Toward Railway Innovation

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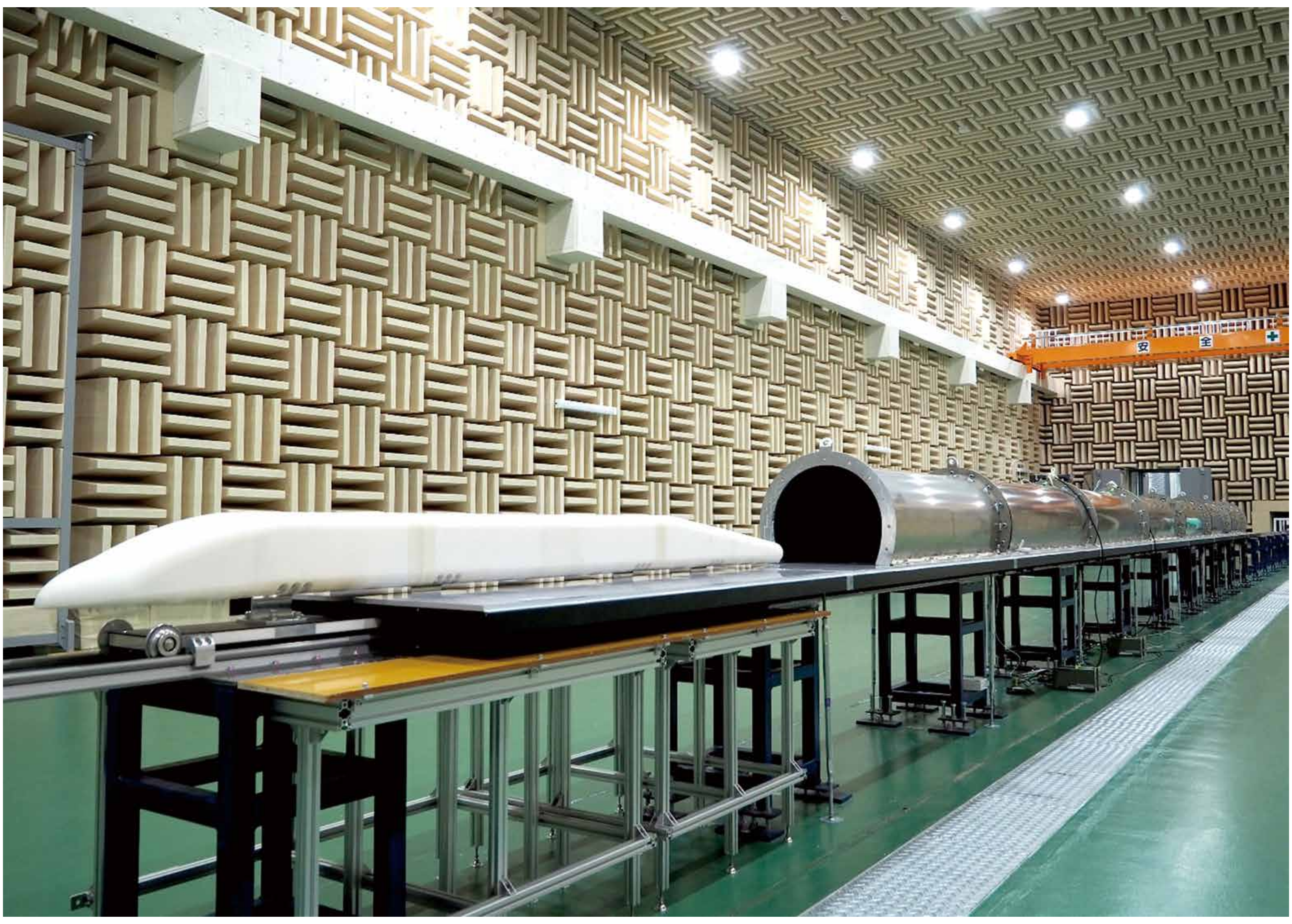
The 60th Anniversary of the Shinkansen



Message from Managing Editor

In October 2024, the Shinkansen celebrated its 60th anniversary. To mark this occasion, this issue presents two articles focusing particularly on recent technological challenges in the Shinkansen. We hope these articles will help you appreciate how the Shinkansen has continuously evolved in response to societal and environmental changes, as well as technological advancements. Additionally, they highlight the significant technical contributions of RTRI with its unique and exceptional facilities and numerical simulation techniques.

(Photo: in front of the 951 Series Shinkansen test train, manufactured in 1969, which achieved a speed of 286 km/h in a running test in 1972, setting the world railway speed record at that time.)

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Front cover photo: Low-Noise Moving Model Test Facility

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Special Roundtable to Commemorate the 60th Anniversary of the Shinkansen's Inauguration

NOTE: This roundtable was held on June 27, 2024. The affiliations and positions of the participants, as well as the information mentioned in the text, are as of that date.

Introduction

Moderator: In 2014, the Railway Technical Research Institute (RTRI) published a feature article in our magazine, RRR, highlighting the technological advancements of the past 50 years since the Shinkansen's inauguration. Today, as we commemorate the 60th anniversary of the Shinkansen in 2024, I invite you to reflect on its progress over the last decade and share your perspectives on its future development.

Hokuriku Shinkansen's Kanazawa–Tsuruga Section Opened

Moderator: It has been three months since the Kanazawa–Tsuruga section of the Hokuriku Shinkansen commenced operations. How are the ridership trends developing?

Tanaka (JR West): Indeed. The Kanazawa–Tsuruga section opened on March 16, 2024. During the first month, we recorded 723,000 passengers traveling between Kanazawa and Fukui, representing a 126% increase compared to the same period last year, with an average of 23,000 passengers daily. These figures significantly surpass both the 2023 numbers and those from 2019, prior to the COVID-19 pandemic. During Golden Week, the peak travel

Departure Ceremony at Tsuruga Station

Norikazu TANAKA
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period in spring, we observed a 114% increase in passengers between Joetsu-Myoko and Itoigawa stations on the Hokuriku Shinkansen line compared to last year. Despite the ongoing impact of the 2024 Noto Peninsula Earthquake in January, the opening of this new section is positively contributing to the recovery and revitalization of the Hokuriku region.

Moderator: That is indeed encouraging news. Could you elaborate on the technical challenges and operational hurdles you faced prior to the opening?

Tanaka: A significant challenge was operating high-speed trains in heavy snow, particularly the unique moisture-rich snow prevalent in the Hokuriku region while ensuring safe and stable transportation. To prevent snow accretion on vehicles, we designed the lateral ends of the bogie end cover plates with a snow cornice dummy structure. Furthermore, to mitigate ground damage from falling snow, we modified the wiring routes of the bonded conductors. These improvements were made in collaboration with the Japan Railway Construction, Transport and Technology Agency (JRTT) to address issues encountered after the opening of the new section.

Moderator: Mr. Santo, can you detail any new technologies JRTT implemented during the construction of the Shinkansen infrastructure?

Santo (JRTT): We employed advanced civil engineering techniques to implement battered pile foundation viaducts with outwardly angled steel pipe piles. This configuration enhances seismic resistance in soft ground conditions and imparts vibration-damping properties to the tracks. During the development phase, we received substantial technical assistance from RTRI. We also adopted, for the first time, full precast viaducts, for

Fully Precast Viaduct

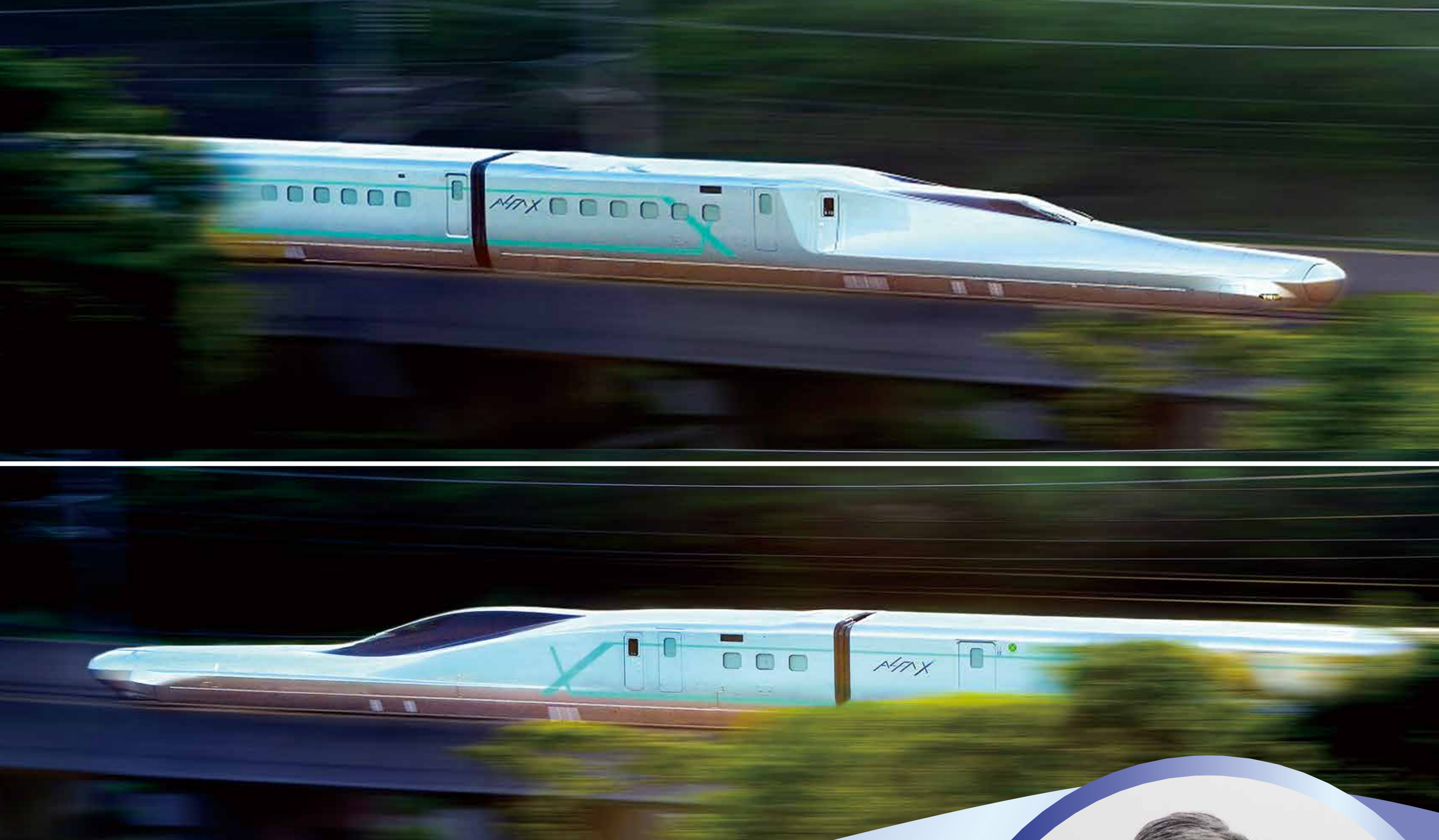
Tetsuo SANTO
Senior Director,
Design Department, Railway Technical Center, Japan Railway Construction, Transport and Technology Agency (JRTT)

which components such as piers, beams, and slabs are manufactured in factories and assembled on-site. This approach shortened construction time and reduced labor requirements. I believe we have made significant pioneering efforts to enhance productivity in railway construction processes. Regarding electrical equipment, we implemented slip joint poles with varying diameters and thicknesses. The diameter of the upper ends of the thicker lower poles was reduced, whereas that of the lower ends of the thinner upper poles was increased, allowing the poles to be coupled together. By reducing the weight of the upper poles, we successfully created overhead catenary line (OCL) poles with enhanced earthquake resistance.

New Technologies Developed in the Last Decade

Moderator: JR East is actively pursuing technological development to increase Shinkansen speeds, including the development of the ALFA-X (Advanced Labs for Frontline Activity in rail eXperimentation) test train. Can you briefly discuss the current development status?

Tsukioka (JR East): With the ultimate goal of developing the next-generation Shinkansen for the future extension to Sapporo, we have implemented the E956 series ALFA-X test train. Our focus beyond high speed includes implementing countermeasures against earthquakes, extreme cold, and snow damage. The test train was manufactured based on four key concepts: enhanced safety and stability, improved ride comfort, advanced environmental performance, and innovative and efficient maintenance processes. Currently, we are conducting research and development involving running tests and evaluating their results. ALFA-X test runs began in May 2019. We designated May 2019 to March 2022 as Phase I of running tests to assess the basic functions of the vehicles, focusing on speed



E956 Series Shinkansen Test Train ALFA-X

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Director,
Advanced Railway System Development Center, Research and Development Center of JR East Group, East Japan Railway Company

improvement, environmental impact, braking performance, and ride comfort, primarily on the Tohoku Shinkansen line between Sendai and Shin-Aomori stations. Since April 2022, we have entered Phase Ⅱ of running tests to verify durability performance and next-generation services.

Moderator: Can you provide examples of the items developed during these tests?

Tsukioka: To improve the safety and stability of the Shinkansen, we have developed several equipment and systems, including the aerodynamic drag plate unit and linear decelerators for rapid stopping after an earthquake, anti-seismic dampers to reduce derailment risk, and a bogie sensing system for continuous monitoring of bogie conditions. To enhance ride comfort, we have developed anti-vibration devices and a vertical vibration suppression system. To improve environmental performance, we have implemented two nose shapes and low-noise pantographs to mitigate tunnel micro-pressure waves and noise. Currently, we are working on technologies that utilize data obtained from continuous monitoring of vehicle equipment and ground facilities for maintenance purposes, as well as basic railway technologies for future automatic train operations. Additionally, we are collaborating with RTRI on several projects, including the development of the aerodynamic drag plate unit, linear decelerators, measures to prevent snow accretion using running wind, and the vertical vibration suppression system.

Moderator: JR Central's N700S series incorporates various innovative technologies. Can you discuss some of them in detail?

Morikawa (JR Central): Launched in July 2020 as the first fully remodeled version since the N700 Series, the N700S features significant safety and stability improvements, including reduced braking distances in the event of earthquakes and enhanced condition monitoring through high-capacity data communications. Moreover, the N700S has achieved a 7% reduction in power consumption compared to the N700A Type by employing SiC device to the drive system— the world's first for high-speed rail— to miniaturize underfloor component as much as possible and by implementing the Dual Supreme Wing design that reduces running resistance. Furthermore, we have achieved a standardized rolling stock design, which, based on the 16-car configuration design, allows for constitution to 12-car or 8-car formations. This was made possible by mounting the main transformer and power converter, previously installed on separate cars, on the same car. Additionally, we have enhanced ride comfort by using a fully active damping control system.

Moderator: From the discussion thus far, it is evident that various technologies have been introduced to reduce weight, conserve energy, and improve ride comfort. I understand that JR Central has also implemented a battery-powered self-propulsion system.

Morikawa: Indeed. We have pioneered a battery-powered self-propulsion system in high-speed rail, enabling trains to run itself during power outages. This allows trains to travel to a location where passengers can safely evacuate, even if they stop inside tunnels or on bridges. For the N700S series Shinkansen trains scheduled for launch from fiscal 2026 onwards, a new feature will be added to enable air conditioning systems to operate with onboard batteries, which will significantly enhance the internal environment during power outages.

Moderator: What kind of technological developments has JR West been working on?

Tanaka: Since the December 2017 incident, which was classified as a serious incident by the Japan Transport Safety Board (JTSB), we have been developing systems for the early detection of bogie abnormalities. Specifically, for the Sanyo Shinkansen's 500, 700, and 8-car N700 series, we have been developing methods to detect early signs of bogie bearing abnormalities. For the Hokuriku Shinkansen's W7 series, we have been developing methods to detect early signs of abnormalities in bogie frames and gear devices. Regarding car bodies and electrical equipment, we are advancing initiatives to collect and analyze vehicle data transmitted wirelessly from running trains to monitor vehicle conditions from the ground. We are also implementing condition-based maintenance (CBM) strategies, including failure prediction by analyzing data related to pre-failure condition trends, enabling early-stage repairs; predictive detection, which compares operational status data for multiple components, such as side sliding doors and air conditioning units, to preemptively perform the necessary repairs; and alternative inspection techniques that utilize the most recent operational data instead of conducting on-site inspections.

Moderator: JR West has been actively utilizing artificial intelligence (AI), hasn't it?

Tanaka: That's correct. For instance, we have implemented wear-detection techniques for detecting arc erosion of pantographs caused by frost accretion on OCLs in winter. We also utilize AI to analyze images of pantograph heads captured while trains are stopped at stations and determine their condition (normal or abnormal). Machine-learning data are increasing year on year, thereby enhancing detection accuracy.

Moderator: Some of the technological developments introduced thus far were achieved in collaboration with RTRI. Can you detail any technologies that RTRI has jointly developed with other companies besides those already mentioned today?

Murono (RTRI): I would like to introduce the precipitation-hardened copper (PHC) simple catenary system. While the three-wire heavy compound catenary system has been used on conventional Shinkansen lines (Tokaido-Sanyo, Tohoku, and Joetsu), we have applied a new material—a PHC alloy—to develop a simpler, two-wire catenary system. This PHC simple catenary system, jointly developed by JRTT, JR East, and RTRI, combines high strength and conductivity to accommodate high-speed Shinkansen operations. By reducing the number of wires from three to two, maintenance is simplified. This system is being gradually adopted across the Shinkansen network.

Moderator: Please discuss the new technologies developed by JRTT over the past decade.

Santo: For the operations of the Nishi-Kyushu Shinkansen line and subsequent projects, JRTT has developed and implemented two key technologies. In civil engineering, we have introduced geosynthetic-reinforced soil (GRS) integrated bridges with a prestressed concrete (PC) structure, and in track engineering, we have implemented sleepers integrated slab track with under sleeper pads (USPs). We have also

N700S Shinkansen

Masashi MORIKAWA
General Manager,
Technology Research and Development Department, General Technology Division,
Central Japan Railway Company

actively engaged in the digitalization of track construction work. This includes storing measurement data in on-site radio frequency identification (RFID) tags, allowing data retrieval through smartphones. Additionally, we have employed alignment sensors to adjust track slab installation alignment, replacing traditional track levelers. The tags embedded in the slabs have enabled the recording of the installation location of each slab. All data obtained are consolidated into the construction information management system. Additionally, we have developed a train schedule management system and an integrated work management system to improve the on-site management efficiency of construction machinery and work crews.

Moderator: I understand that significant time and ingenuity have been invested in these advancements. RTRI's competitive edge lies in its simulation and measurement technologies. Can you explain any new approaches adopted in these technical fields over the past decade?

Murono: Mr. Tanaka of JR West mentioned their countermeasures for cold regions. RTRI has also developed a method for estimating snow accretion and snow dropping from train vehicles. This method can estimate, in real-time, the amount of accumulated snow and the location where it drops off based on train operation data and weather conditions along the line. This information can be used to determine whether snow removal work is necessary on arrival at the station or identify priority sections requiring countermeasures. To provide an example of our R&D efforts related to noise-reduction measures, as mentioned by Mr. Tsukioka of JR East, we have independently developed a portable two-dimensional spiral array system with a microphone array. By applying the latest acoustic processing technologies to the recorded data, we have enabled high-resolution identification of moving sound sources. This array system has sufficient spatial resolution to visualize the distribution of sound sources approximately the size of a wheel, allowing examination and demonstration of the effectiveness of noise-reduction measures for sound sources such as bogies and pantographs.

Countermeasures Against Natural Disasters

Moderator: Reflecting on the past decade, we have experienced major natural disasters, with the impression that numerous massive earthquakes have occurred. The 2024 Noto Peninsula Earthquake on New Year's Day is still fresh in our memory. Have you made significant progress in earthquake-related technologies?

Murono: Over the past decade, Japan has experienced over ten earthquakes with an intensity of 6 or higher on the Japanese scale of 0 to 7. It is believed that the Japanese archipelago has entered a period of increased seismic activity, raising concerns about the potential for major earthquakes in the future. In response, RTRI has been researching and developing countermeasures aligned with four phases of resilience against large-scale earthquakes: prior response, emergency response, initial response, and recovery response.

Moderator: First, please describe your prior and emergency response strategies.

Murono: Prior response refers to anti-seismic measures taken before an earthquake occurs. We have revised the technical standards for the anti-seismic design of structures, significantly enhancing seismic resistance. Newly constructed Shinkansen structures are designed to satisfy safety and restorability criteria for earthquakes with an intensity of seven on the Japanese scale. The Shinkansen's earthquake resistance has been dramatically improved. We have also developed anti-seismic lateral dampers to prevent derailments. This new damper system exerts a high attenuation force to suppress car body vibrations during earthquakes, minimizing the chances of derailment. As an emergency response measure, RTRI has improved the immediacy of alarms and warning accuracy of our early earthquake warning system, which detects earthquakes and promptly stops trains. We have modified our P-wave processing methods and reviewed our noise identification techniques. Furthermore, in collaboration with the National Research Institute for Earth Science and Disaster Resilience (NIED) and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), we have developed an earthquake warning system utilizing an ocean-bottom seismic observation network and implemented it in cooperation with other JR companies.

Moderator: JR companies have also been actively working on prior and emergency responses for quite some time, haven't they?

Morikawa: JR Central has been improving the Tokaido Shinkansen through (1) anti-seismic reinforcement of structures, including steel plate wrapping on viaduct piers, sheet pile cofferdams for embankments, and ground reinforcing methods for embankments; (2) earthquake disaster prevention systems based on our seismometers, Earthquake Early Warnings (EEW) distributed by the Japan Meteorological Agency (JMA), and the ocean-bottom earthquake observation network of NIED; and brake performance improvement for promptly stopping trains and (3) measures to prevent vehicle derailment and deviation.

Tanaka: JR West has been similarly engaged in implementing anti-seismic measures, including the reinforcement of viaducts and poles for OCLs, early earthquake detection methods, and deviation prevention measures.

Moderator: Next, can you elaborate on developments regarding initial and recovery responses?

Murono: As an initial response measure, RTRI has developed the Damage Information System for Earthquake on Railway (DISER), which has been operational since 2019 and utilized by several railway operators. This system predicts ground motion intensity along railway lines and potential structural damage within minutes after an earthquake, disseminating this information to railway operators. By narrowing down the area requiring inspection, it reduces downtime until operations resume. Additionally, for recovery response, we have developed technologies that enable rapid service restoration. These include proposals of design methods that concentrate bearing damage on easily repairable locations and the development of embankment restoration techniques utilizing gabions, which do not require emergency repairs.

Moderator: In the 2022 Fukushima Prefecture Offshore Earthquake, a Tohoku Shinkansen train derailed, and JTSB released their findings regarding the cause. Can you share insights gained from this earthquake and discuss potential countermeasures?

Tsukioka: I believe that numerous vehicle guide devices functioned and prevented vehicles from significantly deviating

Damage Information System for Earthquake on Railway (DISER)

Yoshitaka MURONO
General Director,
Research and Development
Promotion Division, Railway Technical
Research Institute (RTRI)

from the track, which ultimately helped mitigate the severity of the impact. However, some wheelsets deviated because vehicle guide devices did not function as expected. Because derailment and deviation during operation can cause extensive damage, we have improved the shape of the interface of wheelsets equipped with fitting arms to enhance rail contact. This development is complete, and we are gradually implementing these improvements on commercial vehicles. Regarding the anti-seismic lateral dampers Mr. Murono of RTRI mentioned, we are continuing development for their future implementation. In the 2022 derailment incident, some air springs experienced excessive deformation, leading to air loss, which may have contributed to the derailment. Therefore, it is necessary to thoroughly investigate the impact of air springs on derailment and deviation scenarios.

Key Technological Advancements Required for Shinkansen Over the Next Decade

Hokkaido Shinkansen's Extension to Sapporo

Moderator: To conclude, let's discuss the key technological advancements required for the Shinkansen over the next decade. The extension of the Hokkaido Shinkansen to Sapporo will be a major event during this period. First, how are the technical preparations for this extension progressing?

Tsukioka: To ensure the success of the Hokkaido Shinkansen's extension to Sapporo, we must develop technologies enabling safe and stable operations in the extreme low-temperature and heavy snowfall conditions that existing Shinkansen lines have not encountered. Since the initial ALFA-X test run, we have conducted trials on the Hokkaido Shinkansen section every winter in cooperation with JR Hokkaido Railway Company, to evaluate performance under these conditions. As previously mentioned, we are continuously verifying the snow accretion reduction effects of heater-installed bogie end cover plates for suppressing snow accumulation in the bogie cavity and of the bogie covers designed for controlling snow accumulation using intakes that channel airflow into the cover. Additionally, we are verifying adhesion performance under low-temperature and wet conditions and developing activators to enhance adhesion.

Moderator: From your perspective as a construction expert, lowering construction costs is likely a significant challenge. How do you plan to address this?

Santo: Although not directly related to the Sapporo extension, I would like to share some of our company's findings. Last year, we established the Construction digital transformation (DX) Vision. Given the decreasing and aging workforce of skilled technicians and engineers, I believe that (1) mechanization and precast implementation of on-site construction work, and (2) streamlining construction planning and management through digital technologies will improve labor productivity and reduce costs. For example, in viaduct construction, we aim to standardize the on-site assembly of PC components manufactured in advance at factories. We are considering optimizing the entire design and construction management process by using AI to analyze big data related to quality control, work progress management, heavy machinery, and transport vehicles. We also plan to collaborate with RTRI on building information modeling (BIM)/ construction information modeling (CIM), with the intention of applying these processes from design analysis through to maintenance management.

Digital and AI Technologies

Moderator: Mr. Santo just mentioned that digital technologies will improve labor productivity and reduce costs. I have heard that JR West actively utilizes digital technologies, especially AI. Please discuss some of JR West's latest applications of digital and AI technologies for the Shinkansen.

Tanaka: Regarding the utilization of AI technologies to save labor, in addition to the aforementioned AI-based image recognition system, we have developed and implemented a model for estimating snow accretion amounts on train vehicles. This model uses AI to determine the necessity of removing snow accumulated under the vehicles while trains are stopped at stations along the Hokuriku Shinkansen line. Currently, we are collecting data to construct a prediction model for the newly extended section to Tsuruga. Furthermore, we are working on improving operational efficiency by capturing images from the driver's cab and analyzing them at the depot in collaboration with train crews, thereby reducing the need for train and foot patrols. This is another example of our applica-tion of digital technologies. We are also advancing the automation capabilities of our working vehicles, such as those for maintenance or snow removal, and exploring the use of drones for inspecting infrastructure such as viaducts, retaining walls, and bridges.

Moderator: Each company seems to be promoting the use of AI in various ways. I would like companies other than JR West to share their experiences regarding challenges encountered in implementing AI technologies.

Murono: Efforts are underway to automate tasks previously performed through visual inspection by using camera images enhanced with AI. However, AI is not infallible. When the AI system makes judgment errors, we must investigate the causes and address the inherent limitations of AI techniques. Moreover, without understanding the basis for AI judgments, it is impossible to determine the appropriate corrective measures. To address this, RTRI has developed a method for estimating the factors contributing to missed detections by AI in front-monitoring systems designed to detect obstacles in front of trains. This technique analyzes the root causes of false negatives in AI-powered obstacle-detection systems for railway applications. In our evaluations, we successfully identified the factors behind all overlooked instances. This technique can also be applied for performance verification during AI development and other similar purposes.

Automatic Train Operations

Moderator: In the wake of the COVID-19 pandemic and thereafter, developing labor-saving and unmanned systems for train operations and maintenance has become an urgent issue. One highly anticipated example is automatic train operation. What is the prospect of implementing such a system on the Shinkansen?

Morikawa: JR Central is working toward introducing Grade of Automation 2 (GOA2), an automatic operation system, for commercial operation on the Tokaido Shinkansen, which is characterized by long inter-station distances and a highly dense and complex timetable owing to its numerous train services. Therefore, it requires train operations that ensure safety, punctuality, and passenger comfort while responding to factors such as speed restrictions, gradients, weather-related slowdowns, and emergency speed reductions for safety checks, all within this complex timetable structure. To achieve this, we have developed a highly functional Shinkansen automatic operation system that calculates train performance curves in real-time during operation, enabling efficient driving for energy conservation and enhanced ride comfort. Currently, we are conducting running tests of this system on the main line, aiming to gradually commence operations from around 2028.

Carbon Neutrality

Moderator: Next, please provide an overview of the carbon-neutrality initiatives undertaken by each company.

Tanaka: As part of our commitment to achieving carbon neutrality and realizing a decarbonized society, we have set the objective of net-zero CO_2 emissions for the entire group by 2050 as our long-term environmental goal. To achieve this, we are promoting the introduction of renewable energy sources for electricity procurement. By introducing electricity derived from renewable sources, such as solar power generation facilities, we expect that approximately 13% of the traction power for our entire Shinkansen network (1.43 billion kWh annually) will be from renewable sources by the end of fiscal 2027.

Tsukioka: As the demand for reducing environmental impacts continues to grow, particularly in pursuit of achieving the Sustainable Development Goals (SDGs), technologies aimed at CO_2 emission reduction are indispensable. These include reducing the weight of car bodies, enhancing energy efficiency, and minimizing running resistance. Additionally, it is crucial to develop environmentally conscious technologies, including expanding the adoption of recycled materials with lifecycle awareness and reducing the use of materials that contribute to global warming.

Moderator: Speaking of recycling, JR Central is advancing development focused on vehicle recycling. Can you tell us about your company's initiatives in this area?

Morikawa: For vehicle manufacturing, we have established a process for sorting aluminum components from decommissioned vehicles and ensuring the reliability and quality of recycled aluminum as a car body material. This has enabled us, for the first time in Shinkansen history, to utilize recycled aluminum for Shinkansen car bodies, which require high strength. Moreover, for the N700S series scheduled for introduction from the fiscal 2026 onward, we intend to increase the application areas of recycled aluminum to approximately 1.6 times that of conventional Shinkansen trains, further reducing CO_2 emissions in the aluminum process for car bodies. We will continue to reduce the environmental impact of the Shinkansen by promoting technologies that contribute to CO_2 emission reduction, such as energy conservation measures.

Integrated Approaches to Common Challenges

Moderator: We have all shared specific initiatives of each company, and there appear to be many common challenges. How do you perceive these trends and how will RTRI consolidate these findings for future research and development?

Murono: While many technical challenges are common across companies, we believe it is crucial to advance technological innovation through collaborating beyond organizational frameworks and by standardizing and sharing technologies. This approach can reduce development costs and time, and equipment standardization will ensure a smooth supply from manufacturers. With this in mind, RTRI is developing rules and platforms to share technical information and data, such as images of track infrastructure and wayside equipment. Currently, each railway operator collects data and conducts development individually, which limits collection conditions and the volume of image data and requires considerable time and effort. I believe it would be beneficial to establish a foundation for railway operators to share image data, common processing technologies, and evaluation data.

Conclusions

Moderator: Today, we had the opportunity to explore each company's initiatives in developing and improving various Shinkansen technologies and anti-seismic measures over the past decade. Reflecting on today's roundtable, it is evident that all companies have consistently incorporated innovative technologies to enhance passenger comfort and promote labor-saving measures, while constantly prioritizing safety. The exchange of views on future challenges has made this a particularly fruitful discussion. I sincerely hope that we can continue to collaboratively develop the Shinkansen network, which serves as the backbone of our national infrastructure while adapting to societal changes. Thank you all for your participation today.

RTRI's Research and Development Continues to Contribute to the Evolution of Shinkansen

Dr. Atsushi FURUKAWA
Executive Director,
Railway Technical Research Institute

Introduction

The Tokaido Shinkansen marked its 60th anniversary on October 1, 2024. In FY2018, before the COVID-19 disaster, the total number of passengers across all Shinkansen lines is approximately 1.19 million per day. The Shinkansen is now an indispensable mode of transportation for business or sightseeing trips. The noteworthy success of the Tokaido Shinkansen has inspired the development and expansion of high-speed railway networks around the world. According to the International Union of Railways (UIC), as of October 1, 2023, there are high-speed railways with a maximum speed of 200 km/h or more in 21 countries and regions around the world, covering a total distance of 59,498 km[1)]. It is no exaggeration to say that the Tokaido Shinkansen has truly changed the way railways are operated around the world.

The Railway Technical Research Institute (RTRI) has been committed to the realization of the Tokaido Shinkansen and has been working to solve new technical problems since the launch of the Tokaido Shinkansen service. In a huge transport system like the Shinkansen, it is necessary to effectively integrate many key technologies, such as rolling stock technologies for safe and stable running, technologies to ensure safety even during earthquakes, and technologies to cope with noise that increases as speed rises. This article covers some of these technologies to which RTRI's large-scale test facilities and analytical capabilities have contributed since the Japanese National Railways (JNR) was divided and privatized.

Evolution of Rolling Stock —The advent of bolsterless bogies—

When the Tokaido Shinkansen started its operation, the 0-Series trains had a maximum operating speed of 210 km/h. The 100-Series trains were introduced in 1985 for the Tokaido Shinkansen, followed by the 200-Series trains with a snow-resistant structure in 1982 for the Tohoku and Joetsu Shinkansen and the fully remodeled 300-Series in 1992. The 300-Series incorporated a number of innovations developed during the final years of JNR's operations and the early years of privatization into JR companies. A noteworthy innovation were the bolsterless bogies* that were adopted for the first time in Shinkansen trains. For the development of the bogies, RTRI conducted running tests at the rolling stock test plant (*Rolling Stock Test Facility with a Vehicle for Shinkansen*) to confirm the running stability and vibration isolating performance of the bogies at high speeds. After running tests on the main line using the Central Japan Railway Company's 100-Series trains, RTRI was able to install bolsterless bogies with the 300-Series trains.

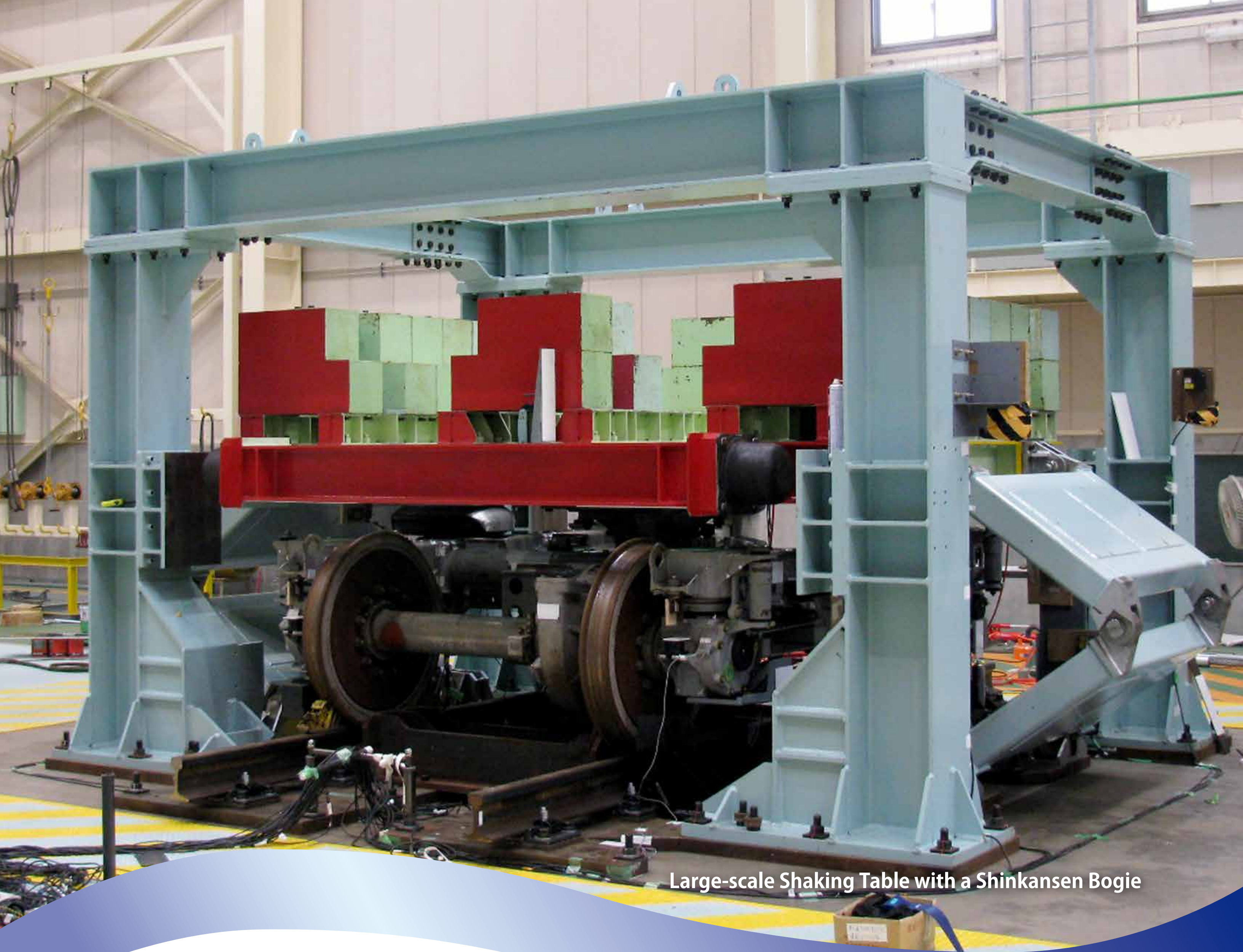
The adoption of bolsterless bogies and other technologies led to the successful weight reduction of the entire 16-car train from 970 to 710 tons for the 0-Series and contributed significantly to the realization of speeds up to 270 km/h. All Shinkansen rolling stock after the 300-Series utilized bolsterless bogies.

＊ bolsterless bogies
Bogies without bolsters, which transmit the load from the car body to the bogie frame. Without bolsters, the car body is directly supported by the air spring between the bogie frames. By eliminating the bolsters, the weight of the bogie is significantly reduced.

Rolling Stock Test Facility with a Vehicle for Shinkansen

Response to Large-Scale Earthquakes —Early earthquake warning system and derailment prevention measure for Shinkansen trains—

In Japan, where large-magnitude earthquakes frequently occur, ensuring the safety of Shinkansen trains during each earthquake is a primary concern. Since Shinkansen trains run at high speeds, they cannot stop immediately even if emergency brakes activate. In contrast, the concept of the early earthquake warning system is to decelerate the train before the secondary wave (S-wave) arrives by using the characteristics of the primary wave (P-wave), which has high velocity and low amplitude and travels through the ground first, followed by the S-wave, which is the principal wave. The Urgent Earthquake Detection and Alarm System (UrEDAS), which incorporates this concept, was introduced in the Tokaido Shinkansen in 1992. However, UrEDAS had problems in the accuracy of estimating seismic parameters (epicentral position and magnitude). After the 1995 Southern Hyogo Prefecture Earthquake, a new early earthquake warning system was introduced on the Kyushu Shinkansen, opened in 2004. This solved the problems with the estimation accuracy by analyzing the large amount of data obtained from the earthquake observation networks developed by public organizations such as the National Research Institute for Earth Science and Disaster Resilience (NIED). This new warning system has been subsequently implemented on existing Shinkansen trains. In addition, an even more upgraded early earthquake warning system, which utilizes the ocean-bottom earthquake and tsunami observation networks developed by public organizations, has been installed in JR companies' Shinkansen trains since 2017.



Large-scale Shaking Table with a Shinkansen Bogie

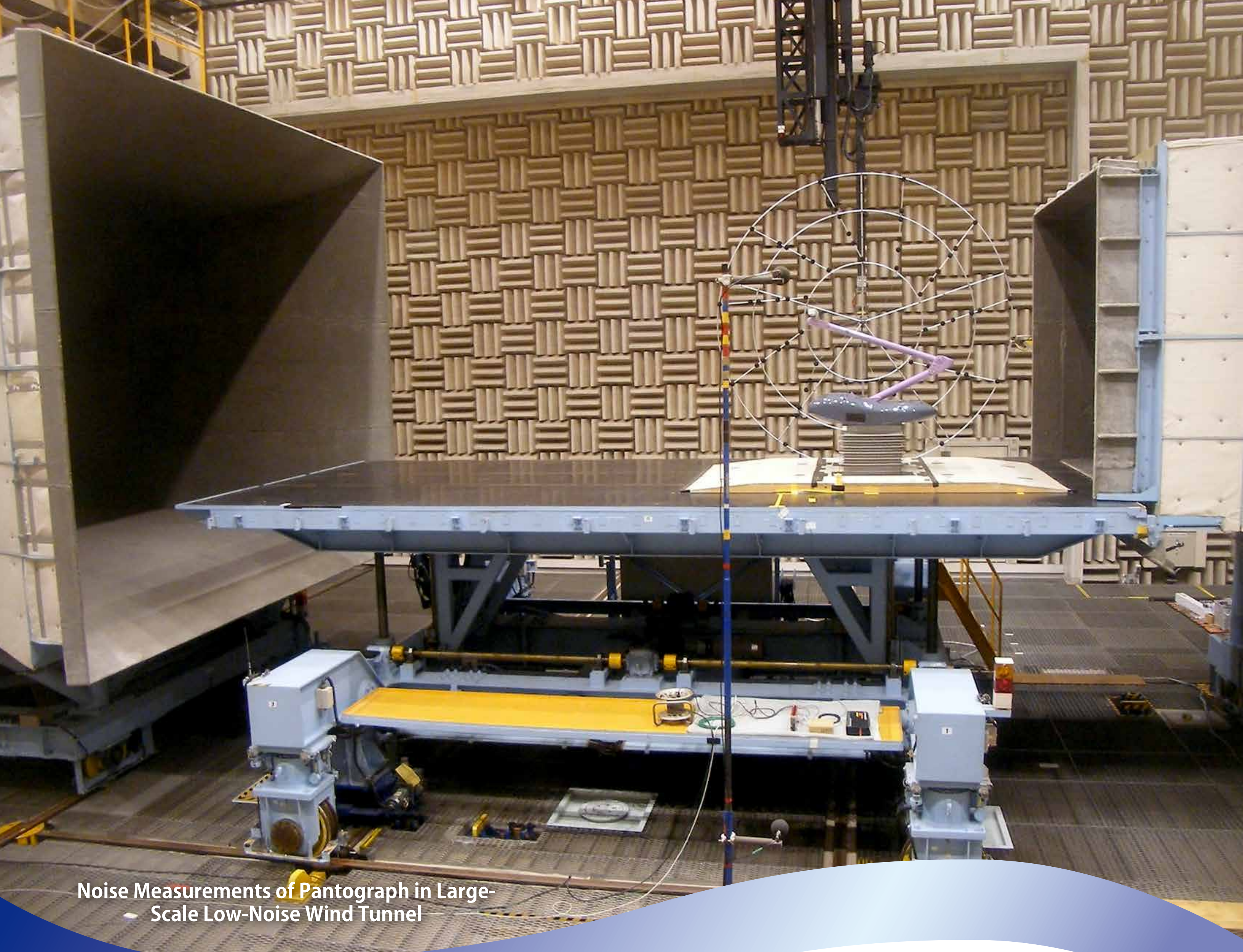
On October 23, 2004, the Mid Niigata Prefecture Earthquake occurred and the Shinkansen train Toki 325 became the first Shinkansen train running with passengers to derail. In response, RTRI, in cooperation with JR companies that operate Shinkansen trains, developed technologies to prevent the derailment or deviation of Shinkansen trains. RTRI's large-scale shaking table (*Large-scale Shaking Table with a Shinkansen Bogie*) and various simulation technologies contributed to the development of these technologies.

Harmony with Trackside Environment —Resolution of various aerodynamic issues—

When the Shinkansen started operations, it had the problem of generating more noise than conventional lines because it runs at a higher speed.

To reduce noise, it is important to know (1) where the sound is coming from (sound source identification) and (2) how much the sound will be reduced by countermeasures (noise evaluation and prediction). So, RTRI developed a technology for identifying the sound source using microphone arrays with microphones arranged in two dimensions, a large-scale low-noise wind tunnel facility (*Noise Measurements of Pantograph in Large-Scale Low-Noise Wind Tunnel*) for evaluating aerodynamic noises generated by each part of the train, and a technology for predicting trackside noises using the propagation characteristics of each sound source.

In addition, after the Sanyo Shinkansen was extended to Hakata (the terminal station in Kyusyu Island) in 1975, “micro-pressure waves” became a problem. This is



Noise Measurements of Pantograph in Large-Scale Low-Noise Wind Tunnel

a phenomenon in which a loud blast sound occurs at the exit of a tunnel when a train rushes into the tunnel. These micro-pressure waves are generated by the following mechanism: when the front of the train enters a tunnel at high speed, the air in front of the train is compressed, causing the pressure to rise, and this forms a compression wave that travels at almost the speed of sound through the tunnel, and when it reaches the exit, it is radiated externally as a pulse-shaped pressure wave. In response, RTRI proposed measures to mitigate the rate of change of pressure in the compression wave in the tunnel, specifically the installation of a tunnel entrance hood and improvements to the shape of the front of the train. As a result of these measures, the maximum operating speed was increased to 300 km/h in 1997 and to 320 km/h in 2013, and it remains at this level to the present day.

Aiming for Further Evolution

The Shinkansen is characterized not only by its high speed, but also by its superior environmental performance compared to cars and airplanes. In Europe, in particular, an ambitious plan is underway to actively utilize eco-friendly high-speed rail to realize a decarbonized society, and simultaneously, to double the number of passengers by 2030[2)]. Japan's Shinkansen trains will also evolve in the future to consume less energy than now and to reduce the environmental influence along their lines.

Anticipating further evolution of Shinkansen trains, RTRI constructed a low-noise moving model test facility (*Low-Noise Moving Model Test Facility*) that

Low-Noise Moving Model Test Facility

can reproduce micro-pressure waves by plunging a 1/20-scale model train into a model tunnel at a maximum speed of 400 km/h, and a high-speed pantograph test facility (*High-Speed Pantograph Test Facility*) that can verify the current-collection performance of an actual pantograph by rotating a disk with a trolley line attached at a maximum speed of 500 km/h. These facilities were constructed for the Shinkansen trains based on the previous master plan, RESEARCH 2020. We will contribute to the further evolution of the Shinkansen by using these new test rigs, unique test facilities and unique analytical capabilities described in this report.

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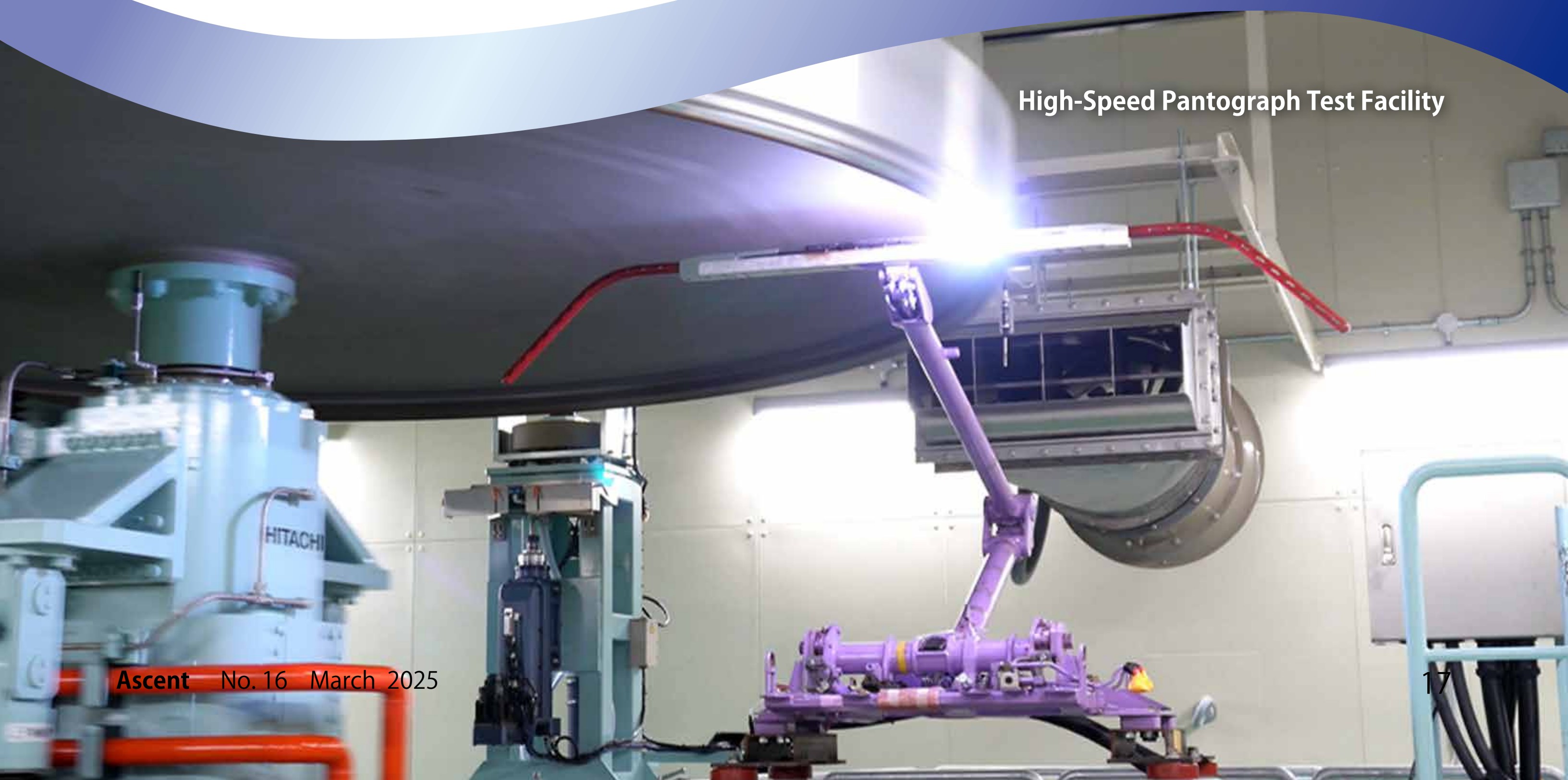

High-Speed Pantograph Test Facility

RTRI Showcases Latest R&D Achievements at InnoTrans 2024

Exterior View of Messe Berlin

The Railway Technical Research Institute (RTRI) exhibited at InnoTrans 2024, an international trade fair for transport technology, held in Berlin, Germany in September 2024 (*Exterior View of Messe Berlin*). At the exhibition, RTRI presented its ongoing research efforts and technological achievements to enhance its international presence.

RTRI participated in a joint exhibition within the JORSA (Japan Overseas Railway System Association) Pavillion, highlighting transformation of railway operations through digital technologies and introducing its latest research outcomes aimed at achieving decarbonization of railway systems (*Exhibition Booth*). The exhibition featured standing displays including technical posters and video screenings, complemented by scheduled presentations throughout the event period.

Exhibition Booth

Standing Exhibits

Video screenings and poster displays provided an overview of:

- RTRI's general R&D activities
- Development results related to digital maintenance and autonomous train operations
- Research outcomes for railway decarbonization

Presentation Session

Presentation Sessions (*Presentation Session*)

RTRI researchers delivered presentations on the following themes:

- Research on Digital Maintenance
  Title: "RTRI's Efforts Aimed at Developing Innovative Railway Maintenance and Anomaly Detection Based on Digital Technologies"
- Research on Autonomous Train Operation
  Title: "Integration of Railway Operation Systems with Digital Technologies"
- Research on Railway Decarbonization
  Title: "Development of Decarbonization Technologies for Railway Vehicles"

Additional Information

The video presentations from our exhibition are now available on RTRI's official YouTube channel: Visit RTRI's YouTube Channel.

RTRI Hosts the 11^{th} SNCF-RTRI Collaborative Research Seminar

The Railway Technical Research Institute (RTRI) invited the French National Railways (SNCF) to its headquarters and hosted the 11^{th} SNCF-RTRI Collaborative Research Seminar for three days, from November 6 to 8, 2024.

RTRI and SNCF signed an agreement on joint research in 1995. Since then, they have been working collaboratively on research covering a wide range of technical fields and exchanging information. The collaborative research seminar is held biennially to manage collaborative research projects, report on the results of the previous seminar to the present day, and formulate future plans. This was the first face-to-face seminar in six years since the 8th seminar in 2018.

Eight people from SNCF, including Mrs. Carole Desnost, Chief Technical Officer, and 40 people from RTRI, including Dr. Ikuo Watanabe, President, participated in this seminar.

At this seminar, a management meeting and presentation meetings were held on November 6 and 7, and a technical visit of RTRI facilities was held on November 8. It was agreed that RTRI and SNCF would continue to work closely together to promote collaborative research, and that the next seminar would be held in France in 2026.

Mr. Valéry Versailles (right), Director, Head of Department, Railway Physics Innovation & Research, SNCF, and Dr. Yoshitaka Murono (left), General Director, Research and Development Promotion Division, RTRI, after signing the Seminar Minutes, which recorded the agreed details

Management Meeting

(1) Management Meeting on November 6

Executives and managers from both organizations participated. RTRI introduced "R&D Against Rainfall Disasters for Railways", and SNCF introduced "Energy and Carbon-Free Railways." The two organizations shared the issues that need to be solved, for example, strengthening resilience against natural disasters, decarbonizing, and saving energy. They confirmed that they would continue to strengthen mutual co-operation to address these issues. In particular, they identified countermeasures against high winds as common issues and decided to exchange opinions in the next focus group discussions.

(2) Collaborative Research Seminar Final Reports and Technical Discussions on November 7

Researchers from both organizations engaged in lively discussions, presenting the results of three collaborative research projects and seven information exchange projects carried out between 2022 and 2024, as well as the plans for two collaborative research projects and seven information exchange projects to be carried out over the next two years from 2024.

Seminar Participants

Railway Technical Research Institute