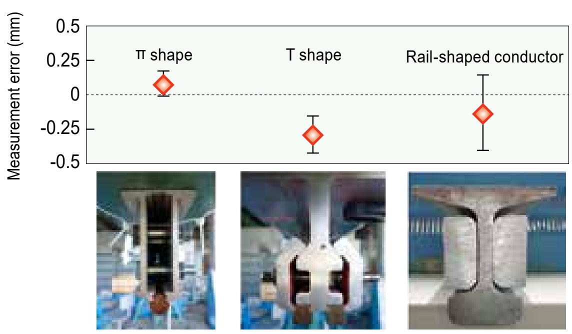


Figure 3 Wear depth measurement error for different overhead conductor rail profiles

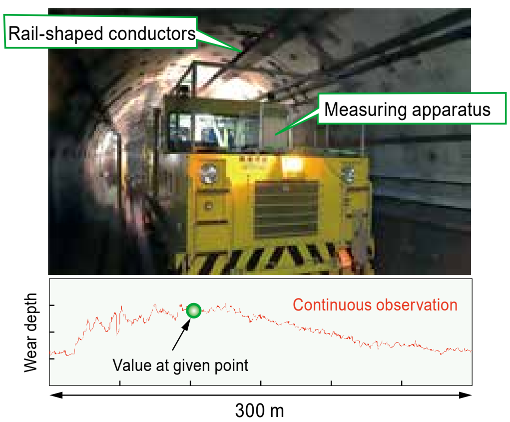


Figure 4 Measuring overhead conductor rail wear depth in situ

13. Imaging analysis method for detecting various anomalies in overhead contact lines

- We developed a method that can detect various anomalies in overhead contact line fittings such as deformation and breaks, and also determine the level of corrosion of messenger wires.
- The tool boosts efficiency by providing preliminary screening for various anomalies.

Overhead contact line fittings are subject to various anomalies including general deformation, localized anomalies such as dropper bar breaks that are traditionally harder to detect, and incorrect bolt configurations. We developed a new machine learning algorithm capable of detecting both localized and combination anomalies via training on digitized data correlations as used in natural language processing (see Figure 1). Using images of overhead contact line fittings captured outdoors during daylight hours, the tool successfully detects anomalies with an accuracy of 90% or better. The tool screens for the four most common anomalies in overhead contact line fittings: deformation, bar breaks, misalignment, and loose or missing bolts.

Shadows within wires such as messenger wires that comprise wire strands have traditionally made it difficult to detect changes in color that indicate corrosion. But now, thanks to machine learning, we can isolate wire strand components within the image, and create color and brightness distributions that can be used as the basis for an overall corrosion score, as shown in Figure 2. As the example in Figure 3 shows, corrosion scores for messenger wires increase and then decrease as the corrosion progresses. Using the corrosion score, it will be possible to track the chronological progression to determine the extent of corrosion in the future.

By combining the tool with images of overhead contact lines captured from the top of an electric inspection car or ordinary commercial car, we can screen the images, detect anomalies sites and assess the extent of corrosion. This is significantly more efficient than the current process of manual inspection for anomalies based on overhead contact line image.

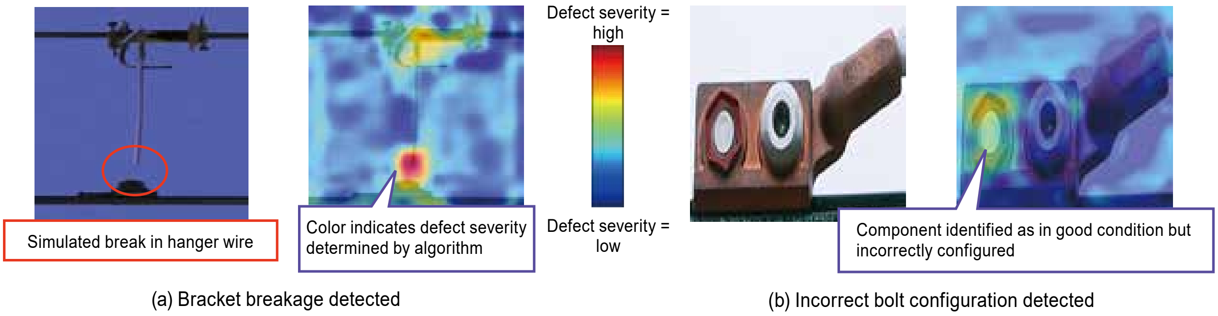


Figure 1 Deformation in overhead contact line bracket

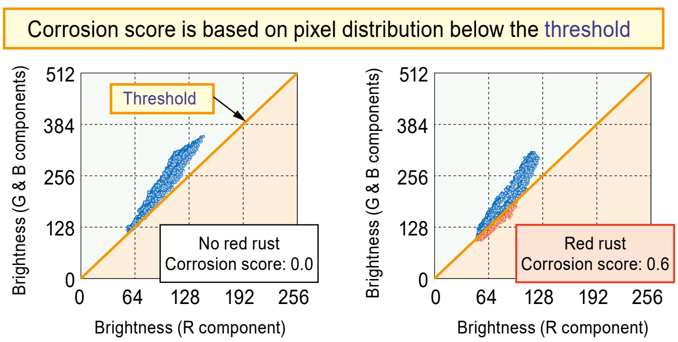


Figure 2 Quantitative analysis of corrosion in messenger wire

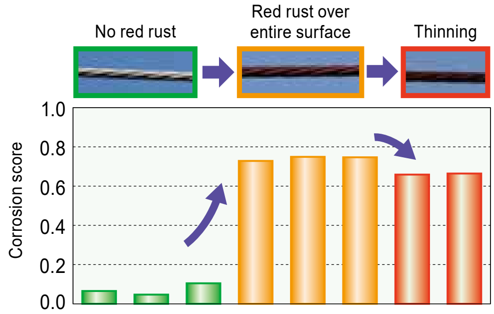


Figure 3 Typical sequence of corrosion scores in messenger wire

14. Automated crew scheduling system

- We developed an automated crew scheduling system for both drivers and conductors.
- The system takes approximately 30 minutes to generate a daily timetable for around 400 trains using the least possible number of crews while satisfying all conditions and requirements.

Every timetable revision requires changes to train schedules as well as scheduling of train crews (drivers and conductors) The aim of crew scheduling is to maintain train operations in accordance with the relevant conditions and requirements while using the minimum possible number of drivers and conductors. At present, it takes an experienced scheduling planner days or even weeks to produce a crew schedule for each section of a line, depending on length. Our system automates this process.

Crew scheduling is a two-stage process. First, we design a duty for each crew member with trains assigned to them for each shift. Then we draw up a roster that orders the various duties and incorporates rest breaks at suitable points. Duties are subject to a variety of restrictions and requirements as per the relevant agreements and regulations, including overall work hours, accumulated driving time, and rest and meal times. Rosters are likewise governed by restrictions on hours spent at home and rest days. To date, mathematical optimization techniques have been of limited use, since the number of combinations increases dramatically as more trains are added, making the computation process so complex and time-consuming as to be unfeasible. We have addressed this by introducing network optimization based on graph theory. By reducing the number of combinations involved, our system is able to generate crew schedules with minimum staffing levels in rapid time. It even takes into account the different restrictions applicable to drivers and conductors (see Figure 1).

Our system, which runs on a standard consumer-level computer, takes no more than about 30 minutes to generate separate crew schedules for driver and conductor sections of a line with around 400 trains per day. This includes duties and rosters that are broadly equivalent to the conventional manually produced versions (see Figure 2). In addition to efficiency and labor-saving benefits for crew scheduling, the system also helps to reduce reliance on the capabilities of individual workers.

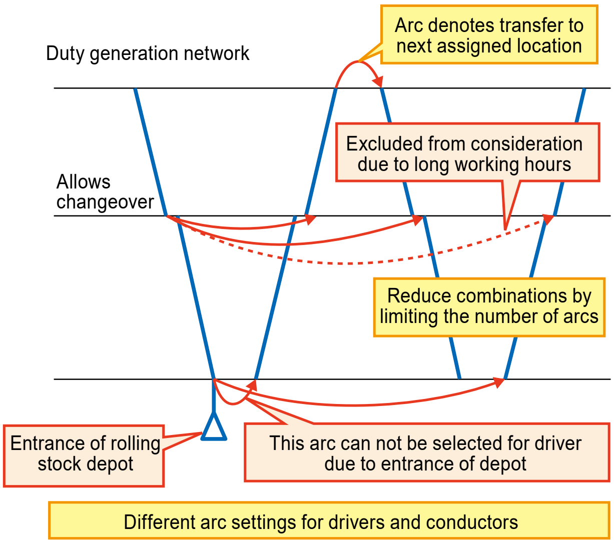


Figure 1 Duty produced with network optimization

Manual vs. automated scheduling

Line	Trains	Method	Crew	Calculation time
A (conductors)	371	Automated	105	7 min. approx.
		Manual	107	-
B (drivers)	431	Automated	117	20 min. approx.
		Manual	120	-

Automated crew schedule for line A

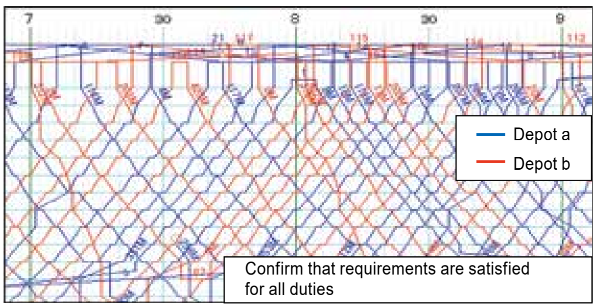


Figure 2 Automatically generated crew schedule

15. Fast-track embankment structure for confined settings

- We have developed a fast-track embankment structure suitable for deployment in confined settings, featuring a combination of fluidized soil that does not require compaction and a protective layer of rubble.
- Sandbag formwork is combined with anchoring materials to make steeply inclined embankments.
- The structure can be erected around 20% faster than conventional embankment works with around 10% less labor input.

Major projects such as track doubling in urban settings frequently involve construction of embankments in confined spaces, using small-scale construction machinery as well as compaction by hand. This is both time-consuming and labor-intensive, and a better solution is needed. Our solution uses fluidized soil, which is made by mixing cement and water into soil from construction works. Fluidized soil has excellent fluidity characteristics suitable for earthwork and does not require compaction, in contrast to conventional embankment construction. To date, fluidized soil has not been used in train embankments due to a lack of data on stability performance when subjected to train loads, and also because it has less strength when dry.

Our proposal adds a protective layer of rubble over the surface to prevent the fluidized soil from drying out (see Figure 1). Taking into account dispersion of train load by the rubble layer, we have demonstrated the performance requirements of the fluidized soil including minimum required strength of 600 kPa. Fluidized soil offers good fluidity during the construction phase and good strength when hardened. Our proposed embankment structure for confined settings uses a combination of sandbag formwork and anchoring materials, as shown in Figure 2. This provides sufficient stability both during construction and once in service, as shown in Figure 3. The construction phase is shorter than for conventional embankments, and the design allows for steeper slope gradients, thereby reducing the space required to accommodate the embankment.

Railway embankments in confined settings are traditionally made with precast retaining walls or similar. We have shown that for an embankment of height 3 m and crown width 7.5 m, our proposed structure can be constructed 20% quicker and using 10% less labor (see Table 1).

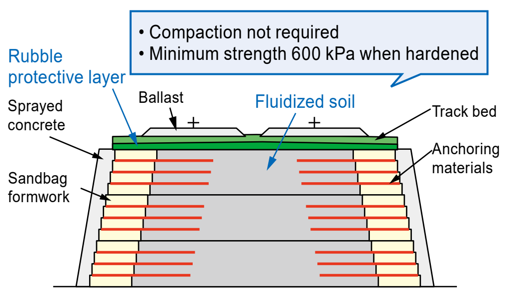


Figure 1 Embankment structure

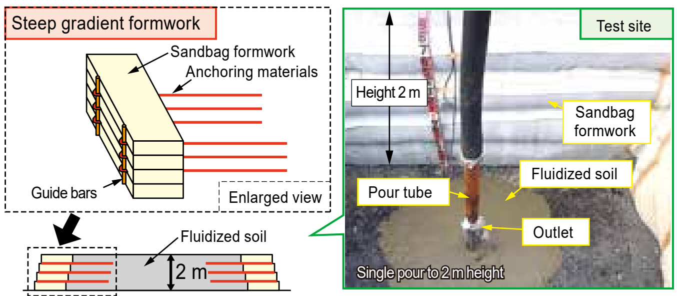


Figure 2 Construction design

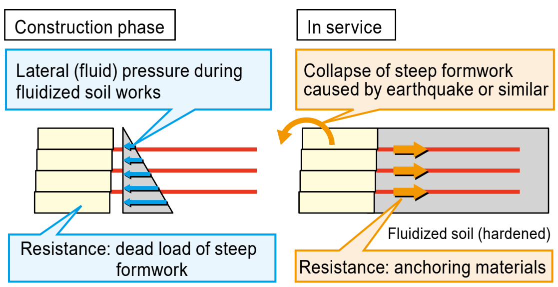


Figure 3 Steeply inclined formwork

Height = 3 m, crown width = 7.5 m	Construction period	Labor	Cost
Conventional L type retaining wall (Precast retaining wall; Ballast; 7.5 m; Track bed; Embankment; 3 m)	1.0	1.0	1.0
Fluidized soil (proposed structure) (Fluidized soil; Protective layer; Track bed; 7.5 m; Ballast; Sandbag formwork; Anchoring materials; Sprayed concrete; 3 m)	0.8	0.9	0.4

Table 1 Proposed structure vs conventional embankment

16. Numerical analysis method for predicting interaction impacts on closely adjacent tunnels

- We developed a numerical analysis method for predicting the potential impacts of excavating a new shield tunnel very close to an existing tunnel, such as subsidence of the existing tunnel and deformation of the new tunnel.
- By providing quantitative predictions tailored to ground conditions, the numerical analysis method can be used to show that soil improvement works are not required in cases where the ground is already in suitable condition.

Demand for new subways in major cities is making for increasingly congested underground spaces, with adjacent tunnels being built ever closer together (see Figure 1). When a new tunnel is excavated next to an existing tunnel and the separation between the two is less than the diameter of the new tunnel, excavation work can potentially impact the existing tunnel, typically by causing deformation. Technical Regulatory Standards state the special condition is required. In the absence of any formal methodology in this area, a blanket approach to soil improvement has generally been applied, regardless of the actual ground conditions, and this can add unnecessary costs. We have developed a numerical analysis method for predicting the impact of excavating a new tunnel very close to an existing one. The numerical analysis method is based on new understandings about the behavior mechanisms of closely adjacent tunnels.

The numerical analysis uses a 3-D tunnel model, and mutual interaction between the tunnel and surrounding ground is expressed using springs. We derived a calculation methodology for decreasing the spring modulus of the interaction spring as ground stability declines (see Figure 2). In trapdoor tests designed to simulate tunnels located very close together, we were able to the tendency for the spring modulus to decrease closer to the intersection point, as well as distortion characteristics in the existing tunnel (see Figure 3). Since it takes ground conditions into account, the method can be used to demonstrate that soil improvement may not be required in cases where the ground is already in suitable (see Figure 4).

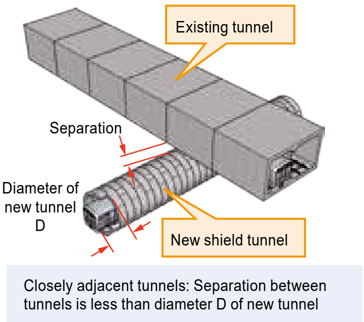


Figure 1 New tunnel close to existing tunnel

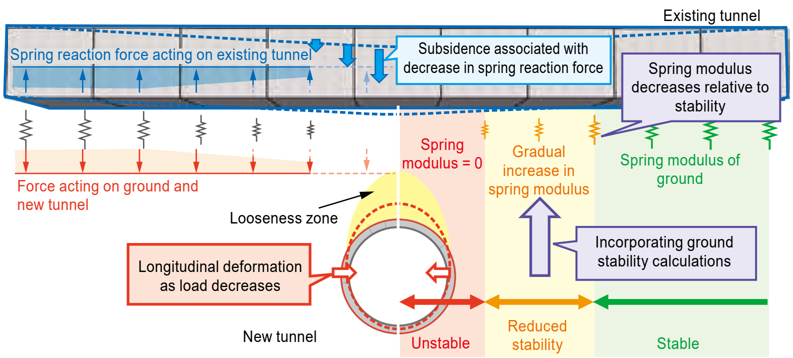


Figure 2 Mechanism of interaction and spring parameters

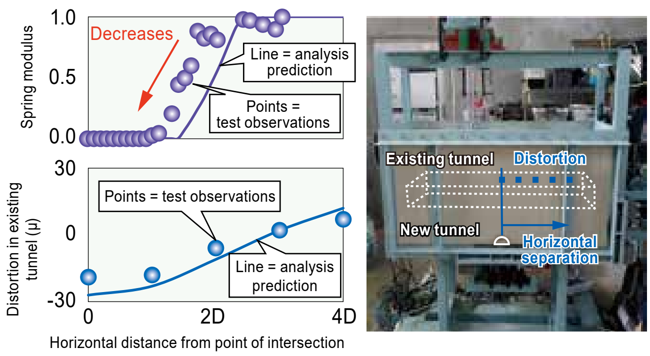
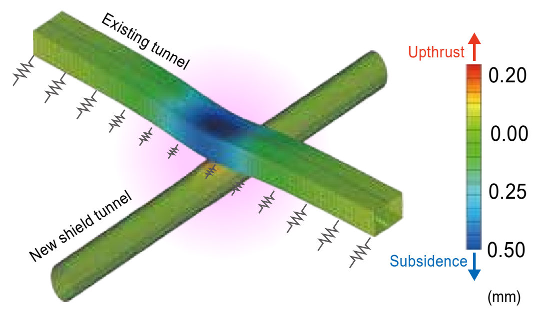


Figure 3 Investigation using interaction spring



Ground strength (N value)	N < 40	N ≥ 40
Analysis prediction	x Soil improvement required	O Soil improvement not required

Figure 4 Adjacent tunnel analysis using the method

17. Method for evaluating girder vibration characteristics with consideration for track rigidity

- We have developed a simple yet highly accurate method for evaluating the flexural rigidity of girders. Our method takes into consideration the rigidity of tracks and other components that have traditionally not been included in bridge design.
- The method demonstrates that the girder vibration amplification factor when a train passes the bridge may be up to 50% less than assumed. This knowledge allows us to reduce the quantity of reinforcing steel members required in the design.

Some Shinkansen bridges exhibit significant resonance vibration as trains pass over. In order to accurately predict the vibration characteristics of a bridge, we need to calculate the flexural rigidity of its girders. Conventional girder design does not consider the rigidity contribution of the tracks and other above-deck components such as roadbed concrete, track slabs and wheel guards, simply because we do not have a proper understanding of their respective rigidity contributions. As a result, girder designs are often uneconomical. We have developed a method for calculating girder flexural rigidity that incorporates consideration for the rigidity of tracks and other above-deck components (Figure 1 upper left). The method even takes into account loss of rigidity associated with cracks in concrete members, in order to provide a more realistic picture of overall structural integrity.

Tracks and other components used on bridges vary widely in terms of type, shape and design. In addition, cracking behavior is different depending on structural types such as concrete and composite girders. Our method incorporates these differences into the girder flexural rigidity calculation by multiplying the cross-sectional rigidity of each component by the effectiveness factor, a simply used indicator of combined structural integrity (the degree of structural integration with the main structure). Through a combination of finite-element method analysis and observation of different girder structures, we have quantified individual effectiveness factors for the rigidity of tracks and other above-deck components (Figure 1 upper right). In addition, we have used fatigue testing to develop a dedicated formula for the effectiveness factor of concrete girders with bending cracks, which can be used to estimate the progress of cracking under repetition and the associated decline in flexural rigidity (Figure 1 lower right). The accuracy of the method has been validated via actual bridge measurements (Figure 1 lower left). The rigidity of reinforced concrete (RC), pre-stressed concrete (PC) and composite girders has conventionally been underestimated. Our method strips up to 50% off the vibration amplitude factor during train passages for such girders. In the example of the RC girder in Figure 1, rigidity is shown to increase by 80% while the vibration amplitude factor drops by 50%, leading to an overall 10% saving in the quantity of steel used in the bridge design.

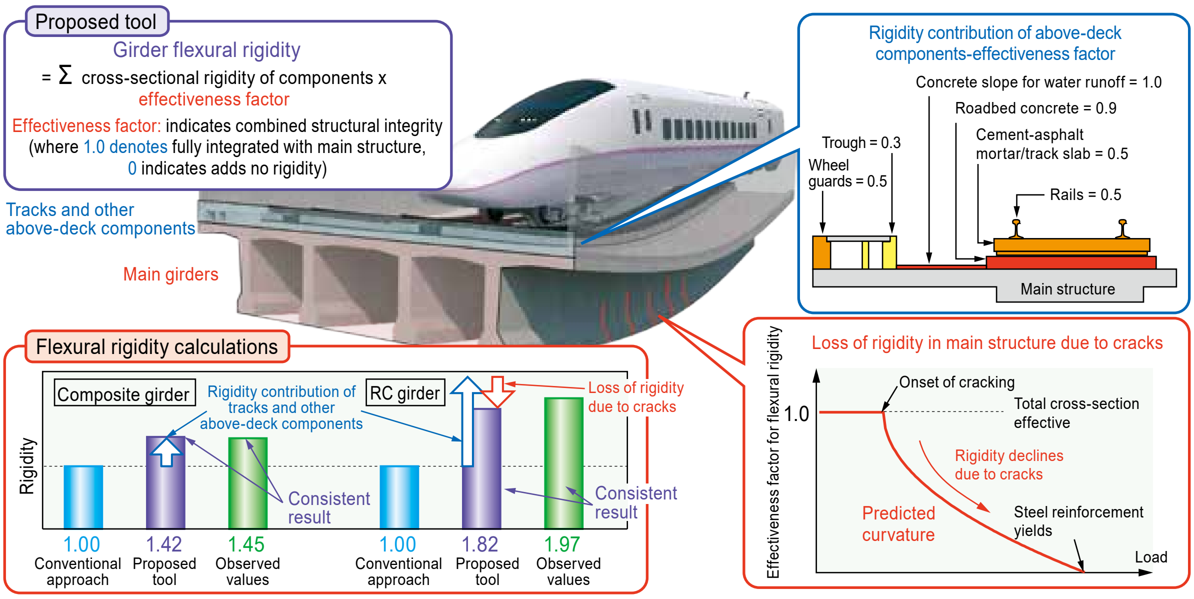


Figure 1 Girder flexural rigidity calculation and application

18. Concrete repair methodology based on crack width and location

- We developed a new concrete repair methodology tailored to the width and location of cracks, based on the findings of a dedicated study of water penetration through cracks.
- Water seldom penetrates into concrete via undersurface cracks, regardless of width, so repairs should focus on preventing flaking. Repairs to cracks on the top surface, meanwhile, should prioritize preventing the ingress of water.

Water ingress via cracks in concrete can lead to significant degradation in reinforced concrete structures. It has traditionally been assumed that damage is proportional to crack width. As such, repair work has sought to prevent water ingress via a combination of grouting and surface coating. Repairing undersurface cracks, particularly on the underside of bridge structures, usually requires scaffolding and is more labor-intensive and time-consuming.

We used an internal imaging system to investigate water penetration in concrete. We found there was less water ingress via cracks on the undersurface compared to cracks on the top and side surfaces. Interestingly, when we compared undersurface cracks of width 1 mm and 0.2 mm, we found less evidence of water ingress through the wider crack, as well as limited penetration (see Figure 1). We also found that applying a coating to the undersurface hinders natural evaporation and actually leads to an increase in internal moisture levels, with the associated risk of steel corrosion (see Figure 2).

In light of the above, we conclude that repairs to concrete cracks on the undersurface should give priority to suppressing concrete flaking rather than preventing water ingress as such. Repairs to top surface cracks, on the other hand, should be designed to prioritize preventing water penetration (see Figure 3).

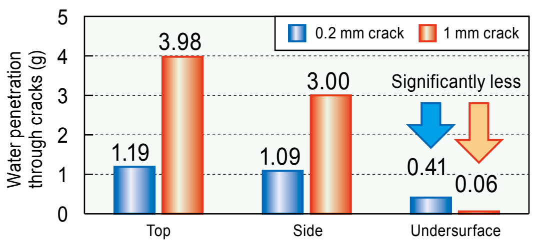


Figure 1 Crack location and water penetration level

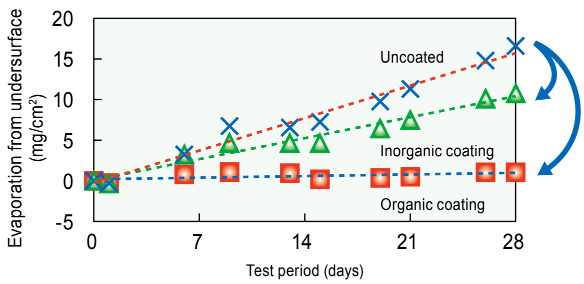


Figure 2 Impact of undersurface coating on suppressing evaporation of internal moisture

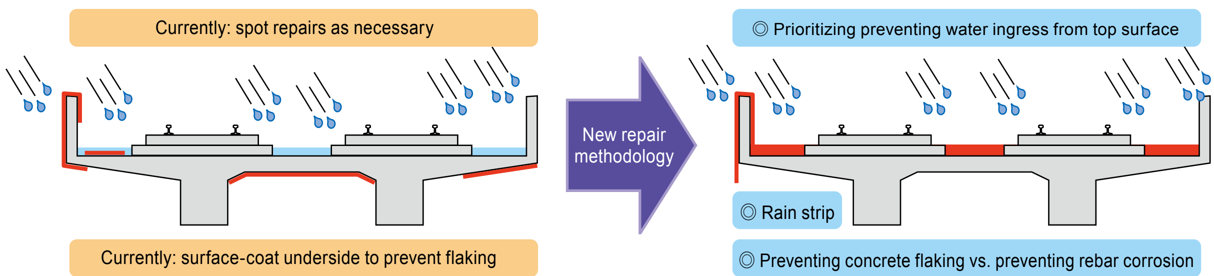


Figure 3 New location-specific approach to repairing concrete cracks

19. Using expansive concrete in track slabs to minimize reinforcement

- We have developed a new track slab formulation and structural design that utilizes the volumetric expansion of expansive concrete to generate compressive force constrained by internal reinforcement.
- The expansive concrete track slab uses a third less reinforcement by volume and is 5% cheaper to produce, yet delivers crack resistance and frost resistance characteristics broadly equivalent to conventional track slabs.

Track slabs are a key component of ballastless track (also known as slab track), which has been carrying train loads for more than 50 years. The reinforcement quantities currently specified for track slabs provide little margin for cracking. Meanwhile, it is effectively impossible to cut back on reinforcement as a cost-saving measure, because the maximum spacing between rebars is strictly defined in the specification (see Figure 1). Our track slab design requires less reinforcement thanks to the use of expansive concrete, which expands as it hardens. The volumetric expansion of the expansive concrete is constrained by the reinforcing bars, generating compressive force that acts to suppress cracking. This allows us to reduce the quantity of reinforcement used. Meanwhile, excessive volumetric expansion can itself cause damage, which may impact on frost resistance.

We investigated a number of different formulations and conducted a series of freezing/thawing tests in order to better understand the impact of the concrete mix proportion (including expansive additives) on volumetric expansion and frost resistance characteristics. We found that the well balance of concrete strength and volumetric expansion can be achieved by introducing the expansive additive at the expense of cement rather than sand, with only a relatively small quantity of additive needed to obtain the required expansion. Frost resistance is also equivalent to conventional track slabs (see Figure 2). Designed to comply with the existing limit for crack width, our track slab requires one-third less reinforcement and delivers a 5% saving in manufacturing costs (see Figure 3).

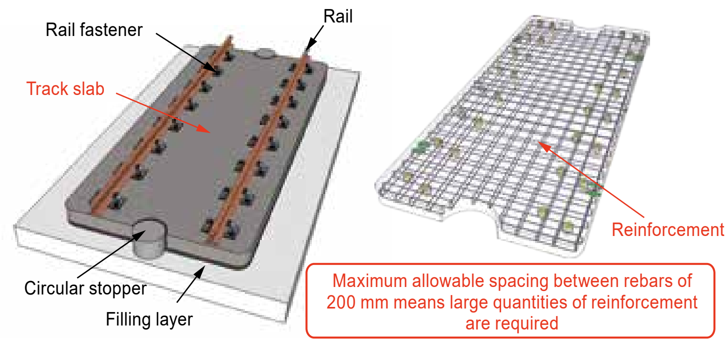


Figure 1 Slab track design

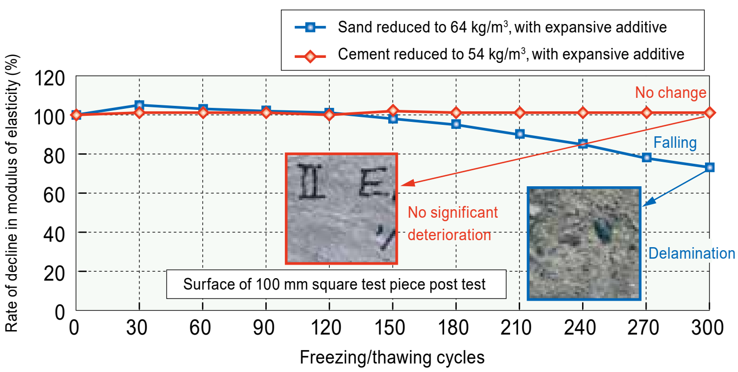
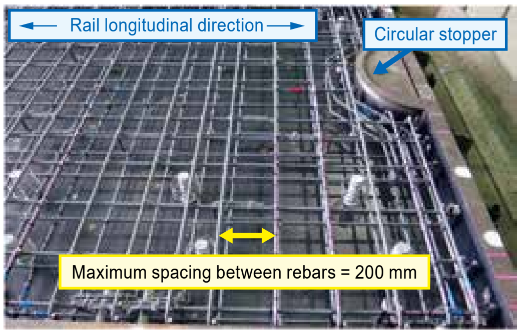
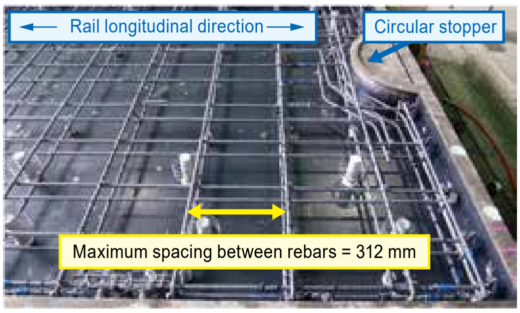


Figure 2 Freezing/thawing test results (equivalent expansion)



(a) Reinforcement for conventional concrete



(b) Rebar arrangement for expansive concrete

Figure 3 Track slab manufacturing process

20. Using temperature sensors to help predict service life of electronic signallingequipment

- Temperature is a key factor governing the service life of electronic signalling equipment. We have developed a system that can accurately evaluate current and future deterioration levels and predict service life.
- The system can be used to determine equipment replacement intervals tailored to the operating environment and usage conditions.

Given the difficulty of evaluating deterioration in signalling equipment, to date a blanket approach has been adopted whereby all equipment is replaced at defined intervals, irrespective of factors such as equipment type, operating environment and manner of use. A more tailored approach is required.

We have upgraded the existing approach for predicting service life, which uses acceleration models for electronic components and solder in signalling equipment, by adding environmental sensors to provide better information about equipment degradation and enable more accurate prediction of future degradation. Temperature is considered a key factor governing the service life of electronic signalling equipment. Our acceleration models link actual equipment operating temperatures (from sensor data) with the temperatures quoted by device and component manufacturers in reliability tests to generate more accurate predictions of degradation and service life for the equivalent period under test conditions per day (see Figure 1). The existing approach defines a specific temperature as the basis for predicting service life, then adds an error margin to reflect potential temperature variation associated with factors such as exposure to direct sunlight and relocation or reconfiguration of equipment. Our system uses data from temperature sensors and is thus able to deliver predictions that reflect actual usage conditions. Trials conducted on electronic signalling equipment located next to rail lines demonstrated that the system generates more accurate predictions than the existing approach in relation to the temperature margin (see Figure 2). Equipment service life predictions can also be based on weather data from the Meteorological Agency, but this is less accurate.

Our system can be used to determine equipment replacement intervals that better reflect the actual operating environment and usage conditions.

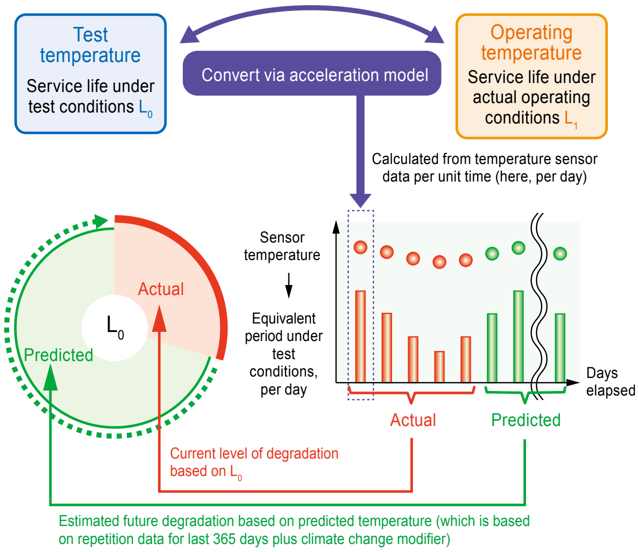


Figure 1 Using temperature sensors to predict service life

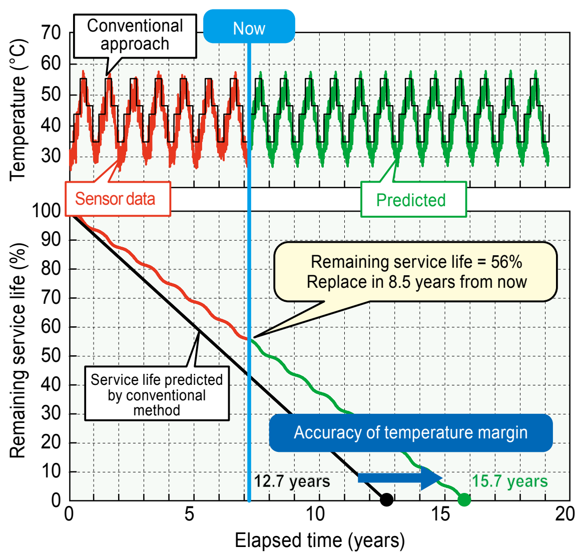


Figure 2 Testing on electronic device close to rails (aluminum electrolytic capacitor)

21. Effective and efficient steam weeding technique

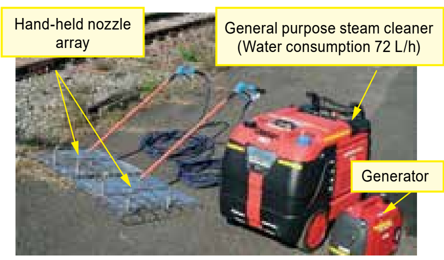
- We have developed a weed control technique using steam that is both effective and easier to use.
- Field tests found that regrowth of a large variety of weed one year after steam weeding fell by 70%.
- The tests also showed that steam weeding is 44% faster than conventional slashing using the bush cutter and requires only three workers instead of five.

Slashing using the bush cutter is generally considered a faster way to remove weeds growing on railway field between the tracks and the side boundaries. During summer, however, weeds can grow back quickly, while workers can only use bush cutters for relatively short periods due to the health impacts of vibration. In addition, signaling and communication cables near to tracks have to be protected from potential damage by the bush cutter. Steam spraying is an effective and efficient weeding technique that is used in the agricultural sector. The heat of the steam causes thermal denaturation of key proteins in weeds and effectively withers them . We have adapted this process for weed control on railway field.

Conventional steam weeding requires considerable quantities of water as well as a dedicated large boiler designed for mains water. Our technique uses a general purpose steam cleaner fitted with a high-efficiency hand-held nozzle array specifically developed for use on railway field, where access to water may be limited. Compared to conventional steam weeding, the nozzle array uses less than one-tenth as much water (72 l/h vs. 1,000 l/h), while still providing sufficient heat to wither weeds and also be easier to use (see Figure 1). In addition no requirement need to protect signaling and communication cables since steam weeding does not involve a slashing blade.

Trials conducted at a test site covered in thick growth of large weeds found that weed regrowth three months after steam weeding was no more than around 10%, while the number of plants reappearing after one year fell by 70% (see Figure 2).

Steam weeding was also found to be 44% faster per unit area. It would take an estimated 50 minutes to cover an area of 300 m2 including preparation to finish, some 30% faster than slashing using the bush cutter, which takes 72 minutes. Steam weeding also delivers a 60% labor saving, since it requires only three workers rather than five.



(a) Equipment

(b) Nozzle array

Figure 1 Steam weeding equipment

Figure 2 Removing large weeds (Solidago altissima)

22. High-efficiency generator design for diesel electric cars

- We developed a technique for boosting power generation efficiency in diesel electric cars using detailed thermal efficiency mapping to modify the engine working points.
- We estimate that the combination of a high-efficiency generator and energy-saving modifications to the engine working points could reduce fuel consumption by around 10%.

Hybrid diesel and diesel electric railcars for non-electrified lines, introduced in a bid to save energy and reduce maintenance workloads, have poor mechanical power transmission efficiency compared to standard diesel hydraulic railcars, which translates to higher fuel consumption. We have designed an improved high-efficiency power generation system centered on the engine and generator.

Two factors are critical to improving the fuel consumption of the power generation system: running the engine in the high-efficiency zone, and minimizing generator losses. Engine efficiency characteristics are not widely known, and to date have not been incorporated into system design. We used detailed thermal efficiency mapping generated from unit tests to derive an efficiency map of the power generation system. We used the efficiency map to identify the most efficient working points in the engine as the basis for our generator design (see Figure 1). Engine output is proportional to the product of engine speed and torque. Our technique involves finding the optimum combination of speed and torque to deliver maximum power generation efficiency without affecting engine output.

We investigated the power generation capacity and efficiency characteristics of the induction machine and brushless synchronous machine, which have been widely used over the years, as well as the more recent permanent magnet synchronous machine. We found that the permanent magnet synchronous machine has the highest efficiency.

We demonstrated that the combination of a high-efficiency permanent magnet synchronous machine together with energy-saving modifications to the engine working points can reduce the fuel consumption of a diesel hybrid railcar by an estimated 10% (see Figure 2).

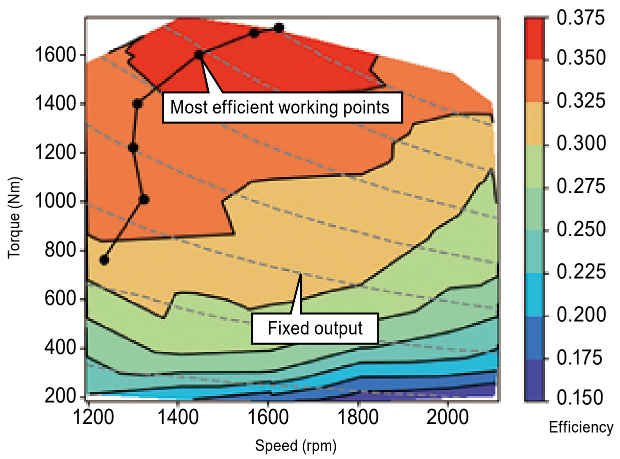


Figure 1 Energy map for power generation system and most efficient working points

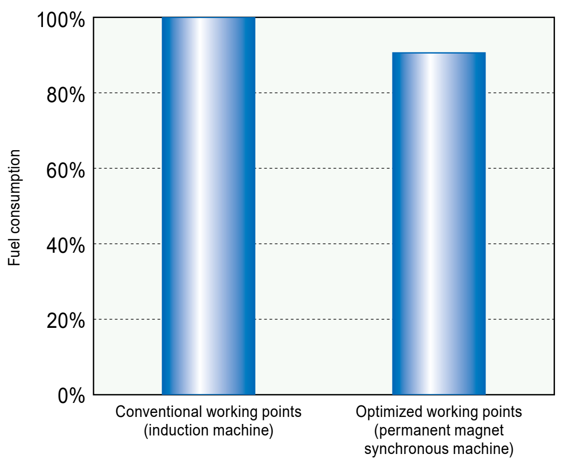


Figure 2 Calculating energy savings of high-efficiency generator in combination with modified engine working points

23.Driver advisory system for long-distance trains by speed transition estimation

- We developed a driver advisory system for long-distance train stopping at limited stations that generates real-time estimations of recommended train speed transition to improve punctuality and save energy consumption, and displays recommended driving operation to the station to be passed.
- In trial operations by several drivers with several trains, the system provided useful driving instruction.
- We also demonstrated that the system achieved energy savings in the range 4% - 14%.

Driving operations of train drivers are various. We developed a driver advisory system that reduces the variance, improve punctuality, and save energy consumption. The system combines train speed and location (from Global Navigation Satellite System data) with route data such as stations and gradients to provide real-time estimation of train speed transitions. The system also recommends driving operations to the stations to be passed thorough. A tablet PC in the driver’s cab estimates several train speed transitions for different driving instructions based on the speed and position of the train at the present time, and selects a driving instruction to improve for punctuality and save energy consumption (see Figure 1). And, the system shows the recommended driving instruction to the driver, and shows the time that the train is expected to pass through the station (see Figure 2). The system also provides audio prompts at the appropriate timing. The system saves energy consumption by eliminating unnecessary acceleration and deceleration and reducing losses associated with running resistance and traction equipment.

We used the system as trials on several freight trains and several drivers. We then interviewed the drivers and also asked them to fill in a survey. The responses were generally positive, indicated that the system is easy to use. We investigated the difference in energy consumption when using the system, and found that it delivers energy savings in the range 4% - 14%, depending on factors such as route, gradient and travel time (see Figure 3).

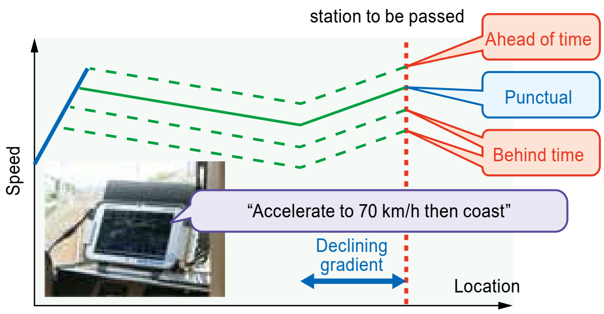


Figure 1 Estimated train speed transition

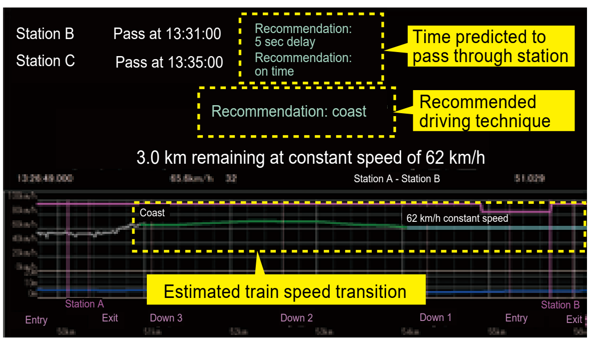


Figure 2 System screenshot

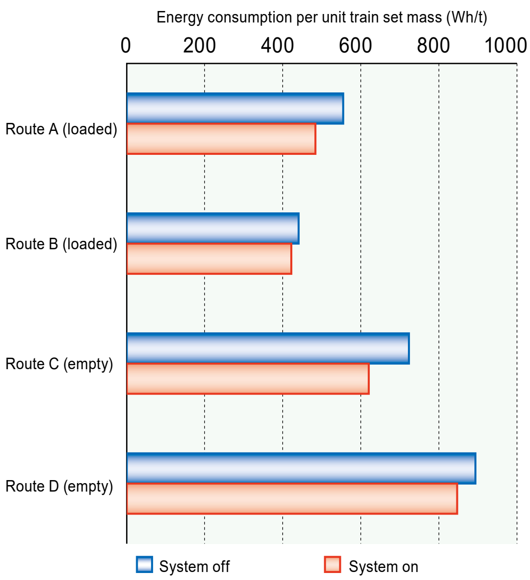


Figure 3 Comparisons of Energy consumption

24. Energy-saving driving operation to minimize the energy consumption during small scale delays

- We have developed an energy-saving driving operation for use during small scale delays that can reduce powering energy and promote regenerative power interchange by coordinating the timing of powering and braking.
- The energy-saving driving operation integrates seamlessly with automatic train operation and helps drive the decarbonization of railways.

In the event of a small scale delay lasting a few minutes, trains are sometimes required to be suspended at stations. The aim is to prevent spikes in passenger numbers and also to avoid having trains slow down or come to a stop between stations. When a train proceeds slowly to the next station (instead of stopping at the previous station), we can reduce powering energy (see Figure 1). Meanwhile, by adjusting the suspension time at stations and coordinating the timing of powering and braking by the affected trains, we can increase regenerative energy (see Figure 1). To date, we have not been able to reconcile these two seemingly conflicting objectives. But our proposed energy-saving driving operation uses mathematical optimization and simulation to achieve both objectives simultaneously. We begin by defining the regenerative power interchange index, the potential for regenerative power interchange during periods when powering and braking coincide for two separate trains (see Figure 2). We then use an existing Train Operation Power Simulator to calculate, for each train in turn, how travel time between stations affects powering energy. Mathematical optimization tries to minimize the difference between total powering energy and the sum of the regenerative power interchange indices multiplied by the coefficient W. A larger W value indicates higher priority to regenerative power interchange.

We analyzed the train timetable over a period of one hour following a small scale delay, which includes the time taken to restore normal operations. We looked at two scenarios: trains suspended at stations, with no consideration of energy consumption; and using our optimization approach. The analysis found that both powering and regenerative energy increased in line with the W value (see Figure 3), and that the optimized energy-saving driving operation delivers energy savings of around 2% (see Figure 4). The energy-saving driving operation is readily incorporated into automatic train operation systems because it updates train arrival and departure times, and speed profiles in real time. It can also be used to build energy-saving considerations into timetable planning.

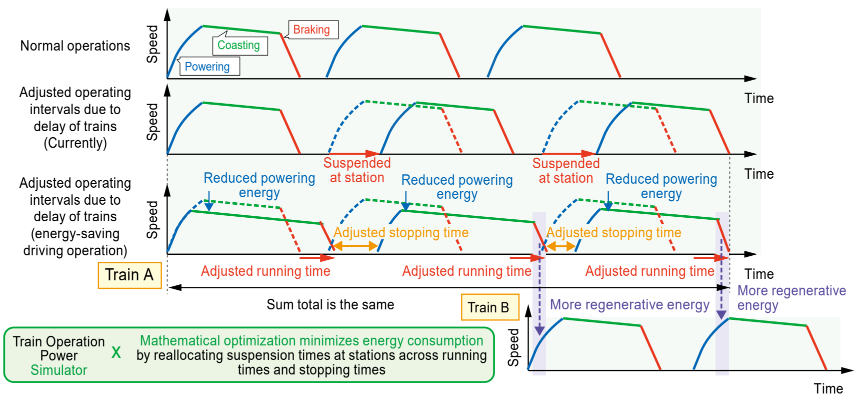


Figure 1 Basic principle of energy-saving driving operation during small scale delays

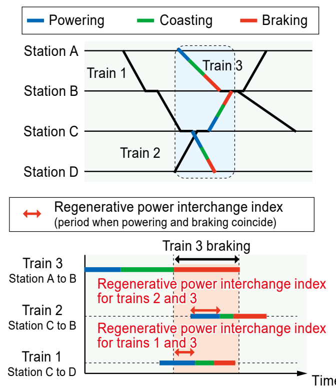


Figure 2 Regenerative power interchange index

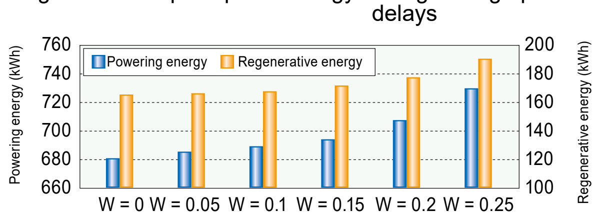


Figure 3 Powering energy vs. regenerative energy

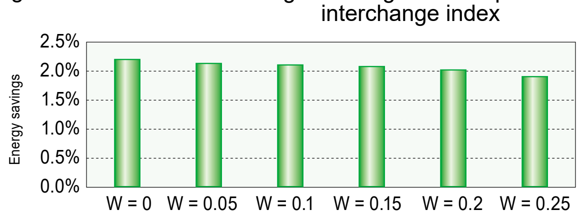


Figure 4 Projected energy savings

25. Modular sound insulating barriers designed to replace existing noise barriers on viaducts

- We have developed a modular sound insulating barrier designed to replace older noise barriers.
- The modular barriers can be assembled and installed by hand, during daylight hours, without need for heavy machinery.
- The barriers feature a laminated sound absorption material that has been tailored specifically to the sound of passing trains, so as to mitigate noise levels along train lines.

Future large-scale renovations on Shinkansen (bullet train) viaducts are expected to include replacement of aging noise barriers. This requires a new type of barrier that is easier to install and also more effective at reducing noise levels. We have developed a modular sound insulating barrier intended as a replacement for existing noise barriers (see Figure 1).

The modular units are essentially tall posts of identical width, which are linked together to form a contiguous wall alongside the railway tracks. Structural strength is provided by corrosion-resistant steel panels treated with an anti-rust coating that weigh about a third as much as traditional concrete noise barriers while still being sufficiently sturdy. Thanks to the lightweight design, our barriers can be assembled and erected manually by workers, without the need for heavy machinery, provided that sufficient measures for safety considerations can be made.

Soundproofing is provided by layers of laminated polyester fiber sound absorption material with differing characteristics on the side facing the tracks (see Figure 1). Sound absorption is equivalent to or better than glass wool, used extensively in noise barriers for many years (see Figure 2). By integrating sound insulating barriers with sound absorption panels, we can reduce noise levels along the entire polyester surface facing the tracks, eliminating the need for additional sound absorbing work. We trialed the modular barrier system on a commercial line, using a directional microphone to measure noise levels. The equivalent continuous A-weighted sound pressure level averaged from nine passing trains (single train sets) was 2.4 dB lower compared to conventional concrete noise barriers (see Figure 3).

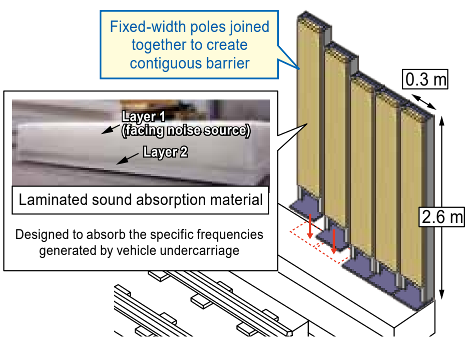


Figure 1 Modular sound insulating barrier

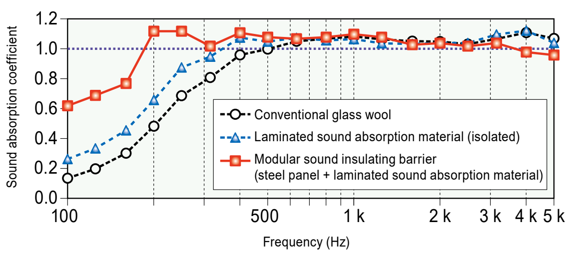


Figure 2 Results of sound absorption coefficient by reverberation room method

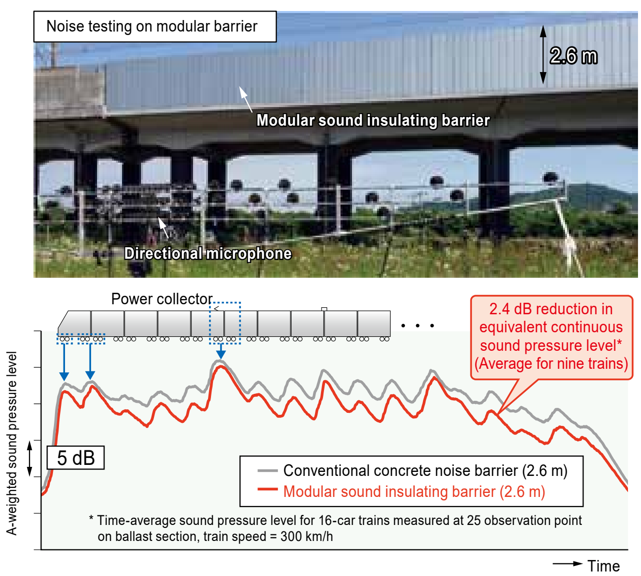


Figure 3 Sound pressure level time history waveform comparison (using directional microphone at 25 m observation point on different noise barrier sections, for identical passing trains)

26. Reducing aerodynamic noise and pressure fluctuation from bogies on high-speed trains

- We developed several strategies for mitigating aerodynamic noise and pressure fluctuation generated by bogies on high-speed trains, and validated their efficacy through wind tunnel tests.
- We then tabulated the wind test data in table form to illustrate the level of mitigation at different frequencies.
- Further tests conducted on real trains showed that these strategies are effective in mitigating both aerodynamic noise and pressure fluctuation.

Reducing both noise and low-frequency pressure fluctuation on open sections is key to improving amenity in the vicinity of rail lines. Noise generated by high-speed trains can be broken down into a number of constituent elements: wheel noise, noise from structures such as bridges, and aerodynamic sound from train bogies, which is the single largest noise source. Past research has shown that bogies are also the primary source of pressure fluctuation from passing trains. We developed several strategies for mitigating both aerodynamic sound and pressure fluctuation from bogies on high-speed trains, and used wind tunnel tests to validate their efficacy (see Figure 1).

We adopted a two-pronged approach to reducing aerodynamic sound and pressure fluctuation: (1) keep internal parts of the bogie away from high-speed airflows, and (2) suppress noise propagation by adding sound insulating materials inside the bogie storage area to mitigate multipath sound reflection. We conducted a series of wind tunnel tests to assess the efficacy of different strategies in reducing aerodynamic sound and pressure fluctuation (see Figure 2). Table 1 shows how the cumulative effect of multiple strategies used in combination reduces pressure fluctuation and aerodynamic sound at key frequencies. In relation to rounding of corners, considered the most easily applicable solution, we measured noise and pressure fluctuation levels on an operational train where the railway operator had already done something similar, and we found that this had proven effective.

In the future, we plan to conduct running tests on low-noise train models and use our findings to inform the development of enhanced practical solutions suitable for deployment on commercial train services.

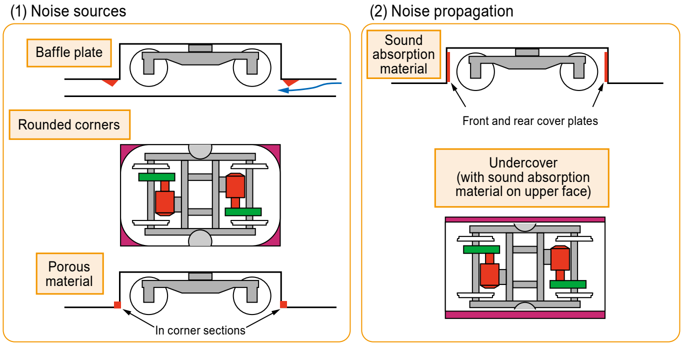


Figure 2 Strategies to reduce aerodynamic sound and pressure fluctuation from train bogies

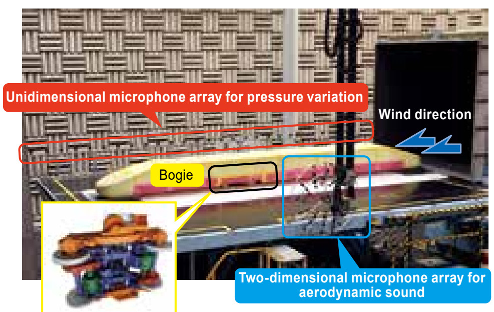


Figure 1 Wind tunnel testing to evaluate aerodynamic sound and pressure fluctuation from train bogies

Table 1 Effectiveness by frequency

Frequency (Hz)	Pressure variation (low frequencies)			Aerodynamic sound (mid frequencies)			
	<16	25	50	250	500	1000	2000
Baffle plate	-0.8	-0.4	0.2	0.4	-1.2	-1.3	-2.2
Rounded corners	-0.8	-0.1	-0.3	-0.3	-0.4	-0.3	0.1
Porous material	0.0	-1.0	-1.4	-0.6	-0.4	0.1	0.8
Sound absorption material	0.0	-0.1	-1.0	-0.7	-1.1	-1.0	-1.2
Undercover	-0.8	-0.3	-0.3	-1.1	-1.7	-0.4	-0.9

Blue indicates impact (dark blue = strong impact), all figures in dB

27. Automatic interim timetabling algorithms in case of disasters and train crew/rolling stock shortages

- We developed an automatic timetable generator that produces interim timetables for use in emergency situations such as natural disasters and in the event of train crew or rolling stock shortages.
- The generator produces interim timetables that are tailored to constraints around crew and rolling stock availability, and also designed to accommodate compounding factors such as longer travel times due to speed restrictions and congestion.

In the event that trains cannot operate along with the base timetable because of crew and/or rolling stock shortages, for instance due to pandemic or natural disasters, an interim timetable with fewer trains is required. It has to take into account crew and rolling stock availability as well as other constraints such as longer travel times due to speed restrictions on some sections. Making a such timetable involves as much work for timetable planners as making a fully new timetable (see Figure 1). The interim timetable has to be renewed when the line section in operation is expanded in the restoration process of the disaster. For a busy commuter line in a big city, it takes five days or more to produce an updated timetable. We have developed a fast timetabling algorithm which can generate an interim timetable for a busy commuter line in a big city, by reducing the minimum necessary number of trains reflecting any operating restrictions.

Our timetabling algorithm calculates the frequency of trains that can be delivered, subject to constraints around crew and rolling stock availability, as the basis for a workable timetable. Where the imposition of speed restrictions causes longer travel times and reduced rolling stock allocation efficiency, the timetabling algorithm calculates the impact on service frequency by applying a multiplier to represent the increased duration of each return trip. The timetable generator also optimizes train intervals and dwell time to break the snowball effects between reduced services (which lead to longer intervals between services, more congestion and extended dwell times) and extended dwell times (which in turn lead to longer intervals between services). Thus, the interim timetable is able to provide transportation services tailored to multiple constraints with minimal delays.

In trials conducted on an operational railway line, the timetabling algorithm was able to generate an interim timetable in a matter of seconds (see Figure 2). This will greatly assist with business continuity planning (BCP) in the event of natural disasters or pandemics.

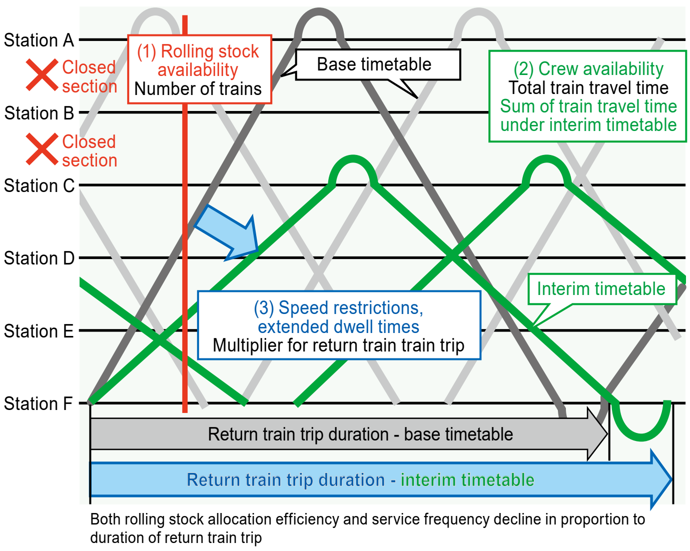


Figure 1 Key constraints and considerations

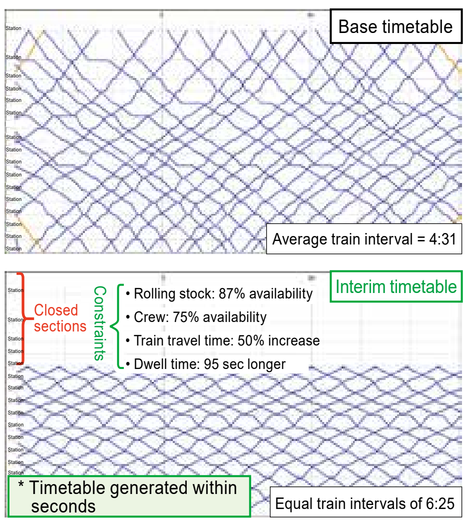


Figure 2 Base vs. Interim timetable

28. Tool for evaluating congestion in terms of passenger discomfort in station

- We developed a tool for evaluating congestion in a station environment in terms of passenger discomfort, based on a combination of passenger flow simulation and modeling of the level and duration of congestion tolerated by different passenger cohorts.
- Passenger discomfort level represents a handy indicator for comparing congestion levels in different sections of a station and also for comparing stations. This information can then be used to prioritize planning and improvements at railway stations.

Queue time — the duration of continuous congestion in a specific location — is currently the main indicator for evaluating congestion in station premises. However, there can be considerable variance between stations with respect to the spatial design and configuration of congested locations (such as staircase width) as well as how they are utilized (such as the relative proportion of those traveling up versus down). Further, the willingness of passengers to tolerate congestion in a station environment differs between cohorts. Queue time alone is therefore not considered an adequate measure of congestion for the purpose of comparison.

We developed a tool for evaluating congestion in a station environment based on the notion of passenger discomfort. The tool combines passenger flow analysis with modeling of the level and duration of congestion tolerated by different cohorts of passengers, as determined through a survey of passengers on congestion (or density) tolerance (see Figure 1). By calculating passenger discomfort, which represents a constantly changing dynamic, the tool augments the traditional measure of queue time to enable quantitative evaluation of congestion levels in different parts of station premises. Passenger discomfort in congested locations is calculated taking into account factors such as passenger attributes and the spatial configuration of the station, as determined via passenger flow analysis. This allows us to derive a common indicator of discomfort that can be used to make direct comparisons with congested parts of other stations. By enabling direct comparison of discomfort levels at different congestion locations within station premises, and also between stations, the tool can be used to prioritize planning and improvements at railway stations.

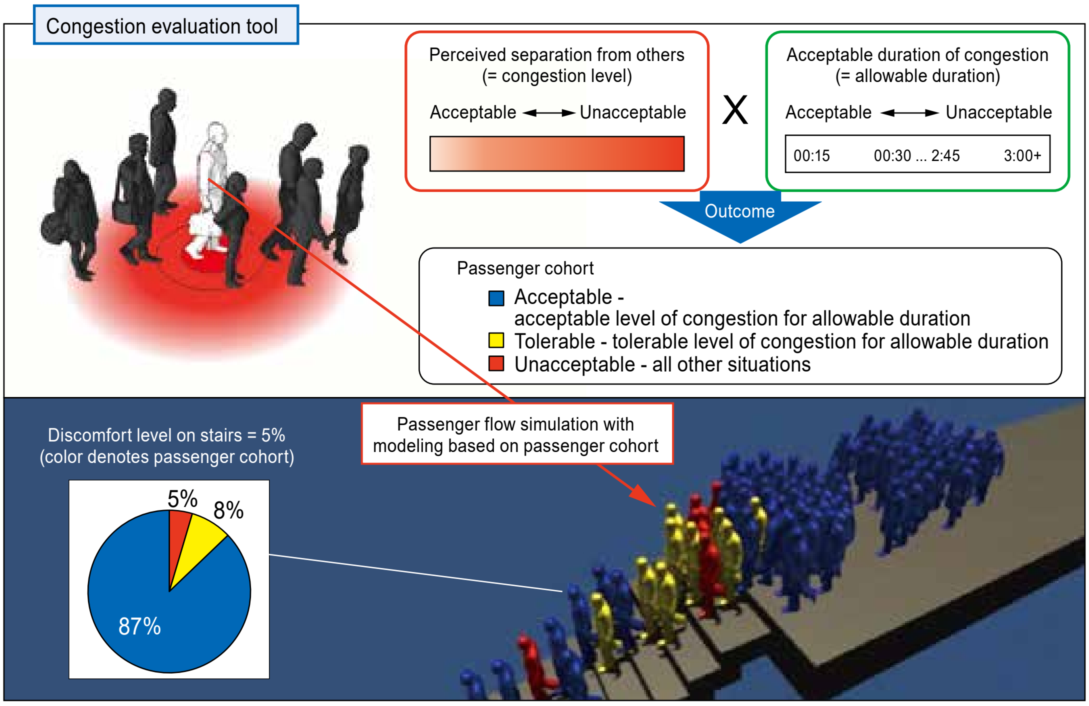


Figure 1 Evaluating congestion at station premises

29. Investigation of vehicle behavior during earthquake with focus on on-rail safety limit

- We have developed a simulator for evaluating vehicle behavior during an earthquake that extends beyond the safety limit of 70 mm relative lateral displacement between wheels and rails traditionally used in simulations.
- Our simulator accurately reproduced the results of excitation tests on a 1/10 scale model of a conventional line train.

To date, analysis of vehicle behavior during an earthquake has traditionally employed a safety limit of 70 mm relative lateral displacement between wheel and rail (hereinafter referred to as “70mm safety limit”). We know little about vehicle behavior outside of the 70 mm safety limit.

We developed a simulator for evaluating vehicle dynamic behavior during an earthquake outside of the 70mm safety limit for conventional simulations (see Figure 1). We conducted excitation tests on a 1/10 scale model vehicle of a conventional line train using the large-scale shaking table at the Railway Technical Research Institute. Figure 2 shows the excitation amplitude at which derailment occurs for various excitation frequencies. The graph shows the predictions from our vehicle dynamics simulator to be highly consistent with the test results of the model vehicle.

We also performed a simulation of a conventional line train to determine the limit point beyond the 70mm safety limit at which the vehicle finally cannot stay on the rails anymore. Figure 3 compares this limit point (we call this new criterion “on-rail safety limit”) with the 70mm safety limit. In the 0.4 - 0.6 Hz range, the on-rail safety limit exists at excitation amplitudes of up to 100 mm beyond the 70mm safety limit.

Our findings can be used to inform in-depth studies of vehicle running safety during an earthquake, as well as improved vehicle designs that offer better resistance to derailment.

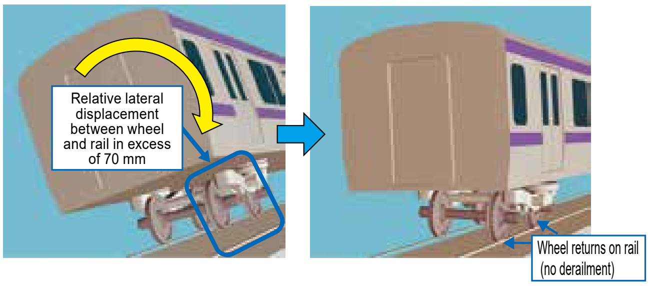


Figure 1 Simulation outcome of returning on the rail behavior after displacement of more than 70 mm.

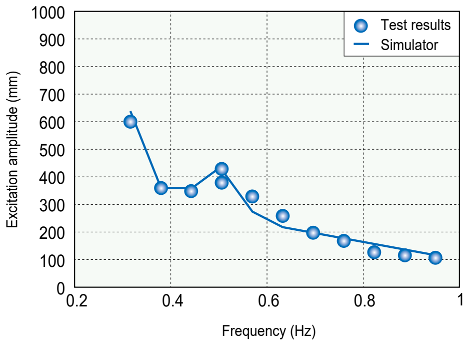


Figure 2 Simulation results vs. derailment tests on model vehicle (model test, simulation results, excitation frequency and amplitude scaled up to actual car size)

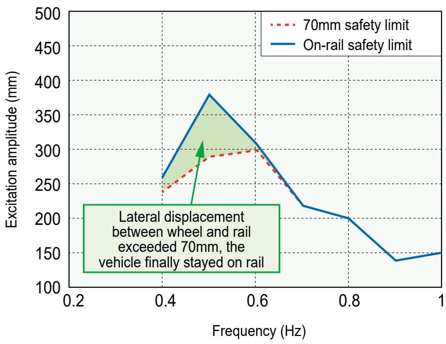


Figure 3 70mm safety limit vs. on-rail limit

30. Numerical simulation tool for RTRI Large-Scale Low-Noise Wind Tunnel

- We developed a numerical wind tunnel simulation tool that reproduces air flows in the Large-Scale Low-Noise Wind Tunnel at the Railway Technical Research Institute (RTRI).
- The tool includes a complete system incorporating processes from geometric definition of specimens through to computation.
- Used in combination with real-life wind tunnel testing, the tool enhances efficiency and allows tests to be tailored more closely to the requirements of railway operators and other bodies.

The Maibara Large-Scale Low-Noise Wind Tunnel, a key aerodynamics research facility at the Railway Technical Research Institute, is utilized more than 200 days per year for a variety of wind tunnel tests. By faithfully reproducing the wind tunnel testing environment, our numerical simulation tool helps to boost the efficiency and accuracy of wind tunnel testing at this facility.

The tool was developed through observation and numerical reproduction of airflows in the Maibara Wind Tunnel (see Figure 1). The numerical reproduction phase involved a series of complex flow calculations performed on the powerful in-house airflow simulator at the RTRI. We used a 3D laser scanner for geometric modeling of specimens, and constructed a system that encompasses all processes from geometric definitions through to computation (see Figure 2). The findings generated by the numerical simulation tool were found to be highly consistent with test results (Figure 1 right, Figure 2 right).

Our numerical wind tunnel simulation tool is designed to augment and enhance conventional wind tunnel testing, primarily by allowing researchers to use a narrower set of test conditions and fewer measurement points. Used in combination with conventional wind tunnel testing, the tool helps to speed up the testing phase, which means that research projects can be completed sooner. The tool also provides railway operators and others with an additional option for investigating issues as they arise, and one that can be used in combination with (rather than relying solely on) wind tunnel testing.

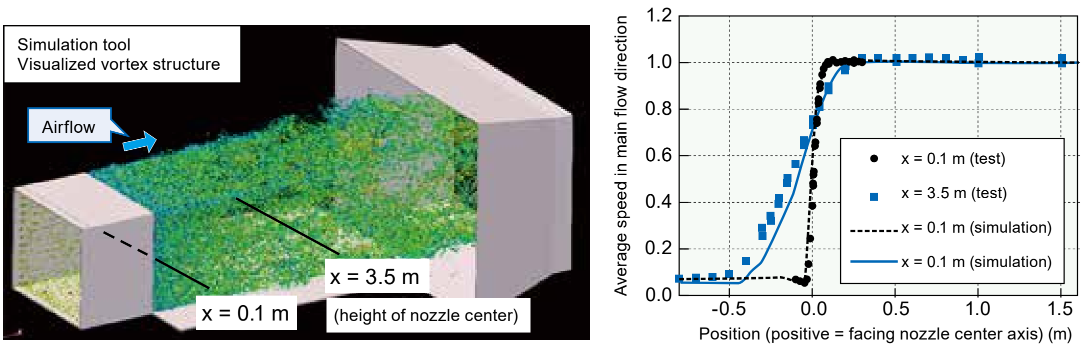


Figure 1 Numerical simulation of airflows in the Large-Scale Low-Noise Wind Tunnel

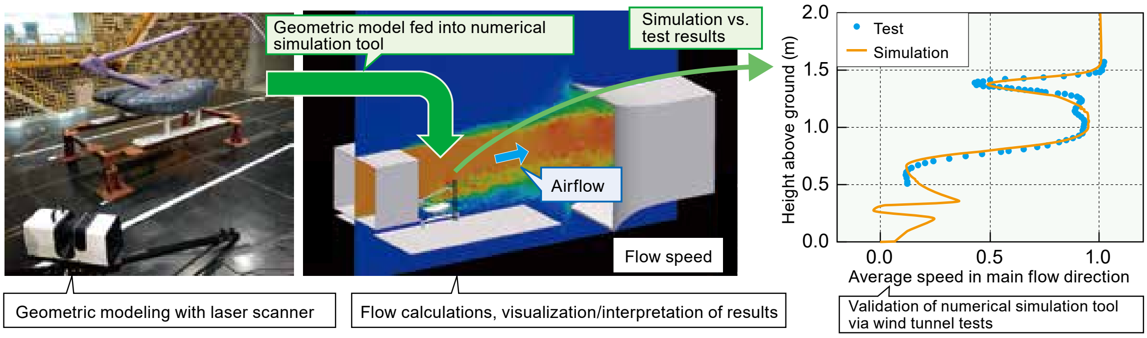


Figure 2 Integrated system from geometric definition of specimens through to computation

31. Snowplowing simulator coupled with vehicle dynamics simulator

- We developed a snowplowing simulator that calculates the force acting on a snowplow during self-snowplowing running operations, and verified reproducibility in tests on a 1/10 scale model vehicle.
- When coupled with vehicle dynamics simulator, our simulator can be used to evaluate vehicle running safety during self-snowplowing running operations.

Speed controls are sometimes imposed on Shinkansen (bullet train) services at high snow depths on the tracks, based on snowplowing tests performed on actual vehicle. Actual vehicle tests are costly and time-consuming, and are also hampered by availability constraints. We have developed a snowplowing simulator as an analytical tool to supplement actual vehicle tests. The simulator is a modified version of the particle simulator currently under development at the Railway Technical Research Institute (RTRI).

The snowplowing simulator was developed in parallel with a series of snowplowing tests performed on a scale model vehicle. The tests were conducted at the RTRI snow testing station in Shiozawa. A 1/10 scale model vehicle fitted with a snowplow was mounted on a truck and driven along a 60-m guide rail track into a snow bed (see Figure 1). The snowplowing simulator successfully modeled the properties of snow and demonstrated resistance to deformation up to the point where fluidity begins to occur. Figure 2 shows the force acting on the snowplow when it hits the snow bed, as observed in the 1/10 scale model tests and as predicted by the simulator. It can be seen that the simulator accurately reproduces the Shiozawa test results (see Figure 3). We also developed a coupling methodology that inputs the snowplowing force estimated by the simulator into the vehicle dynamics simulator in order to derive the car attitude and movement amount (see Figure 4). The coupling methodology is useful in several scenarios: preliminary analysis of snowplowing conditions for tests on actual vehicle; assessing the safety of self-snowplowing running; and in new snowplow designs.

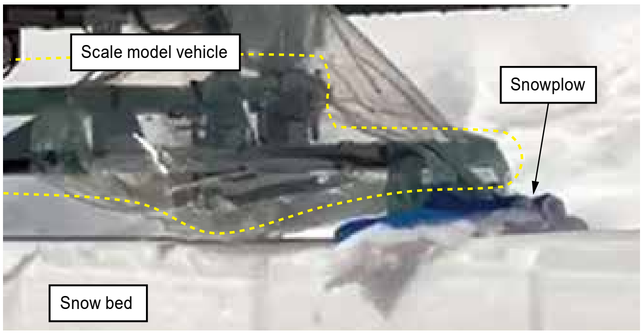


Figure 1 Testing at Shiozawa

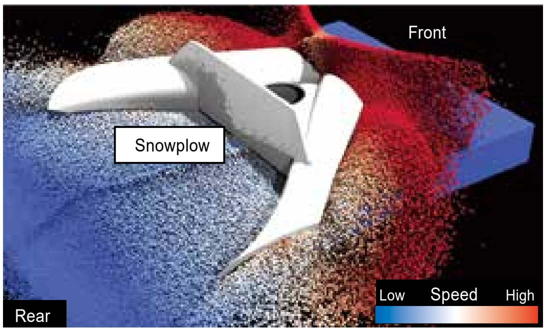


Figure 2 Simulator graphic

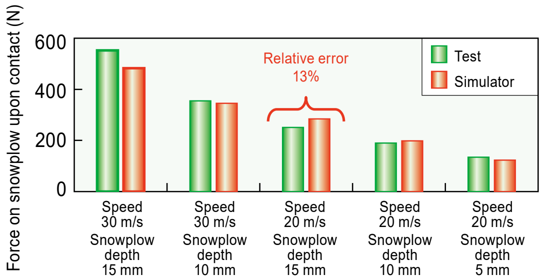


Figure 3 Force acting on snowplow - simulator vs. test results

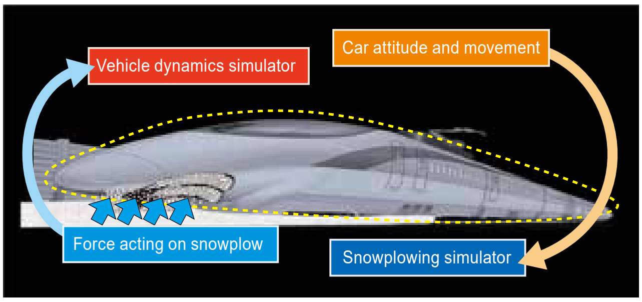


Figure 4 Snowplowing simulator coupled with vehicle dynamics simulator

Notes

IMPROVEMENT OF SAFETY

- 1 was undertaken in conjunction with the Honshu-Shikoku Bridge Expressway Company Limited.
- 4 was funded in part by a rail technology development grant from the Ministry of Land, Infrastructure, Transport and Tourism.
- 5 was undertaken in conjunction with Toshiba Energy Systems & Solutions Corporation.
- 8 was undertaken in conjunction with Japan Steel Works (JSW).

COST REDUCTION

- 12 was undertaken in conjunction with Nippon Densetsu Kogyo.
- 13 was undertaken in conjunction with National University Corporation Shizuoka University and Meidensha Corporation (Meiden).

HARMONIZATION WITH THE ENVIRONMENT

- 25 was undertaken in conjunction with Nippon Steel Metal Products.

News Release

R&D

M / D / Y	Title	
Jul 11, 2022	RTRI Develops Ballast Inspection System Using transmitted Sounds	link
Sep 09,2022	RTRI Develops a New Method to Prevent Fouled Ballasted Track from Subsiding	link
Sep 16,2022	Japan-Led International Standards for Driving Simulator Issued by ISO	link
Oct 25, 2022	RTRI Develops Slope Soil Testing Machine	link
Nov 30, 2022	Japan-Led International Standard on AC Power Compensator Issued	link
Dec 07, 2022	RTRI Develops Acid-Resistant Geopolymer Mortar Emitting Less Carbon Dioxide	link
Dec 14, 2022	RTRI and Nippon Densetsu Kogyo Develop a Device to Measure Wear of Overhead Conductor Rails Using a Light-Sectioning Method	link
Dec 22, 2022	Japan-Led International Standard on Train Running Time Calculation Issued	link
Mar 10, 2023	RTRI Develops a Program to Predict Frost Formation on the Contact Wire	link
Mar 16, 2023	RTRI Develops a Device to Prevent Bridge Collapse	link

Award

M / D / Y	Title	
May 25, 2022	RTRI’s Researcher Receives Young Scientist Award	link
Oct 28, 2022	RTRI’s Researchers Commended for Their Contribution to Developing Industrial Standards and for Achievement in IEC/TC9 Activities	link

Event

M / D / Y	Title	
Jun 21, 2022	WCRR 2022 Held in Birmingham	link
Dec 23, 2022	The 10th SNCF-RTRI Collaborative Research Seminar Takes Place	link

Data

Quarterly Report (QR)

QR is an electronic quarterly journal published in English to present RTRI's research and development achievements to overseas readers.

Vol. / No.	M / Y
Vol.63 / No.2	May / 2022
Vol.63 / No.3	Aug / 2022
Vol.63 / No.4	Nov / 2022
Vol.64 / No.1	Feb / 2023

World Railway Technology (WRT)

WRT is an electronic quarterly magazine that timely provides the latest railway technical information from overseas.
NOTE: WRT ceased publication with the issue of January 2023 (No. 1 issue of Vol. 14).

Vol. / No.	M / Y
Vol.13 / No.2	Apr / 2022
Vol.13 / No.3	Jul / 2022
Vol.13 / No.4	Oct / 2022
Vol.14 / No.1	Jan / 2023

Ascent

Ascent, an English-language electronic public relations journal published at twice a year, introduces RTRI's research and development efforts to overseas readers.

No.	M / Y	special feature
No.11	Oct / 2022	Research and Development at RTRI toward the Achievement of Net-Zero by 2050
No.12	Mar / 2023	Technology to Enhance the Safety of Railway Structures During Earthquakes

Collaboration with Other Organizations

Collaboration is in progress with the following railway operators, research institutes, universities, and other organizations for joint research, commission research, technical collaboration, and the like.

Organisation Name
University of Birmingham
Rail Safety and Standards Board (RSSB)
International Union of Railways (UIC)
Gustave Eiffel University (UGE)
French National Railways (SNCF)
Polytechnic University of Milan
German Aerospace Center (DLR)
DB Systemtechnik (DBST)
High Speed Railways Innovation Centre (HSRIC)
China Academy of Railway Sciences (CARS)
Korea Railroad Research Institute (KRRI)
Taiwan Railways Administration (TRA)
National Science and Technology Development Agency (NSTDA)

International Affairs, Research and Development Promotion Division,
Railway Technical Research Institute
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