

# Railway Dynamics Division

The Railway Dynamics Division is performing fundamental research on dynamic problems in railway vehicles, catenaries, tracks, and structures, focusing on phenomena occurring at the boundary regions between vehicles and structures/tracks, rails and wheels, and pantographs and overhead contact lines. We are developing and utilizing unique techniques, including measurement evaluation, testing, and simulation techniques, to elucidate railway degradation and safety-related dynamic phenomena and propose specific solutions to identified issues. This report introduces our latest research and development (R&D) achievements and activities.



**Dr. Fumiaki Uehan**  
Director,  
Head of Railway Dynamics Division

## Introduction

Railways comprise several components, such as vehicles, catenaries, tracks, and structures, all of which interact with each other in their boundary regions, resulting in complex and dynamic phenomena specific to railways. Understanding these railway-specific phenomena and proposing specific solutions to key issues are necessary to improve safety, mitigate railway accidents and disasters, and realize the efficient maintenance of deteriorating equipment and facilities. In the Railway Dynamics Division, five laboratories covering a wide range of fields (Vehicle Mechanics, Current Collection, Track Dynamics, Structural Mechanics, and Computational Mechanics) collaborate to develop measurement

evaluation techniques for on-track testing, testing techniques using unique test facilities, and numerical simulation techniques. The division seeks to elucidate railway-specific phenomena and propose concrete solutions that could be game changers for the maintenance and development of railways via the sophisticated integration of measurement evaluation and testing techniques executed in real space with numerical simulation techniques executed in the computer space (*Integration of measurement evaluation, testing, and simulation techniques*).

We are developing several measurement evaluation techniques to measure the dynamic behaviors of vehicles and ground equipment, as well as status evaluation techniques based on measurement data.

We are using numerical simulations to efficiently verify the validity of these techniques. Moreover, we intend to develop our measurement evaluation techniques as tools for collecting information to integrate actual railway tracks with virtual test tracks.

We are also developing unique test equipment that can reproduce railway-specific phenomena<sup>1)</sup> and improving testing procedures by integrating testing techniques with numerical simulations. Additionally, we are building a numerical laboratory, as a digital twin<sup>1)</sup> of the actual test equipment, in the computer space using simulation techniques.

Finally, we are developing new analytical techniques, as well as a railway simulator, by integrating the simulation techniques previously developed by the Railway Tech-

nical Research Institute<sup>2)</sup>. We are building virtual test tracks and digital twins of actual railway tracks in the computer space via the large-scale coupling of the physical phenomena occurring in various railway components.

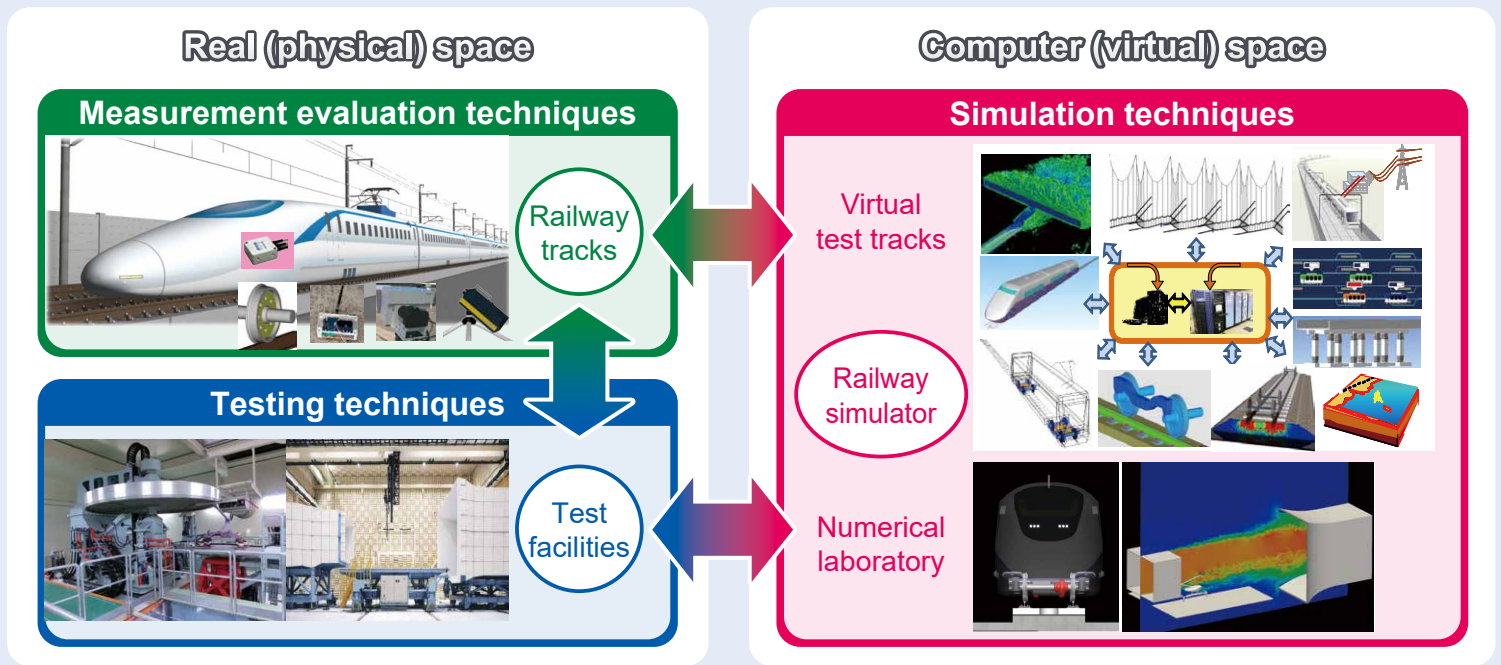
Some of the most recent research activities and achievements of the Railway Dynamics Division in the areas of measurement evaluation, testing, and simulation techniques are presented below.

**On-board evaluation of the structural soundness of railway bridges**  
**—Measurement evaluation techniques—**

First, as an example of the development of techniques to measure and evaluate dynamic phenomena occurring in vehicles and ground equipment on actual railway tracks, we built a technique for evaluat-

ing the performance of railway bridges by means of on-board measurement. Numerical simulations play an important role in the development of measurement evaluation techniques by verifying the hypotheses of measurement evaluation theories and the appropriateness of measurement results, the details of which are omitted here.

The vibrations and girder deflections of a train passing over a railway bridge are



Elucidation of railway degradation and safety-related railway-specific phenomena and proposal of specific solutions by developing and integrating measurement evaluation, testing, and simulation techniques

**Integration of measurement evaluation, testing, and simulation techniques**

typical evaluation indicators of train ride comfort and the structural soundness of railway bridges. The measurement of vibrations and girder deflections is performed at the ground level, one bridge at a time; therefore, this endeavor requires a great deal of labor and time. As an alternative to ground-based measurements, we are developing a technique for inspecting railway bridges using train vibrations and track irregularities measured by sensors mounted on trains passing over bridges.

### On-board detection of resonant bridges —Measurement evaluation techniques—

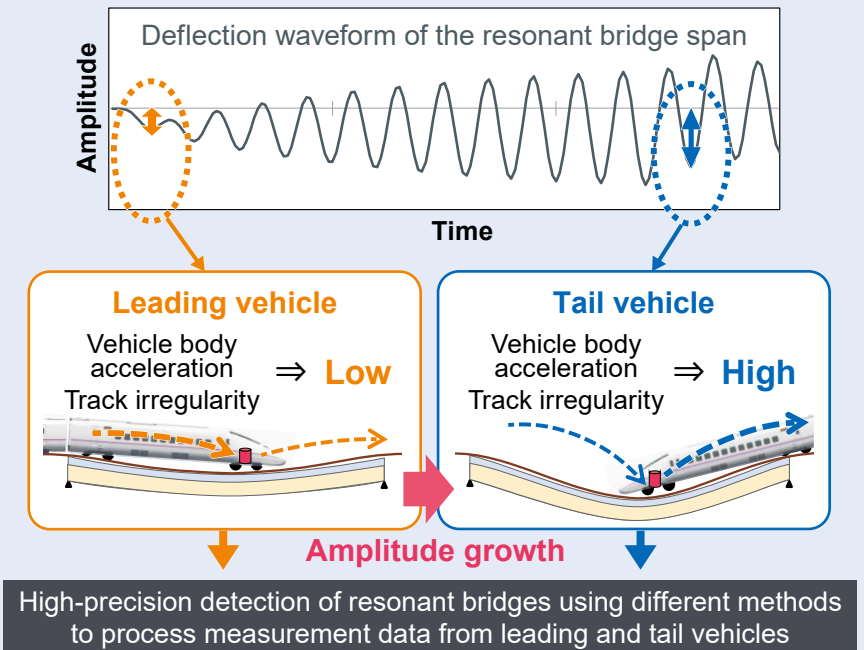
We have designed on-board measurement evaluation techniques for resonant bridges. The resonance phenomenon of railway bridges<sup>\*2</sup> is known to cause large vibrations when a train passes over a bridge<sup>3)</sup>. The developed techniques utilize sensors mounted on the leading and tail vehicles, and can detect increases in bridge vibrations when the tail vehicle passes over a railway bridge compared with that observed when the leading vehicle passes

#### \*1 Digital twin

A model that uses digital techniques to accurately reproduce a virtual space that exists in real space.

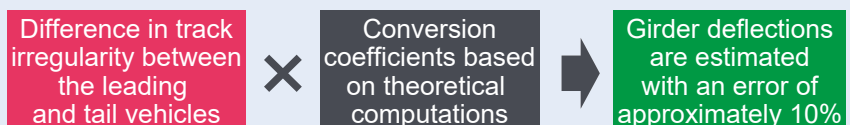
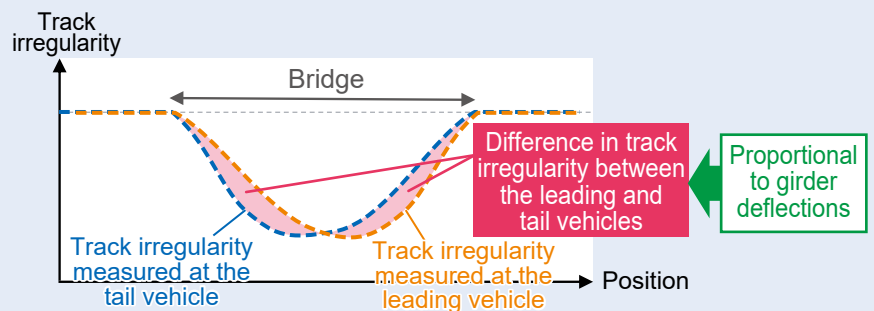
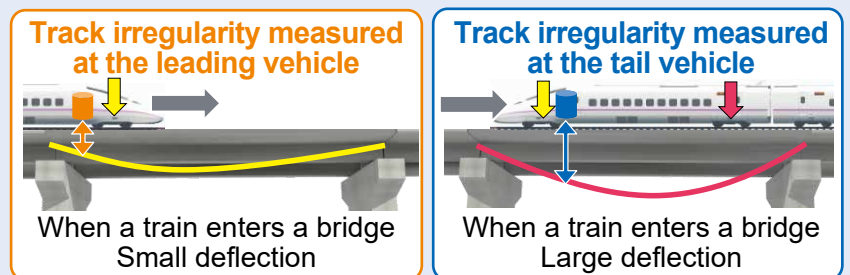
#### \*2 Resonance phenomenon of railway bridges

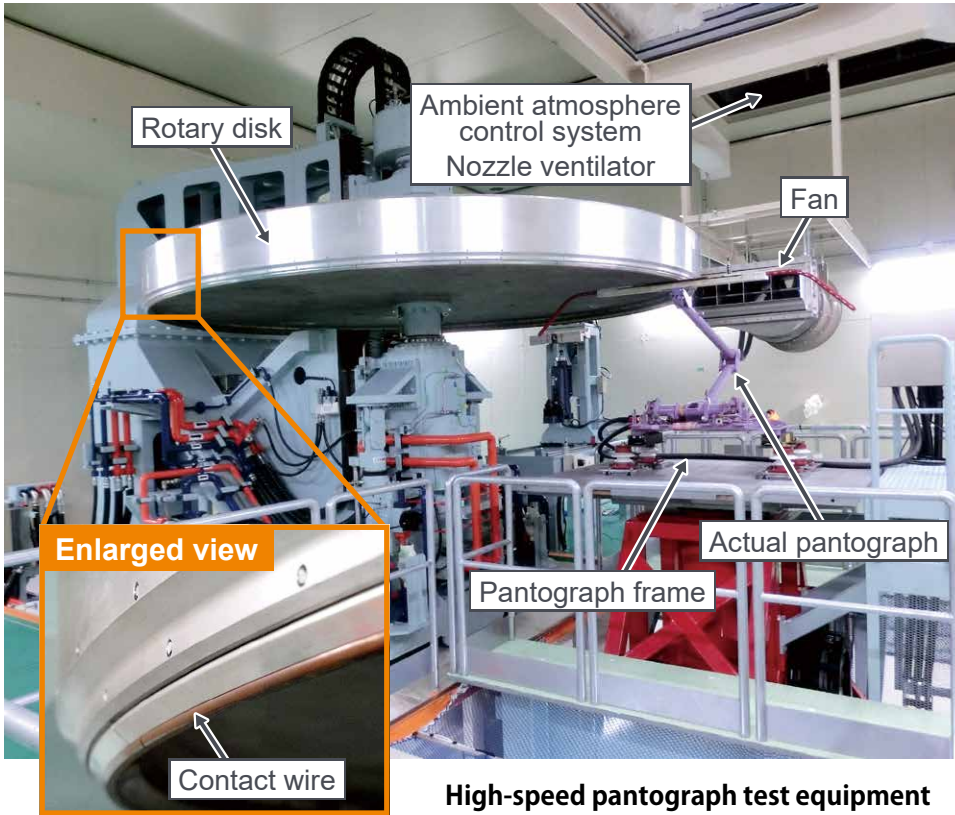
When a train passes over a railway bridge, a vibration with a specific frequency is generated owing to the regular axle arrangement of vehicles; when this frequency approaches the natural bridge frequency, resonance occurs and causes excessive vibrations on the railway bridge.



### On-board detection technique for resonant bridges

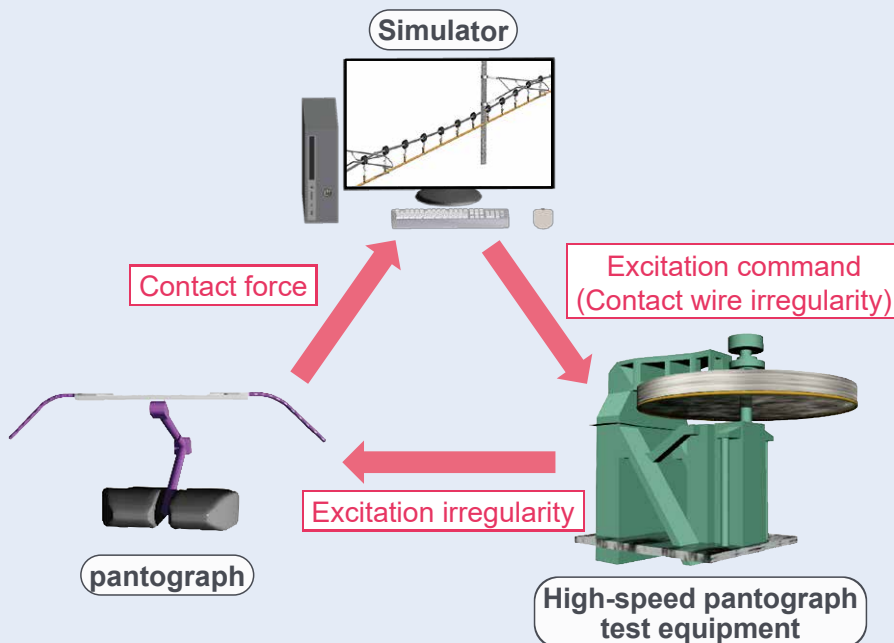
### On-board measurement technique for bridge deflections





**High-speed pantograph test equipment**

**Components of the overhead contact line/pantograph HILS system**



over the bridge (*On-board detection technique for resonant bridges*).

**On-board measurement technique for bridge deflections —Measurement evaluation techniques—**

We have developed techniques for estimating the girder deflections that occur when a train passes over a bridge based on the track irregularities measured on board. We theoretically elucidated that the difference between the track irregularity (high and low) measured at the leading vehicle and that measured at the tail vehicle of the train set contributes to the girder deflections that occur when a train passes over a bridge. Additionally, we estimated the girder deflections by multiplying the maximum difference in track irregularity with a conversion factor based on the span of the railway bridge (*On-board measurement technique for bridge deflections*). Using validation tests on an actual track, we showed that these techniques can be used to estimate girder deflections with an error of approximately 10%<sup>4</sup>). We are currently developing techniques for estimating girder deflections not only by measuring track irregularities at the leading and tail vehicles but also by using the difference in height measurements obtained by two-car inspection, which is often used in conventional lines.

These measurement evaluation techniques are being technically verified by field tests using dynamic interaction simulations<sup>5</sup>) between vehicles and structures developed by the Railway Dynamics Division and noncontact vibration measurements<sup>1</sup>).

**High-speed pantograph test equipment and hybrid simulations —Testing techniques—**

This section present examples of R&D work being conducted to realize more ad-

vanced testing through the development of testing techniques and test equipment unique to the Railway Technical Research Institute, and the integration of testing equipment and numerical simulations.

To evaluate the performance of pantographs by means other than on-track testing, we are conducting computer simulations of motion and various tests in our facilities. The Railway Dynamics Division has developed techniques to simulate the motions of overhead contact lines and pantographs, as well as tests and investigations using high-speed pantograph test equipment (*High-speed pantograph test equipment*)<sup>6)</sup>. Our high-speed pantograph test equipment can conduct various tests on stationary pantographs by operating (rotating vertically and laterally displacing)

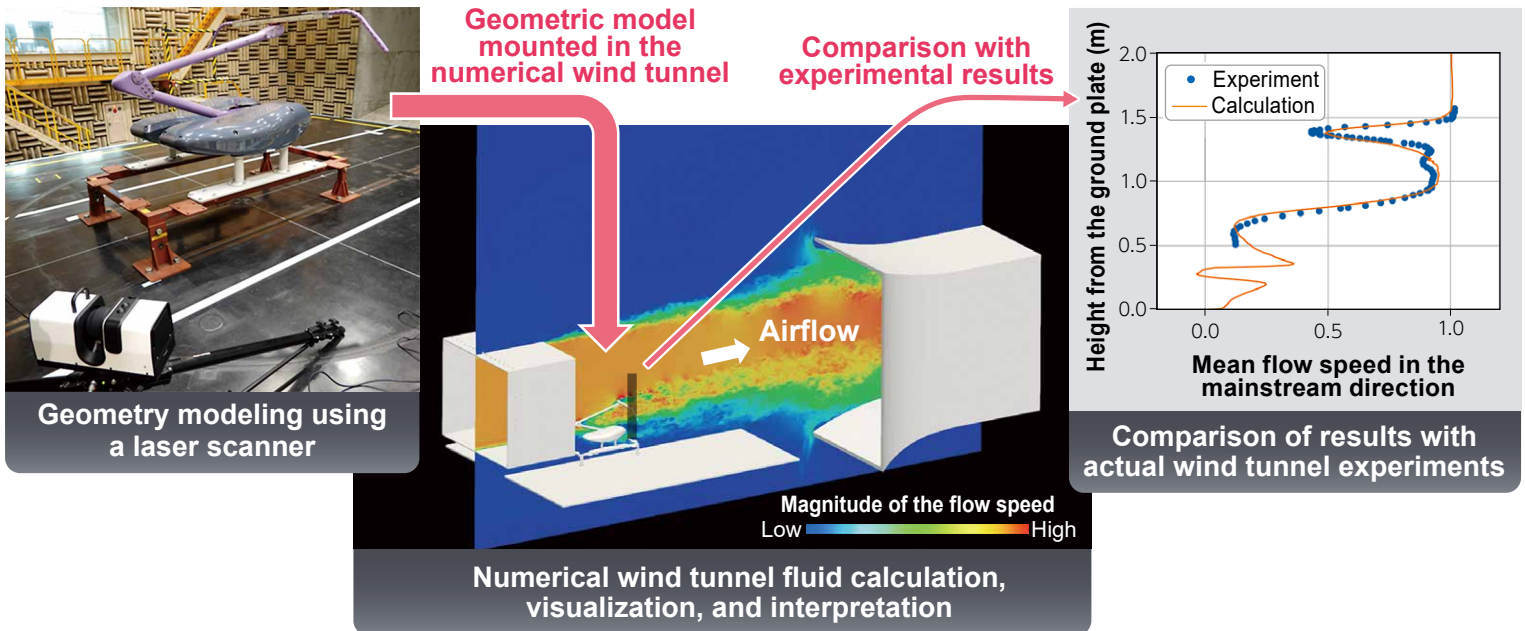
a disk corresponding to an overhead contact line in a temperature- and humidity-controlled test chamber, simulating running conditions of up to 500 km/h.

Although the movement of the disk is generally preconfigured, more advanced hardware-in-the-loop simulation (HILS) tests<sup>7)</sup> can be performed by integration with the aforementioned simulation techniques. HILS is a technique that integrates actual equipment and computer simulations in real time. The overhead contact line/pantograph HILS system was developed by linking real-time simulations to the vertical motions of the disk in contact with the pantograph of the actual equipment (*Components of the overhead contact line/pantograph HILS system*). This integration enables the mutual coupling of

overhead contact lines and pantographs in high-speed pantograph test equipment, allowing tests to be performed under conditions that are closer to those that produce the observed phenomena. We intend to advance these techniques further to lower development costs and facilitate the more efficient maintenance of pantographs.

### Numerical wind tunnel for large-scale low-noise wind tunnels —Simulation techniques—

Finally, a case example of the development of a numerical laboratory in which the test equipment is reproduced in a virtual space using numerical simulations is presented. A numerical laboratory was constructed to reduce the number of test ac-



**Numerical wind tunnel**  
(left: model, center: visualization of the calculation results,  
right: comparison of the numerical wind tunnel and experimental results)

tivities by coupling numerical simulations with actual test equipment, investigating the influence of the size and specification limitations of the actual test equipment on the test results, and conducting numerical experiments that exceed the capabilities of the test equipment.

The large-scale low-noise wind tunnel in Maibara, wherein various wind tunnel experiments are conducted for over 200 days annually, is an important tool for aerodynamic R&D at the Railway Technical Research Institute. To obtain more efficient and advanced wind tunnel experiments, we have developed a numerical wind tunnel that reproduces the results of actual wind tunnel experiments using numerical simulations.

During the construction of the numerical wind tunnel, which was developed as a digital twin of the Maibara wind tunnel, we identified and numerically reproduced its airflow characteristics. To numerically and efficiently reproduce the complex geometry of the airflow, we used an airflow simulator developed by the Railway Technical Research Institute. We introduced a technique for modeling the geometry

of a specimen using a three-dimensional laser scanner and built a system that can perform the entire process from defining the model geometry to performing the subsequent calculations (*Numerical wind tunnel*). We compared the results of the numerical wind tunnel calculations with the experimental results and found that they were in good agreement.

The constructed numerical wind tunnel can be used as a complementary tool to wind tunnel experiments, for example, by focusing on specific experimental conditions and reducing the number of measurement points. Integrating the numerical wind tunnel with actual wind tunnel experiments will help shorten experiment and, in turn, R&D times. In addition, this integration will present a new approach for railway operators and other interested parties to quickly address sudden challenges without relying on wind tunnel experiments.

## Conclusions

This report covers the R&D policy of the Railway Dynamics Division, which is the

basis of our work on elucidating railway-specific phenomena and proposing specific solutions by developing and integrating measurement evaluation, testing, and simulation techniques. As examples of our latest achievements and activities, this report introduces techniques to evaluate railway bridges using on-board measurements, testing techniques for pantographs, and a numerical wind tunnel for simulating large-scale low-noise wind tunnels. More information on other R&D projects can be obtained from the official website of the Railway Dynamics Division of the Railway Technical Research Institute (<https://www.rtri.or.jp/rd/division/rd50/>). The Railway Dynamics Division will continue to develop and integrate unique measurement evaluation, testing, and simulation techniques to produce research results that can contribute to improving railway safety and realizing efficient railway maintenance and management, ultimately meeting the needs of society and the railway industry, which are changing along with innovations in digital technology.

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## References

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