Toward Railway Innovation

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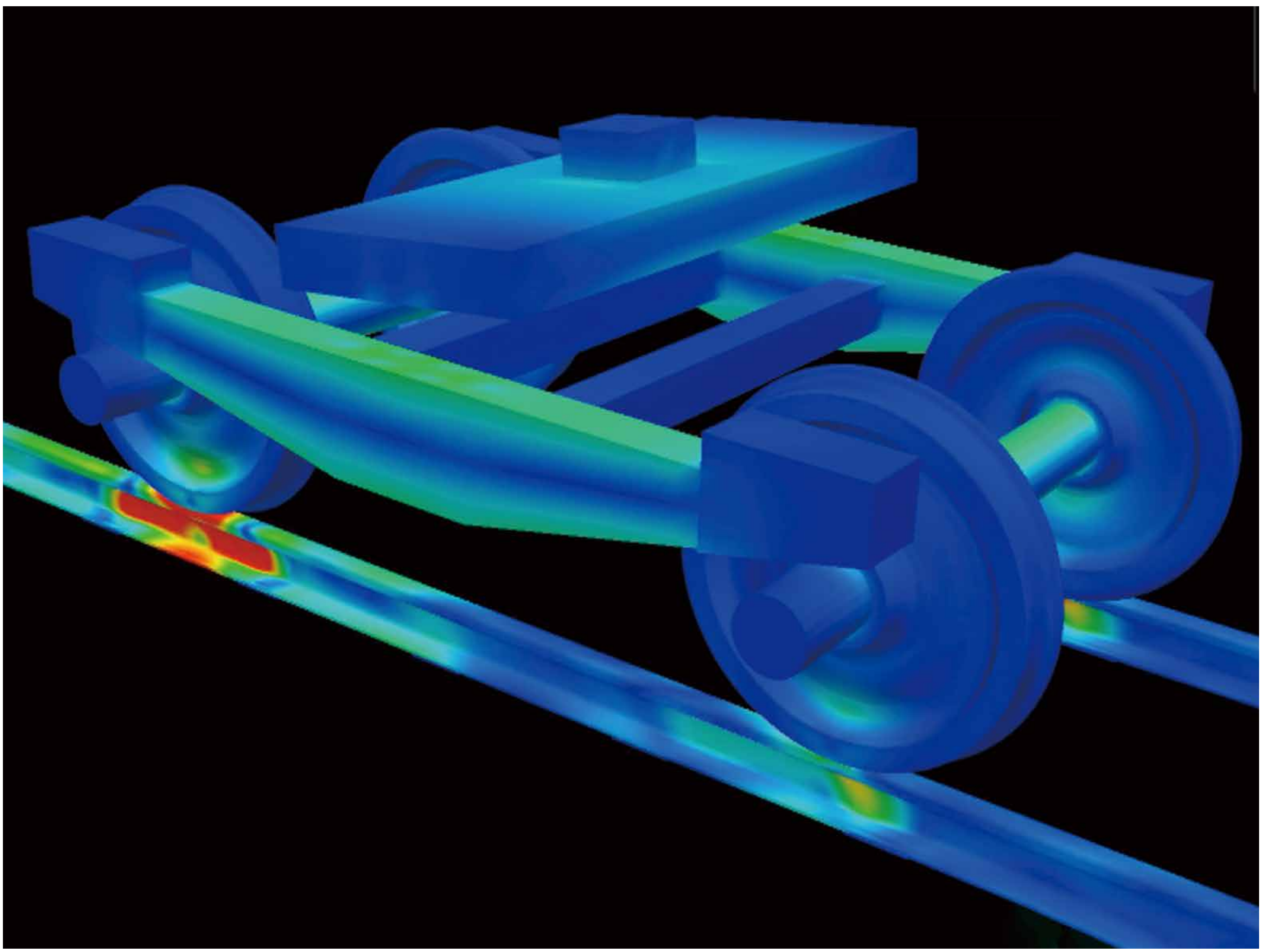
Simulation Technology

Preface

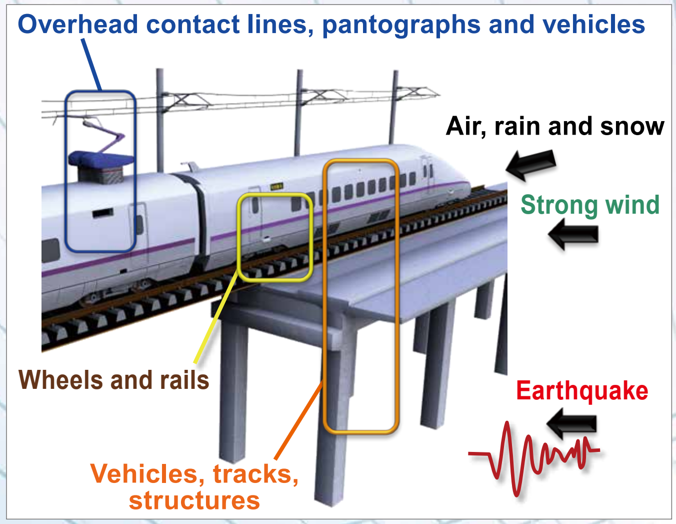
Articles



RTRI Simulation Technologies

A railway system is a dynamically complex network of structures, tracks, vehicles, overhead contact lines and other components where "railway dynamics" phenomena, in which interaction between moving vehicles and facilities on the ground plays an essential part, occur. Dynamic interaction between pantographs and overhead contact lines, between rails and wheels, between structures and tracks and vehicles, between vehicles and the surrounding environmental elements such as air and water (rain and snow), and between other components can affect the safety, maintainability, environmental harmony, and other attributes of the railway (Coupled analysis of phenomena involving various components and elements).

Dr. Fumiaki Uehan
(General Director, Railway Dynamics Division)



Coupled analysis of phenomena involving various components and elements

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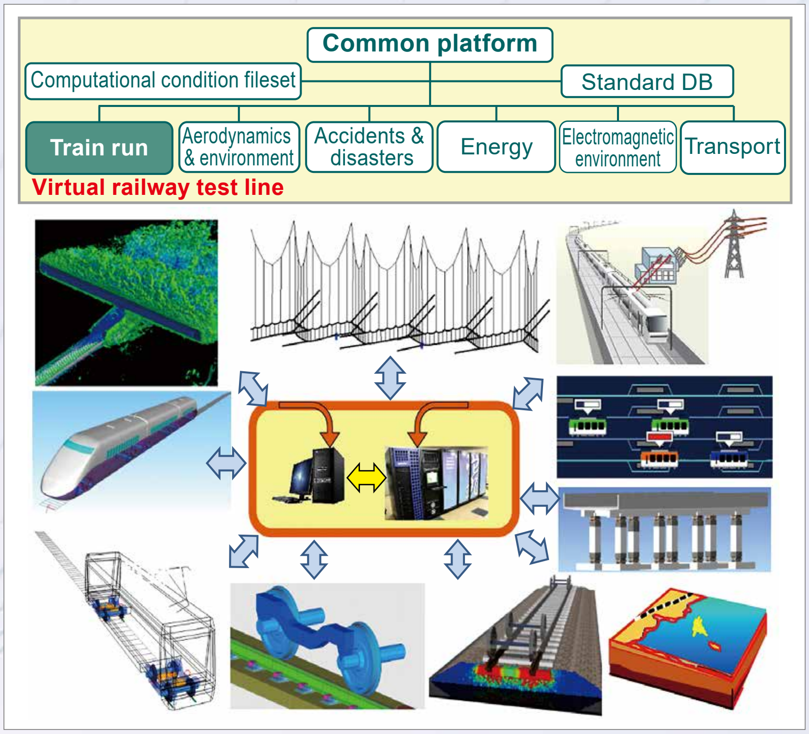
Front cover Photo: Simulation example of a bogie using a wheel with tread flat damage

RTRI has been engaging in the development of railway simulators as a tool to improve the quality and efficiency of research and development efforts and thereby help optimize railway systems and understand complex phenomena.

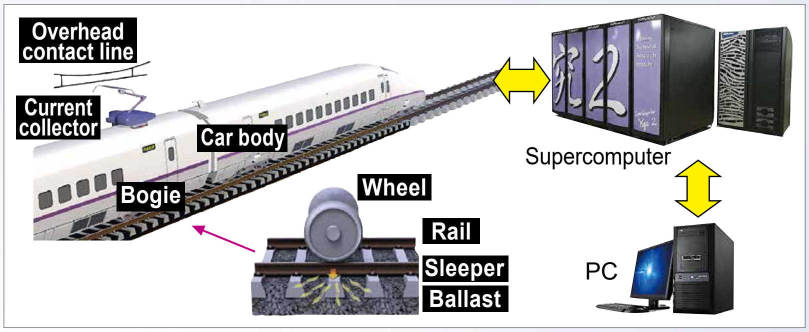
System configuration for railway simulators shows the overall configuration of the railway simulators developed by RTRI up to 2020. The railway simulators are linked to each other for research and development purposes, offering enhanced capability especially in large-scale parallel and coupled computation of multiple simulators.

Virtual railway test line

The virtual railway test line is a railway test line created in a virtual space on a computer by coupling dynamics-related train running simulation techniques (for vehicles, tracks, current collection, etc.) (Railway test line in a virtual space). The virtual test line was developed by the following process: first the train run simulation techniques were improved while techniques for coupling those simulations were studied; then techniques were developed for the simulation of vehicles and tracks capable of handling elastic tracks and car bodies (Simulation of vehicle



System configuration for railway simulators



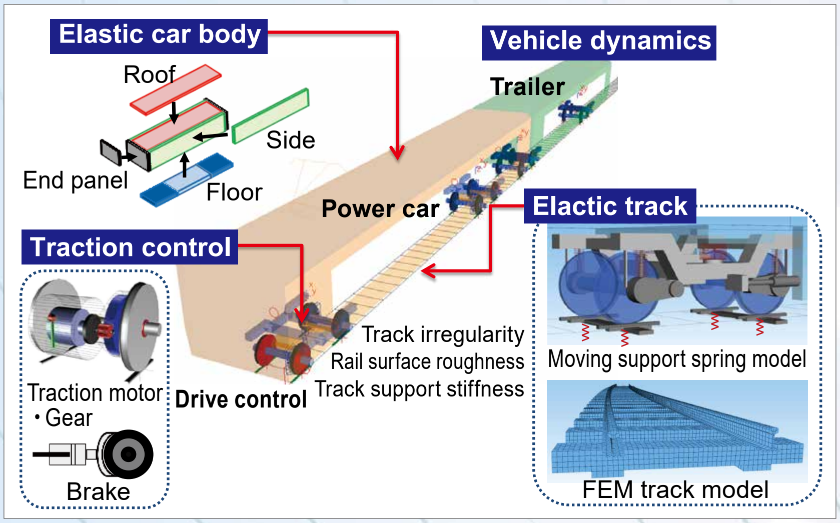
Railway test line in a virtual space

Dr. Tetsuo Uzuka
Managing Editor
(General Director, International Division)

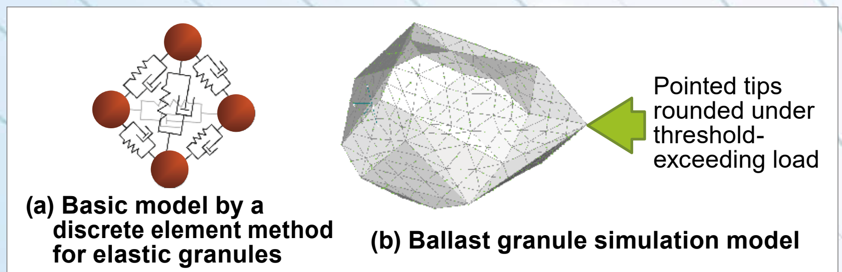
Preface Message from the General Director Dr. Tetsuo UZUKA

Calculation and simulation are among the most fundamental elements of railway research and have been performed at RTRI for a long time.

Traditional simulation methods divide the object into small parts and calculate the (kinetic) interactions. The more recent, so-called Digital-Twin method reproduces and combines the coherent functions of a complete railway system within a computer. Whichever method we choose, we need to strike a balance between field testing, laboratory experimentation, and simulation.



Simulation of vehicle dynamics



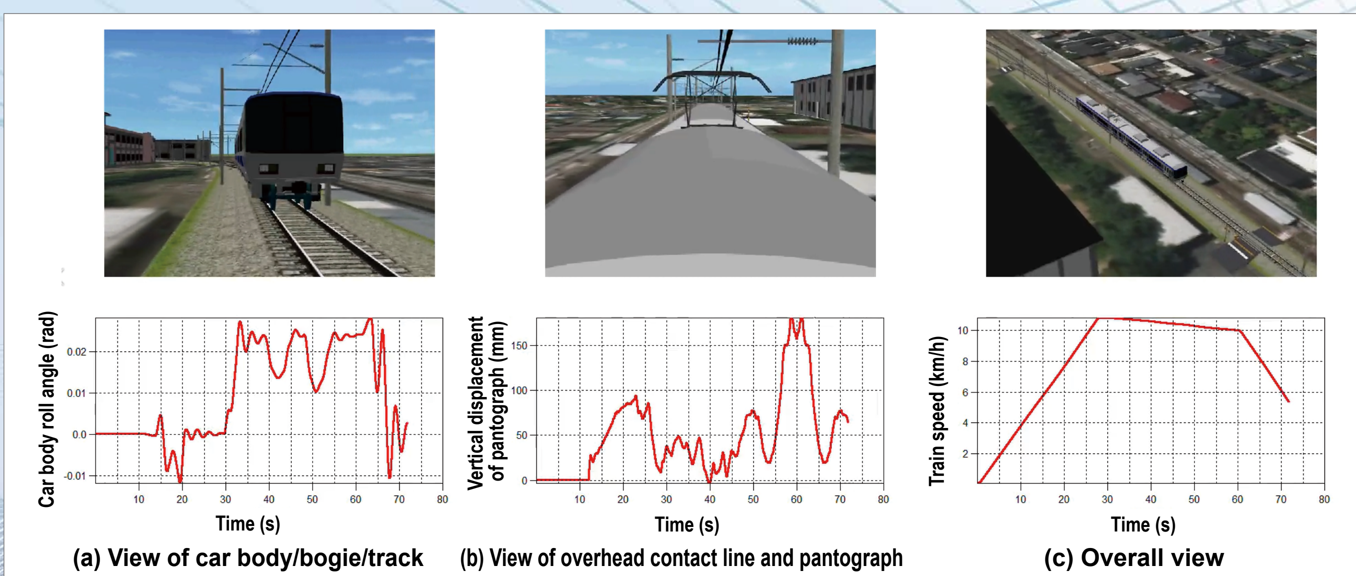
Modeling of ballast granules by a distinct element method for elastic granules

dynamics), the simulation of overhead contact lines and pantographs capable of handling detailed 3D structures, the simulation of wheel/rail rolling contact capable of handling a single bogie model and the simulation of ballasted tracks capable of large-scale and long-term deterioration analyses (Modeling of ballast granules by a distinct element method for elastic granules); and finally the technique for coupling those simulations was developed.

The simulation technique makes it possible to observe all necessary details from whatever angle desirable and view videos that show how vehicles, overhead contact lines, tracks and other components behave and change their behavior over a period, as if they are all real (Representation examples of results of virtual railway test line simulations).

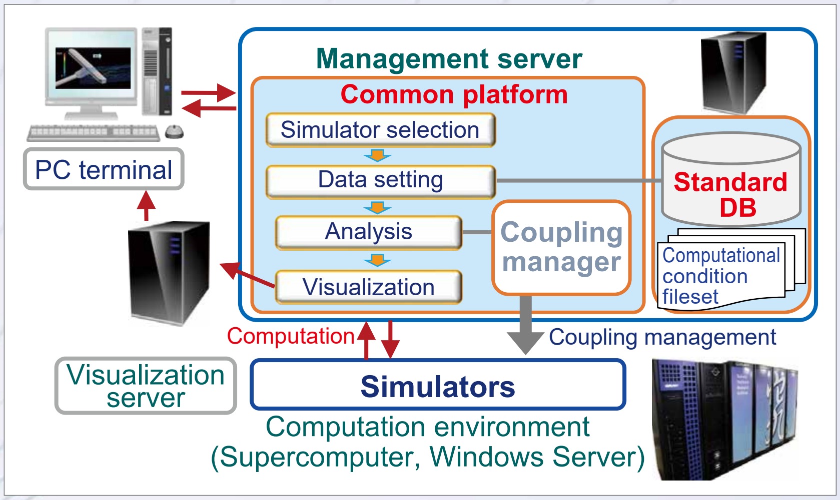
Non-train Run Simulations

RTRI also has developed various simulation methods, including the following: The Airflow Simulation, based



Representation examples of results of virtual railway test line simulations on the Cartesian grid method, is used to elucidate aerodynamic phenomena around the vehicles. Train Operations/Passenger Flow Simulation is used to comprehensively evaluate advanced train control methods, including passenger flows. The Railway Communication Environment Simulation analyzes the transmission quality of communications within the railway system in an integrated manner, as well as radio noise and electromagnetic induction. The Earthquake Damage Simulation can automatically conduct modeling from faults that generate earthquakes up to structures and perform seismic response analysis.

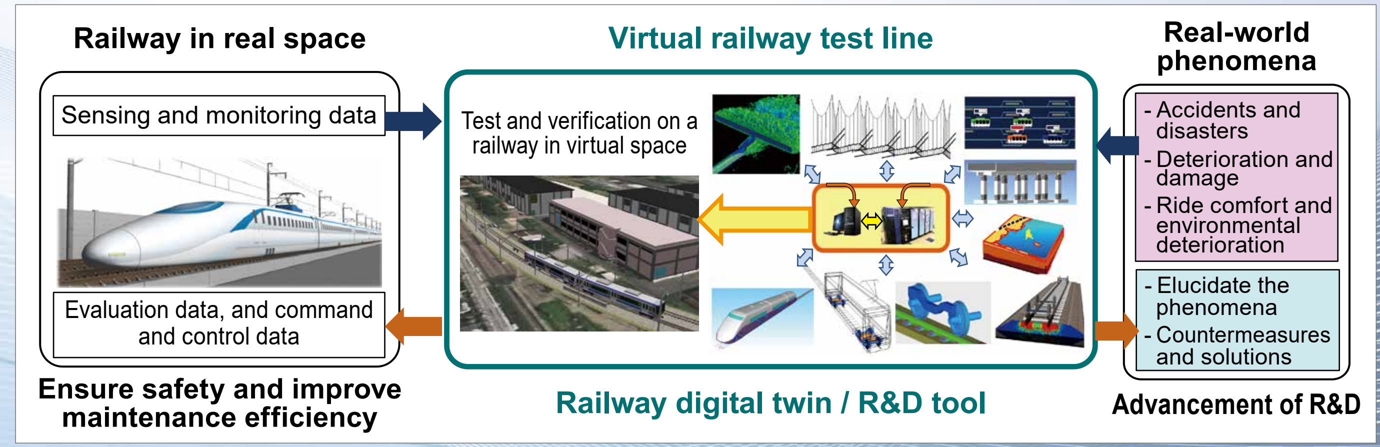
Regarding the railway simulators, we have been configuring the system so that the various simulation methods shown so far can be executed in a unified environment (System configuration for railway simulators). The common platform built in the management server is the simulation execution environment. Simulations are executed by super computers and Windows Servers that are automatically selected for the execution. These servers are connected to each other on the network for transmission of input and output data, program execution control and other actions. In addition, a visualization server is provided to display simulation results.



System configuration for railway simulators

Future Railway Simulators

In the near future, we will develop railway simulators and virtual railway test lines into tools, for example, to elucidate the dynamic phenomena of railways, reproduce accidents and disasters that cannot be tested, and grasp long-term deterioration and damage. Furthermore, we would like to operate them as railway digital twins in virtual space and develop them into tools that provide useful data for the safe operation of railways and the efficiency of maintenance by modeling main line sections and incorporating sensing and monitoring data from actual line sections in near real-time (Role of the virtual railway test line in the future).



Role of the virtual railway test line in the future

Reproducing the Airflow around Railway Vehicles

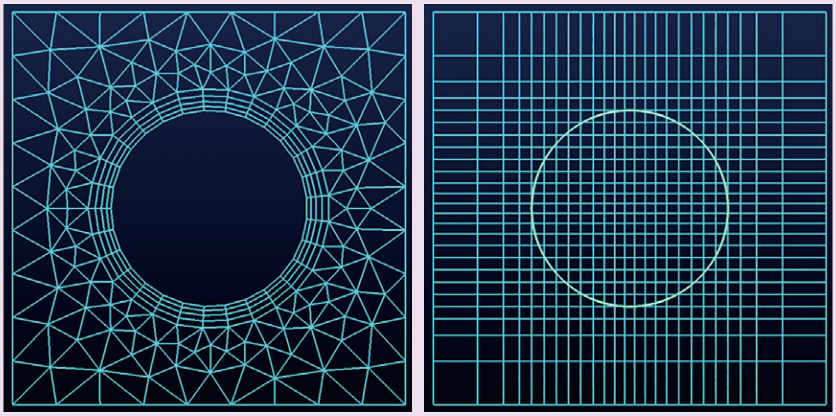
Dr. Koji Nakade
Chief Researcher
Computational Mechanics

Research methods for elucidating airflow include measurements on real targets, tests using wind tunnels, and numerical analysis using a computer. The numerical analysis provides detailed information about the airflow around railway vehicles. This paper outlines the features of the Airflow Simulator, which is our numerical analysis tool. As examples of reproducing the airflow around railway vehicles with the Airflow Simulator, the paper presents numerical simulations of (i) airflow around vehicles in cross winds, (ii) train set airflow around vehicles, and (iii) airflow outside and inside commuter vehicles (in vehicle ventilation during running with windows open).

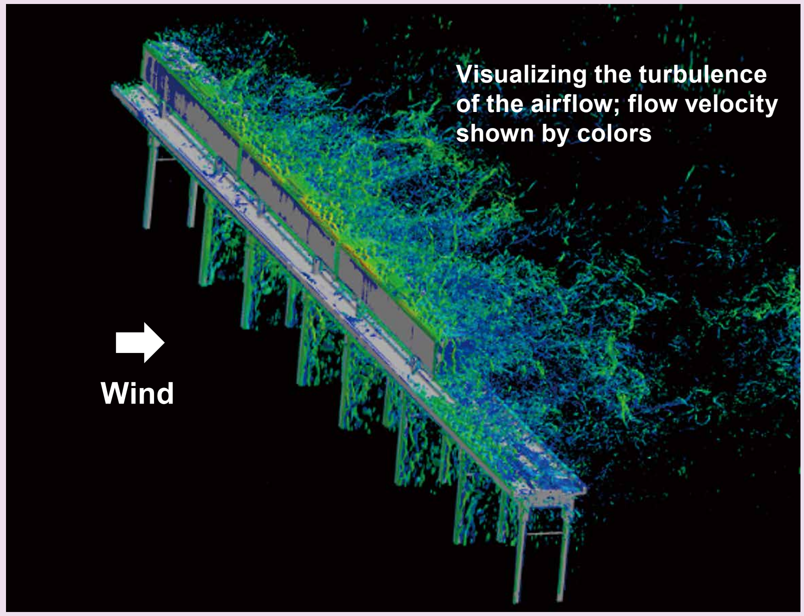
About Airflow Numerical Analysis

Airflow can be expressed by the Navier Stokes equations, which were derived about 180 years ago. They are nonlinear partial differential equations, and instead of finding an exact solution analytically, we choose to find an approximate solution by numerical analysis using a computer.

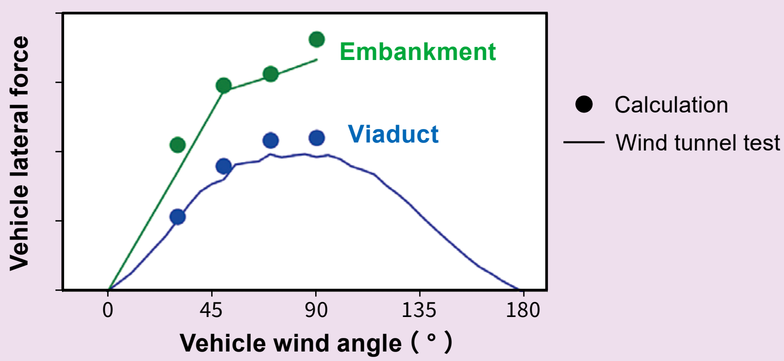
When numerical analysis is applied to the airflow around railway vehicles, that flow is reproduced by the computer within the range of calculation accuracy. That is, we can observe how the airflow changes with time and location. This is a major feature of the numerical analysis method, which allows us to "watch the airflow" in detail. It allows us to understand not only the causes and effects of phenomena but also their progress (i.e. mechanisms). In addition, with the numerical analysis, we can adjust the computation conditions and examine ideal conditions and virtual conditions as well as the actual conditions, thereby allowing us to predict the airflow for various situations. Furthermore, airflow numerical analysis is becoming used as a means to obtain railway vehicle shapes with excellent aerodynamics, which are difficult to obtain from empirical prediction, by fusing it with information science and combining optimization calculation (automatically computing the solution for the desired condition with a computer) with airflow numerical analysis.



An example of computational grids for calculating the airflow around a cylinder



(a) Airflow in the viaduct condition



(b) Comparing the vehicle lateral force with the wind tunnel test

Numerical simulation of the airflow around the vehicles in cross winds

Airflow Simulator to analyze the airflow of complex shape

In the airflow numerical analysis, the Navier Stokes equations are solved for limited points by dividing the space into smaller sections, called computational grids. In conventional airflow numerical analysis, computational grids (boundary adaptive grids) along the object shape are used to compute the airflow near the object with high accuracy (An example of computational grids for calculating the airflow around a cylinder (a)). However, computing a complex shape this way is very costly in computer processing time. Therefore, we focused on Cartesian grids (An example of computational grids for calculating the airflow around a cylinder (b)), which can almost automate the grid generation, and adopted the Cartesian grid method in the Airflow Simulator. The Cartesian grid method is also characterized by its high parallel computing efficiency (i.e. ability to perform multiple operations in parallel), which is essential for large scale computations, and may become a powerful fluid analysis method in the future ultra large scale parallel computer environment. Thus, detailed computational grids in large scale analysis can be expected to ensure calculation accuracy.

Airflow around the Vehicles In cross winds

To realize safe and stable transportation of railway vehicles in strong winds, it is important to know the aerodynamics of railway vehicles in cross winds. To this end, we have been evaluating cross wind aerodynamics by wind tunnel tests using scale models. However, in the evaluation, many parameters must be included, such as the vehicle shape, aboveground structure, and wind characteristics, and it may be difficult to verify all the necessary conditions only by a wind tunnel test. Thus, it is expected that airflow numerical analysis will be useful as a tool for formulating an efficient test plan by narrowing down the test conditions. This section shows an example of a computation that was conducted to verify the prediction accuracy of cross wind aerodynamics by an airflow simulator.

We conducted a numerical analysis using the Airflow Simulator regarding two typical conditions (the first with a vehicle on a viaduct and then on an embankment) of the previously conducted cross wind tunnel tests. With the Airflow Simulator, natural winds were simulated as in the wind tunnel tests, and the airflow around vehicles was subjected to airflow numerical analysis (Numerical simulation of the airflow around the vehicles in cross winds (a)). Comparison of the calculation results with those of the wind tunnel tests demonstrated that the Airflow Simulator can reproduce a wind tunnel test well (Numerical simulation of the airflow around the vehicles in cross winds (b)). The "lateral force" in the figure indicates the lateral force on the vehicle, and the "angle between the vehicle and wind" is defined as 90° when the wind is from the side and as 0° when it is from the front. In future, we will continue to apply the Airflow Simulator to vehicles and aboveground structures with different shapes, increase the number of demonstrated calculation examples, and further study the prediction accuracy.

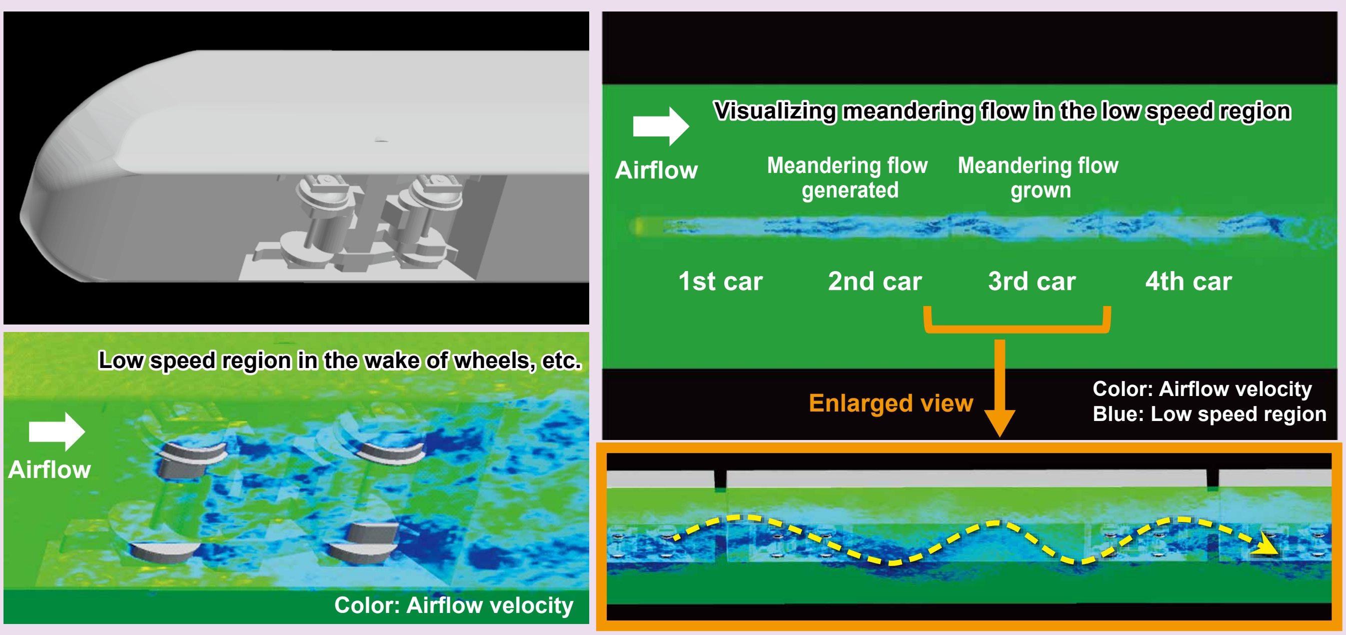
Airflow around Train Set Vehicles

The airflow under the vehicle floor is related to many railway aerodynamic issues such as ballast surface wind speed, vehicle air resistance, snow accretion near bogies, aerodynamic noise generated from the bottom of the vehicles, and car body vibration in the tunnel. We tried to clarify the vehicle underfloor flow by using an airflow numerical analysis.

We conducted an airflow numerical analysis using the Airflow Simulator for the vehicles in a four car train set. The computation results show that, from the flow behavior near the first bogie, a low speed region exists in each wake of a wheel, as shown in Numerical simulation of the airflow around the train set vehicles (a). In addition, by observing the flow of the entire train set vehicles, a meandering flow was found under the vehicle floor, as shown in Numerical simulation of the airflow around the train set vehicles (b). This meandering flow was verified through a wind tunnel test, demonstrating that it was also valid experimentally. Furthermore, the airflow during running through the tunnel was also investigated, which showed that the vehicle underfloor meandering flow seen in the open section spread to the side of each car body (i.e. side near the tunnel wall). It was suggested that the pressure fluctuation caused by this meandering flow acts on the side surface of each car body and that a lateral variable aerodynamic force is generated on the vehicles. We succeeded in demonstrating that the frequency of the fluctuating aerodynamic force predicted herein corresponds to the car body vibration of approx. 2 Hz, measured on the Shinkansen in the past. We presumed that, in conclusion, the primary cause of car body vibration in the tunnel is the meandering flow formed around the vehicles. In this way, we were able to advance the elucidation of the airflow phenomenon around the train set vehicles by using the airflow numerical analysis.

Airflow outside and inside Commuter Vehicles (In Vehicle Ventilation during Running with Windows Open)

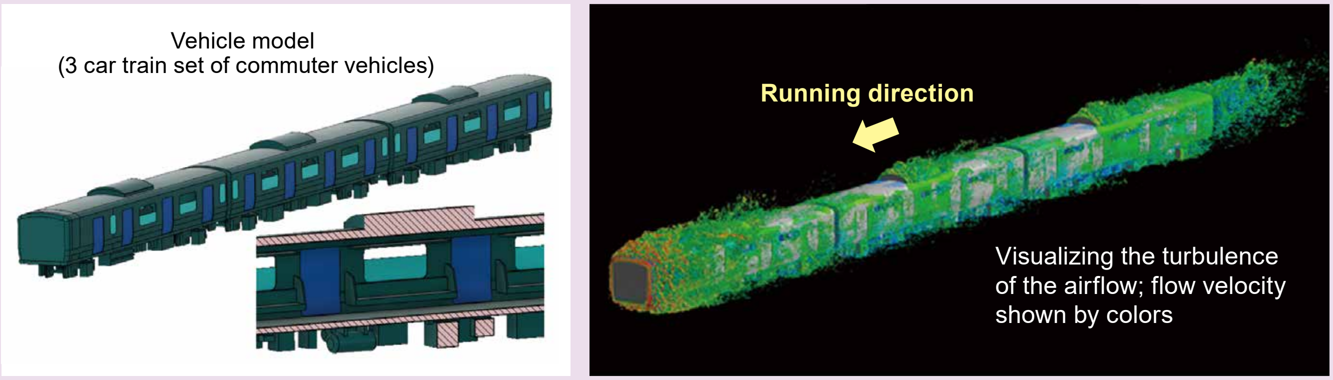
Among the measures against spreading infectious diseases in commuter vehicles, one is to avoid Sealed Space in vehicle ventilation by opening windows. We know empirically that opening the windows improves ventilation in the car.; However, since there are few findings regarding the ventilation volume of running railway vehicles there is a need to quantitatively evaluate the in vehicle ventilation volume.



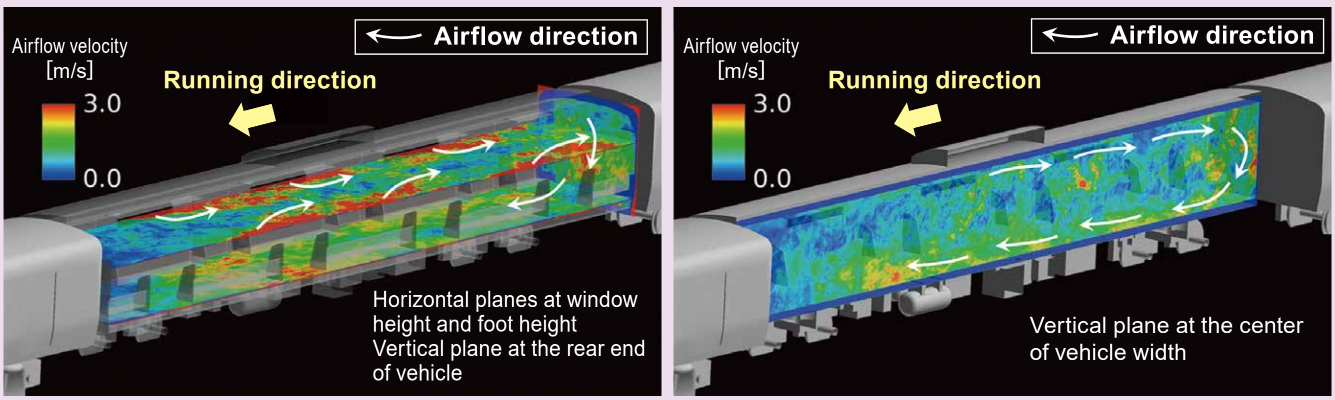
(a) Airflow near the first bogie

(b) Underbody flow of train set vehicles

Numerical simulation of the airflow around the train set vehicles



(a) Airflow around commuter vehicles



(b) In vehicle airflow (vehicle speed 72 km/h, empty, no air conditioner)

Numerical simulation of in vehicle ventilation during running with windows open

We evaluated the in vehicle ventilation volume during running with the windows open by simultaneously computing the airflow outside and inside vehicles using the Airflow Simulator.

Numerical simulation of in vehicle ventilation during running with windows open (a) shows the airflow around the vehicles, and Numerical simulation of in vehicle ventilation during running with windows open (b) shows the airflow inside the vehicles. By applying the numerical simulation to various conditions such as the window opening amount, the vehicle speed, the occupancy rate, the air conditioner airflow, and the seat layout, we found the following about the in vehicle ventilation volume resulting from opening windows during running: the ventilation volume is proportional to the window opening area and vehicle speed, and the effects are small from the occupancy rate, air conditioner airflow, and seat layout. Finally, we organized these results and proposed a simple prediction formula for the ventilation volume. We verified that the ventilation volume obtained by the simulation roughly matched the measured data.

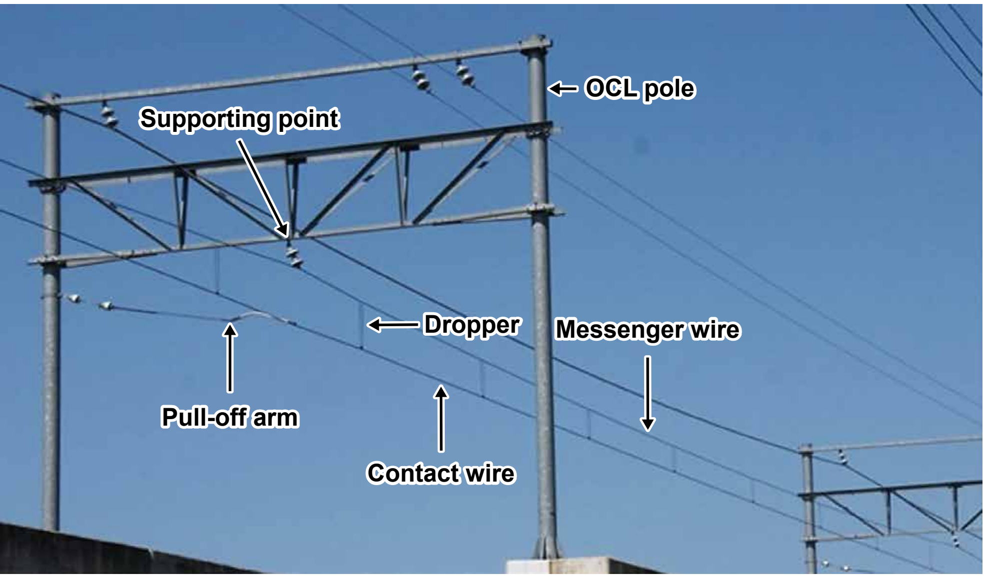
Conclusion

The main goal is to expand the capabilities of airflow numerical analysis. This R&D has demonstrated three new applications of the method. There are now many cases where the method can be used compared to 10 years ago. We should continue the R&D to expand this range. Effective use of numerical simulation backed by actual measurements is important in research to elucidate phenomena.

Reproducing the 3D Behavior of Overhead Contact Lines and Pantographs

Mr. Tatsuya Koyama
Senior Researcher
Current Collection

Facilities unique to electric railways include overhead contact lines (OCLs, Example of OCL (simple OCL)), which supply electric power to rolling stock, and pantographs (Pantograph example (single arm pantograph)), which take electricity into rolling stock. The pantographs contact with OCLs to take in electricity. Simulations are used to develop OCLs and pantographs, and to consider increasing the speed of trains. Recently, it has become increasingly difficult to adequately evaluate the performance of OCLs and pantographs in conventional 2D simulations (Conventional 2D simulation constructed by modeling with the OCL and pantograph as lumped mass). Thus, we have developed a simulation to understand 3D behaviors of OCLs and pantographs. This paper outlines the solution.

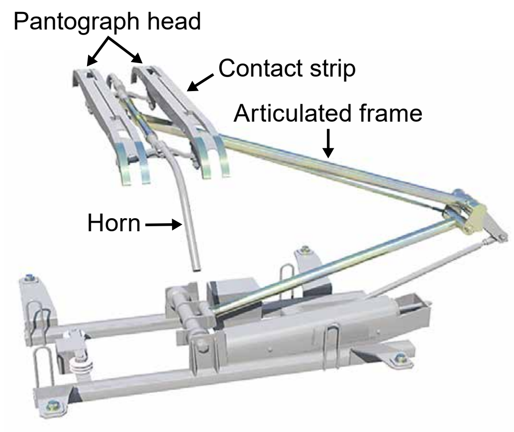


Example of OCL (simple OCL)

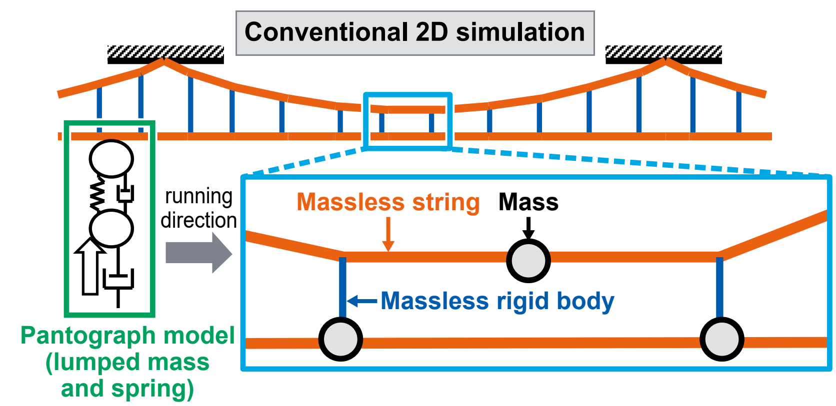
Introduction

The pantograph contains contact strips that are in direct contact with the contact wire, a pantograph head that holds the contact strips, and an articulated frame for moving the pantograph up and down to follow changes in the height of the contact wire. In addition, a horn is provided on each end of the pantograph head in order for the pantograph to safely slide on the OCL even when a vehicle negotiates a meeting or branching point (detailed later).

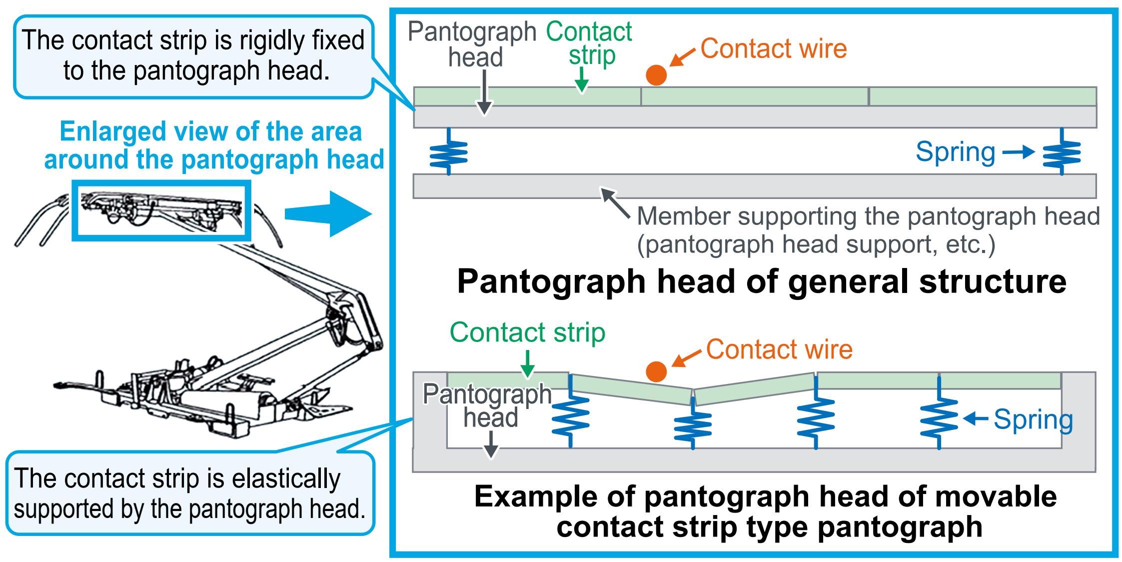
The pantograph performs current collection to take electricity from the contact wire into the vehicle. The force acting between the OCL and the pantograph is called the contact



Pantograph example (single arm pantograph)



Conventional 2D simulation constructed by modeling with the OCL and pantograph as lumped mass



Pantograph head structure

force. While the vehicle is at a standstill, the pantograph is in contact with the contact wire with a nearly constant contact force (50 to 60 N). However, during running, the contact force fluctuates due to the effect of, for example, the height difference of the contact line between the supporting points and the middle part of them. Excessive contact force may cause breakage of the contact wire, damage to various metal fittings, or increase in the amount of wear of the contact wire. On the contrary, when the contact force goes to zero, the pantograph may move away from the OCL (contact loss). In that case, an arc generated between the contact wire and contact strips may increase both wear of them.

In order to develop an OCL or current collector, or to increase the train speed, we should make sure that the above issues will not occur. However, fluctuations in contact force are caused by various factors, such as vibrations of the OCL and pantograph, changes in the height of the OCL, and waves propagated through the OCL. Therefore, it is not easy to understand the interaction between the OCL and pantograph. Thus, a computer simulation is used that includes modeled OCLs and pantographs.

Overview of 3D Simulation

To understand the interaction between the OCL and pantograph, we have developed a simulator using 3D models of these system (Pantograph head structure and 3D model of OCL and pantograph). This simulator models the OCL and pantograph by combining multiple finite elements for each of them. With these models, we can consider the following: (i) for the OCL, the 3D layout including the lateral deviation, and (ii) for the pantograph, the layouts of the members along the track and those perpendicular to the track. Each of these models is used to reproduce the behavior of the OCL and pantograph during train running.

Force exchange occurs between the pantograph and OCL by contacting each other, which is called dynamic interaction. As shown in Contact point and contact force, the simulation models dynamic interaction by applying forces of the same magnitude and opposite directions at the contact point between OCL and pantograph.

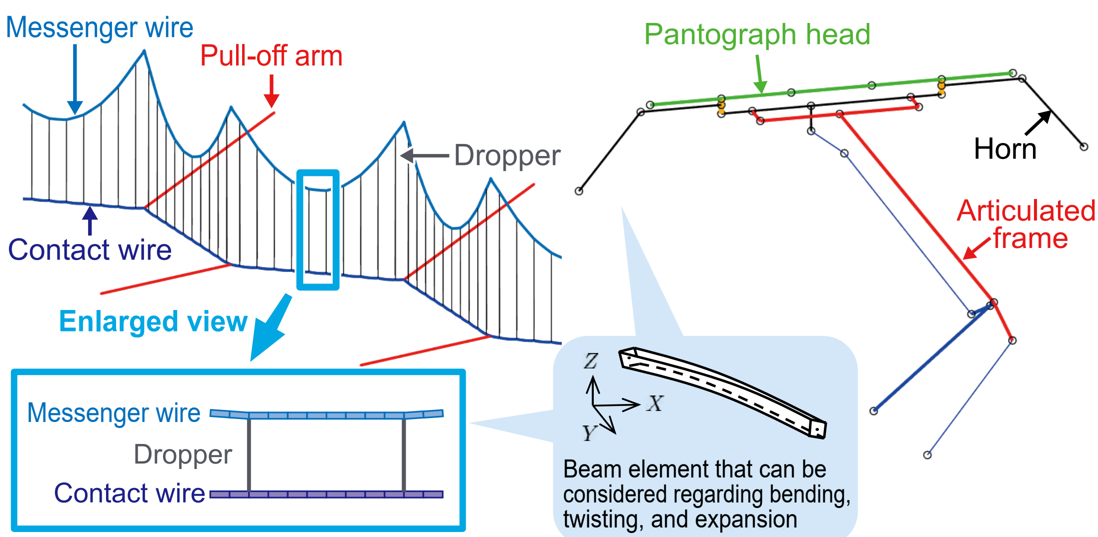
The simulator uses the penalty method to calculate the contact force. Specifically, a virtual spring (Contact point and contact force) is inserted between the OCL and pantograph, and if they are in contact, the force corresponding to the amount of contraction of the spring is defined as the contact force.

The following are two examples that use this simulation for the calculations.

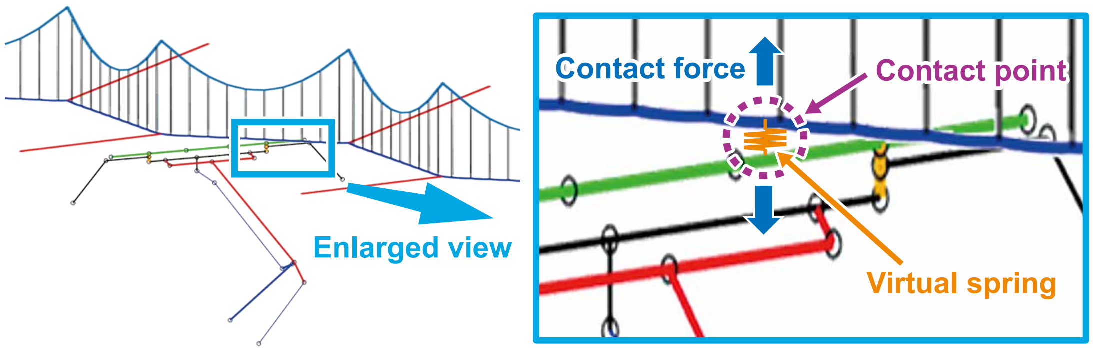
Pantograph Behavior Analysis

Computation results of movable contact strip type pantograph shows the analysis results of the movable contact strip type pantograph described above as an example of analyzing the 3D behavior of the members that make up the pantograph. In Computation results of movable contact strip type pantograph, the pantograph is moving from the front to the rear of the view. Also, in a pantograph with such a structure, it can be seen that the moving contact strips are only those near the contact point with the contact wire, and those away from that point are not moving.

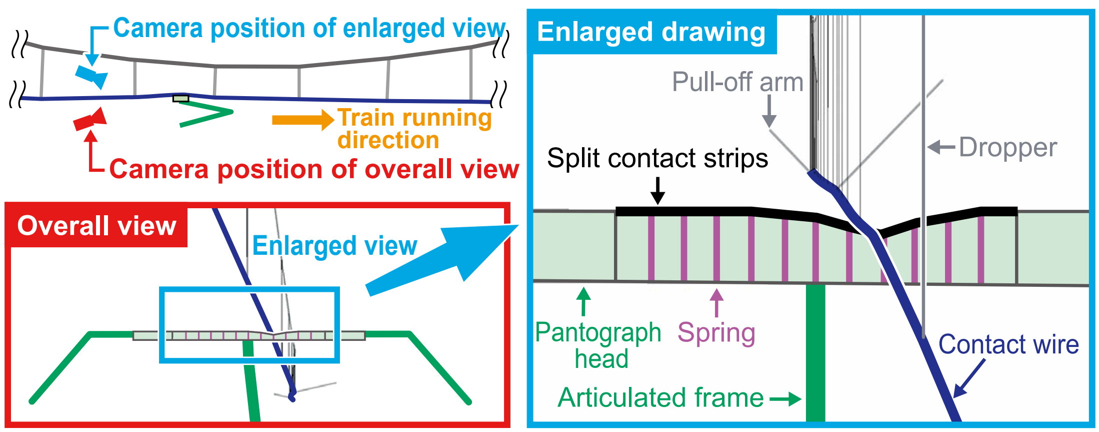
By constructing such a new computational model, it would be possible to evaluate the performance of pantographs with complicated structures , these were previously difficult, and it will be thought



3D model of OCL and pantograph



Contact point and contact force



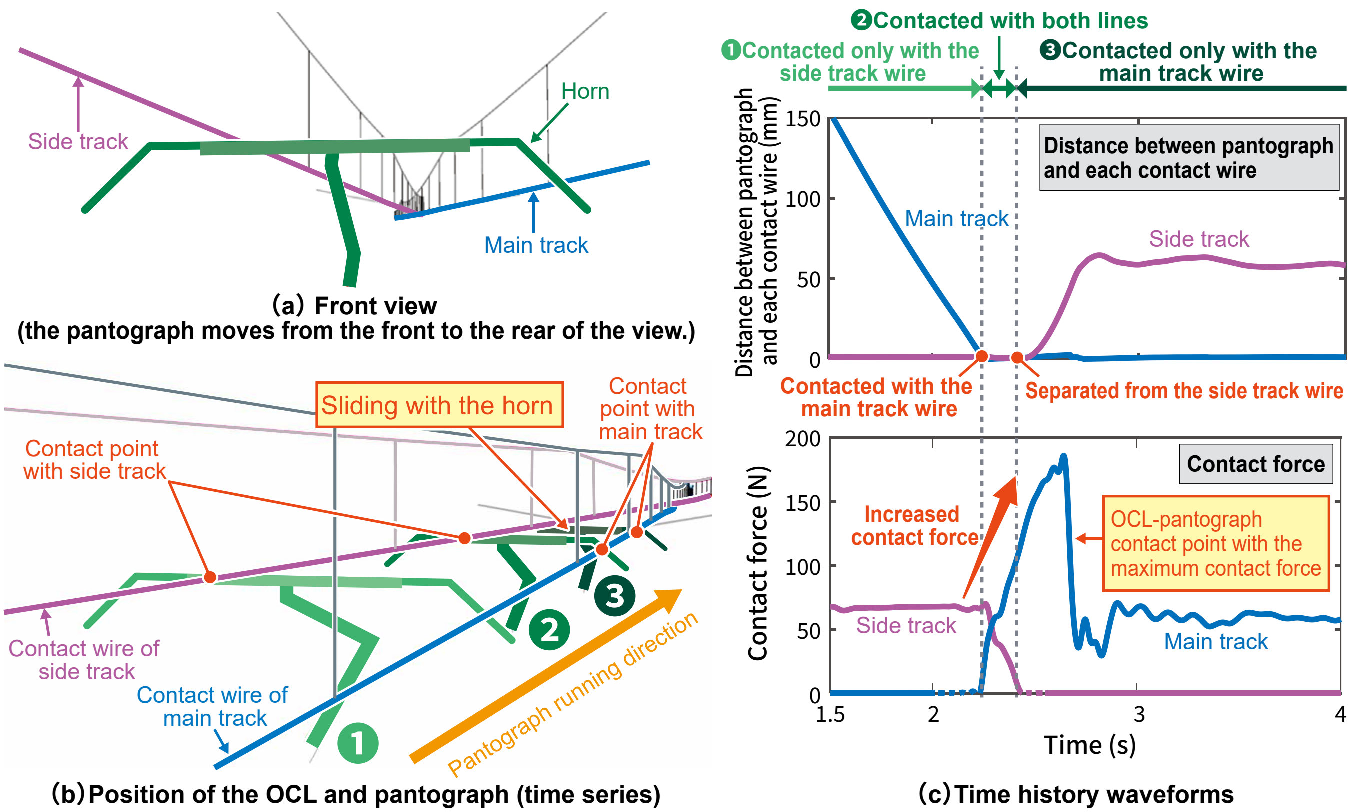
Computation results of movable contact strip type pantograph

that the model can be used for the development and improvement of pantographs with more complicated and sophisticated mechanism in recent years.

Analyzing where the Tracks Meet

To show an analysis that considers 3D OCL placement, Results of analyzing where the tracks meet shows an example of analysis targeting the points where tracks meet. At such a location, a total of two sets of OCLs, one above each track, are installed in an intersecting manner or nearby each other. When a vehicle is running on the main track, the pantograph of this vehicle only contacts the contact wire of the main track which is lower than that of the side track. On the other hand, as in Results of analyzing where the tracks meet (a), when a vehicle is entering the main track from the side track, the pantograph of this vehicle should make a smooth transition from the contact wire of the side track to that of the main track.

Results of analyzing where the tracks meet (b) shows the position of the pantograph and the contact point with the OCL at each point when the vehicle enters the main track from the side track. At point ①, the pantograph is in contact with only OCL of the side track, whereas at point ②, while the pantograph contacts OCL



Results of analyzing where the tracks meet

of the side track, OCL of the main track is pushed up with the horn. Beyond point ③ further advanced, the pantograph would move away from OCL of the side track and contact only OCL of the main track.Results of analyzing where the tracks meet (c) shows the results obtained in this analysis. The upper graph shows the change in the distance between the pantograph and each contact wire, and the lower graph shows the change in the magnitude of the contact force between the pantograph and each contact wire. From these figures, it can be seen how the pantograph moves away from the contact wire of the side track to that of the main track before and after point ② .

Conclusion

This paper explained a simulation that reproduces the 3D behavior of the OCL and pantograph. Utilizing a 3D simulation as described above example would make us to improve the development efficiency of OCL and pantograph development, understand 3D behaviors, and investigate the cause of accidents between OCL and pantograph. In the future, we will utilize this simulation to solve various issues with OCLs and pantographs.

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1) Koyama, T., Nagao, K., Ikeda, M., "Three-dimensional Simulation of Catenary/Pantograph Dynamic Interaction," Quarterly Report of RTRI, Vol.62, No.2, pp.104-109, 2021

Elucidating Deterioration due to Wheel-Rail Rolling Contact

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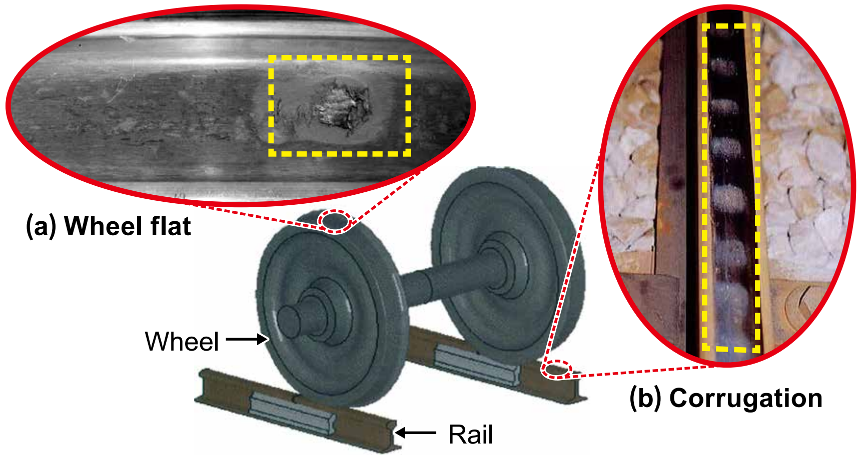


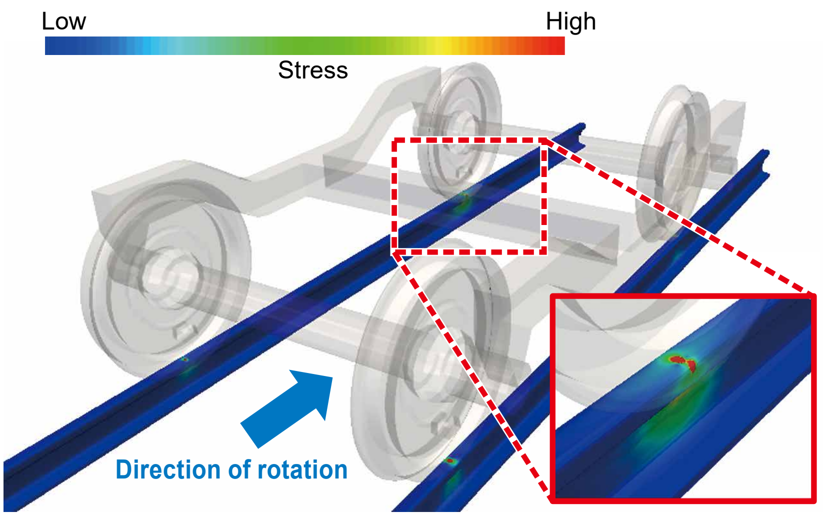
Examples of damage to wheels and rails

As vehicle wheels repeatedly roll on rails, the wheels and rails gradually deteriorate (Examples of damage to wheels and rails). There are various deterioration phenomena that are related to many causes such as the hardness and temperature of the material, in addition to the magnitude and direction of the acting force. Thus, to elucidate the mechanism of deterioration phenomena and propose countermeasures against the deterioration, RTRI is developing the Wheel-Rail Rolling Contact Simulator, which provides a method of simulating rolling contact between wheels and rails (Example of calculation using the Simulator (result of visualization of railway bogie stress distribution during curve running)). This paper shows the results of performing a numerical simulation targeting hollow wear of wheels, one of the deterioration phenomena, after making improvements for handling thermal effects and wear.

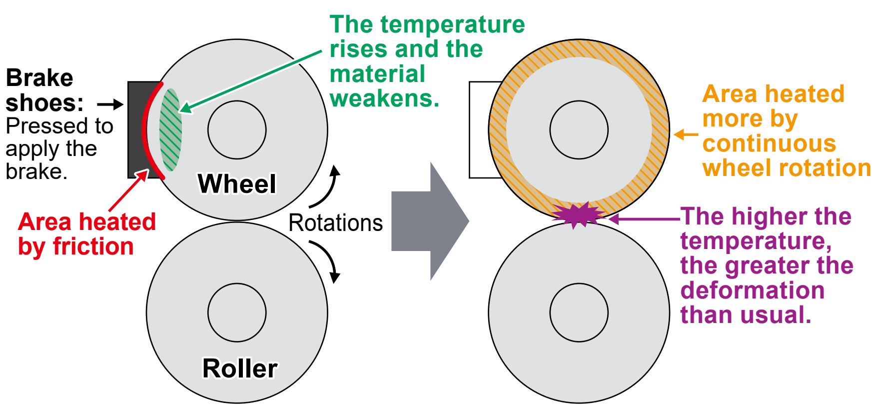
Reproducing wheel-rail contact phenomena using numerical simulation is an effective means for elucidating deterioration phenomena and estimating deterioration causes. Thus, we are working on the development of the Wheel-Rail Rolling Contact Simulator (hereinafter merely “Simulator”), which provides a simulation method that can continuously reproduce the contact state while solving the force balance between the wheel and rail).

One of the wheel deterioration phenomena is hollow wear, which refers to the tread of the wheel being permanently deformed into a hollow shape (Hollow wear conceptual diagram). Previous tests conducted by RTRI have demonstrated that the higher the wheel temperature, the greater the amount of permanent deformation. From this fact, it is considered that hollow wear is a phenomenon in which wheels with temperature rises due to the brakes and reduced strength come into contact with the rails, causing the wheels to undergo greater plastic deformation than usual (Mechanism of formation of hollow wear shape, estimated from test results). However, in tests, only the final wheel shape can be known, making it impossible to identify which of the above causes is the primary cause of permanent deformation.

Thus, to the Simulator, we added a function that can consider thermal effects, permanent deformation, and wear, and reproduced the experimental wheel deformation state by using a numerical simulation.



Example of calculation using the Simulator (result of visualization of railway bogie stress distribution during curve running)

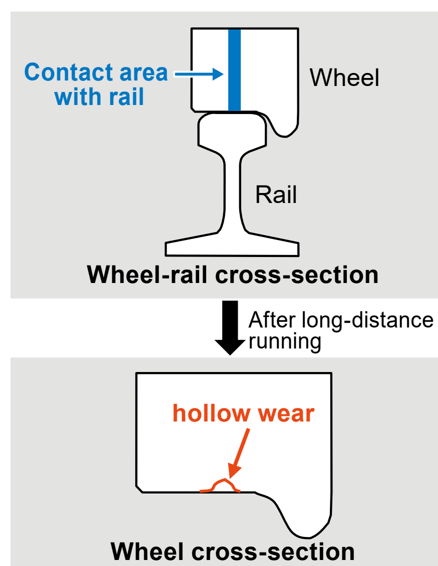


Mechanism of formation of hollow wear shape, estimated from test results

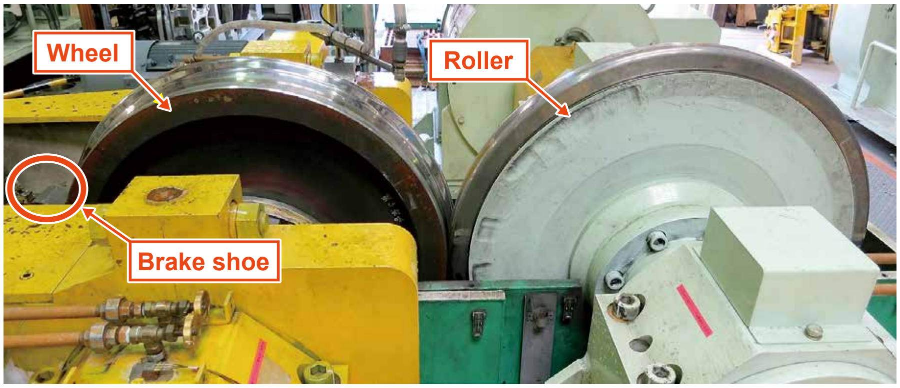
Heat Computation

There are three methods of heat transfer: heat conduction (heat transfer in an object), heat transfer (heat transfer between contacted objects), and radiation (heat transfer by electromagnetic waves), which can all be handled by the simulation method we are currently developing. In addition, the method can also take into account the heat generated by the friction between objects (i.e. frictional heat).

Thus, in this development, we assumed a



Hollow wear conceptual diagram



Brake test equipment

brake shoe contact area on the wheel side instead of actually pressing it against the wheel. We have developed a mechanism (heat input boundary) that automatically applies the amount equivalent to frictional heat according to the wheel rotation speed, to the wheel surface (i.e. the area that generates heat due to friction in Mechanism of formation of hollow wear shape, estimated from test results) in the contact area. This reproduces the wheel temperature rise while reducing the computation load.

The Simulator enables conducting numerical simulations that take into account the relationship between material deformation and heat.

Calculation Example Considering the Effects of Heat

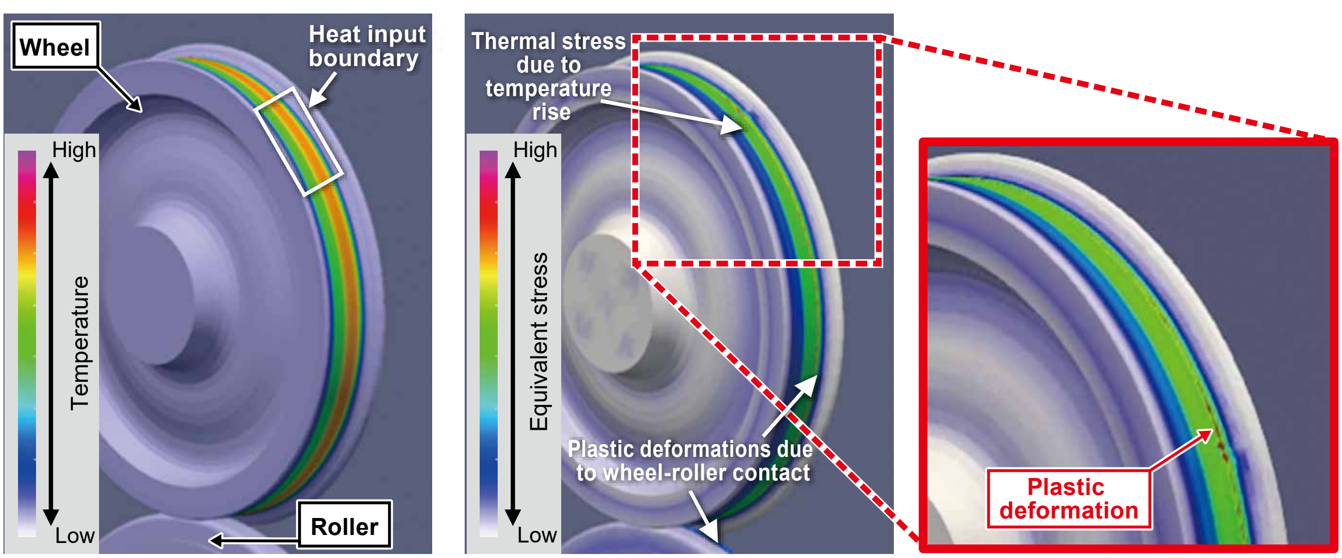
Brake test equipment shows RTRI's test equipment that uses disc-shaped wheels (rollers) that imitate wheels and rails. This simulates the braking of an actual railway vehicle by accelerating the wheel to the predetermined rotation speed and then pressing the brake shoe against the wheel tread.

The test decelerated the wheel from 130 km/h by pressing the brake shoe and measured the temperature by the sensor embedded inside the wheel. We have verified that the numerical simulation method we have developed reproduces the deceleration of the wheels and the rise of the temperature with an error of approximately 10%.

In addition, the numerical simulation can calculate and visualize attributes that are difficult to measure (e.g. equivalent stress acting on a wheel or roller; state of plastic deformation) and can be useful for elucidating the mechanism of damage phenomena (Results of wheel deceleration simulation that considers thermal effects (wheel temperature distribution and equivalent stress distribution)).

Wear Computation

There are multiple types of wear, and we adopted the Archard's law from several

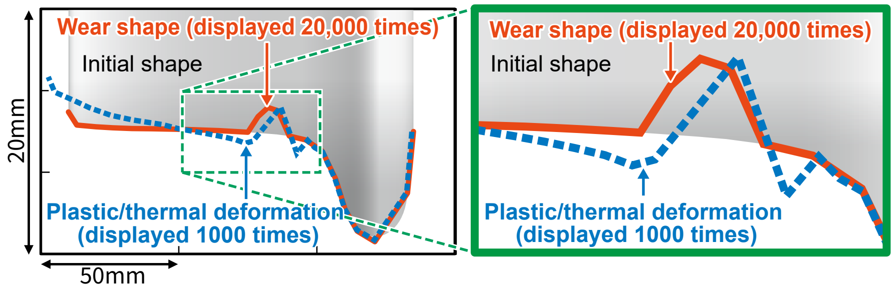


Results of wheel deceleration simulation that considers thermal effects (wheel temperature distribution and equivalent stress distribution)

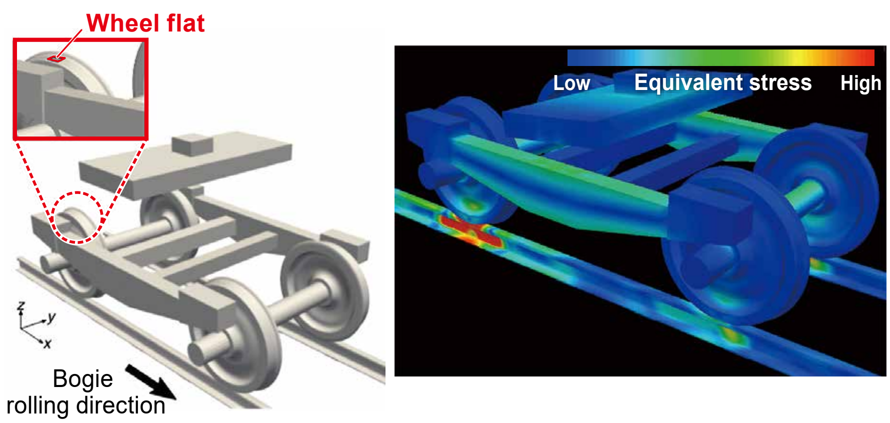
equations that have been proposed to model wear. We have proposed and introduced the new concept of a wear assignment ratio, where the respective wear amounts are assigned according to the ratio between the wheel and rail hardness. The use of this method results in the following: if the hardness's of the wheel and rail are significantly different, the wear amount that completely matches the case of using Archard's law can be obtained; if the hardness of both is close, the wear amount is evaluated to be less than before. We have verified that the simulation results of wear by the developed method generally match the amount generated in tests conducted within RTRI.

Example of Hollow Wear Computation

Using the Simulator, we performed a numerical simulation that simultaneously considered thermal effects, plastic deformation, and wear. Hollow wear simulation results (initial shape of wheel cross-section, plastic/thermal deformation, and wear shape) contains deformation diagrams of the wheel cross-section that was used for calculating the amounts of plastic and thermal deformation and wear resulting from wheel rotation, by using a model with the same shape as the analysis model used in Results of wheel deceleration simulation that considers thermal effects (wheel temperature distribution and equivalent stress distribution). The amount of thermal deformation due to temperature rise and the amount of plastic deformation due to wheel-rail contact are displayed at 1,000 times the initial shape, and the deformation amount due to wear is displayed at 20,000 times. From Hollow wear simulation results (initial shape of wheel cross-section, plastic/thermal deformation, and wear shape), we verified that plastic or thermal deformation is approx. 20 times larger than the shape change due to wear, suggesting that it is highly possible that hollow wear is a deterioration phenomenon caused by plastic or thermal deformation rather than wear.



Hollow wear simulation results (initial shape of wheel cross-section, plastic/thermal deformation, and wear shape)



Simulation example of a bogie using a wheel with tread flat damage (analysis model, and equivalent stress distribution during impact between the flat section and rail)

Conclusion

The Simulator can contribute to elucidating the mechanism of deterioration phenomena by focusing on processes such as the occurrence and growth of deterioration phenomena, such as the case of hollow wear simulation. We aim to study the following: (i) the distribution of the force generated between the wheel and rail and the range of effects of the propagated force can be studied by performing simulations using an analysis model, as in Simulation example of a bogie using a wheel with tread flat damage (analysis model, and equivalent stress distribution during impact between the flat section and rail), in which the wheel and rail are damaged in advance, and (ii) by investigating the state near the force generating portion in detail, the effects of deterioration of the wheel or rail on other members can be studied and the mechanism and for proposing countermeasures based on them can be elucidated.

Part of this research was carried out by collaborative research with National University Corporation The University of Tokyo.

Evaluating Wheel Slide Protection Performance Responding to Train Braking

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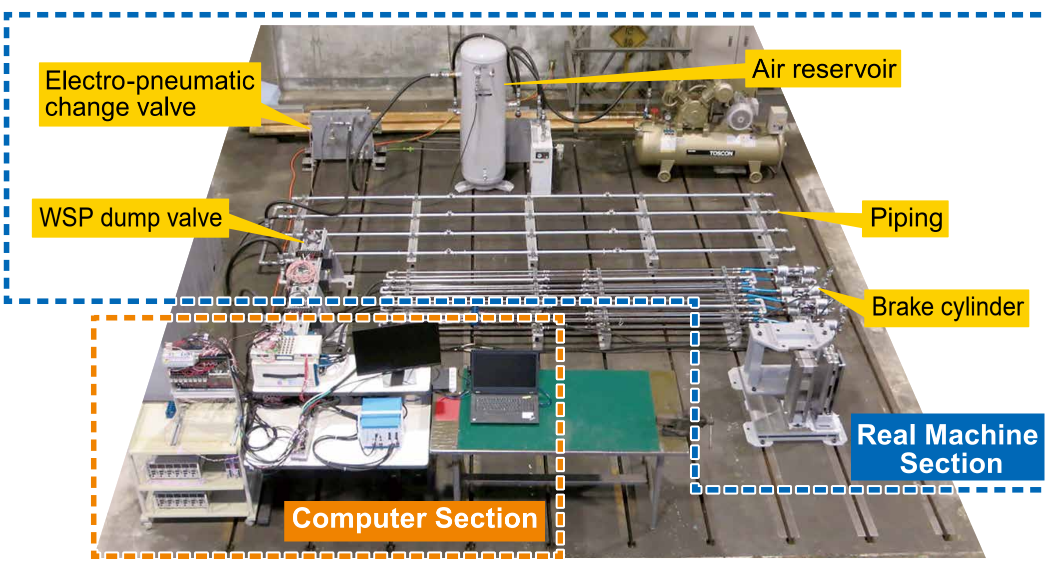
The wheels of railway vehicles are slippery, and if a slide occurring during braking it may result in risks of extending the stopping distance and damaging the wheels; wheel slide protection (WSP) is provided to countermeasures against these. WSP is a mechanism that adjusts the braking force according to the wheel slide state. WSP is an important safety-related technology and undergoes performance evaluation by a running test. However, since the slipperiness cannot be known until the train actually runs, it can slip too much or loosen the brakes too much. Thus, we considered a test method that simulates the slipperiness on a computer. This paper outlines the WSP performance evaluation method we have developed.



Overall view of the WSP Simulator

Overview of the WSP Simulator

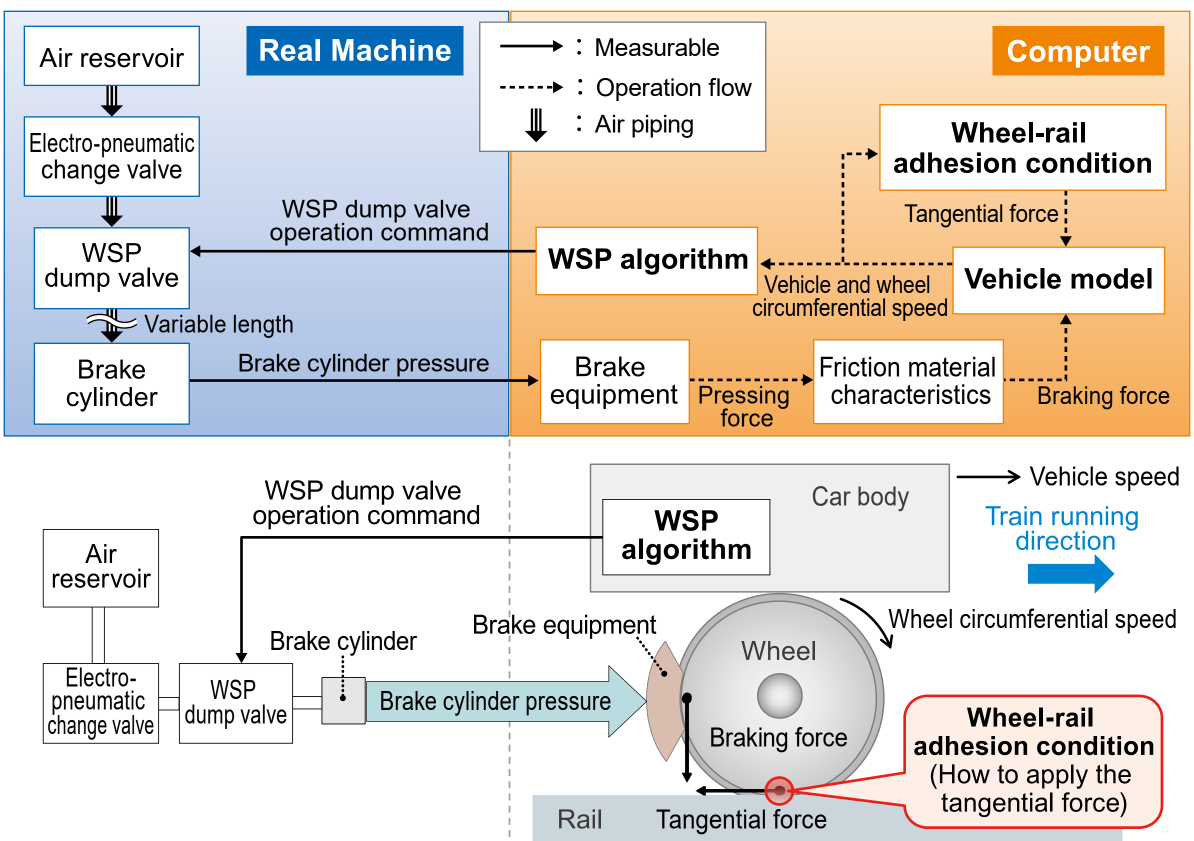
Overall view of the WSP Simulator shows the overall view of the WSP Simulator we have developed. It is test equipment for air brakes and is a hybrid simulator that uses a real machine to reproduce the brake cylinder (BC) pressure, which is difficult to model on a computer because the behavior differs greatly depending on the pipe length and volume, and uses a computer to simulate the other elements.

As shown in Block diagram and schematic, the simulator consists of the Real Machine Section and the Computer Section, the former of which uses piping and control valves for one actual vehicle from the air reservior to the BC, and the latter of which mainly specifies the vehicle model, WSP algorithm, and adhesion condition.

The vehicle model, which consists of mathematical formulas that express the movement of the vehicle inside the simulator, represent the movement in the traveling direction of the vehicle and the rotational movement of the wheels. The WSP algorithm automatically adjusts the BC pressure during a slide. It commands one of the three operations of exhaust, hold, and air supply to the WSP dump valve according to predetermined conditions. The adhesion condition refers to the frictional state between the wheel and rail, and herein it means how the tangential force between the wheel and rail is applied.

WSP Simulator Output Example

WSP Simulator output example shows the result of reproducing the deceleration of the vehicle by using the WSP Simulator. After starting the braking at time 0 s on the horizontal axis there is a rise in BC pressure. Only this BC pressure is the measured value, and based on this data,



Block diagram and schematic

the Computer Section computes the speed information, including the vehicle speed and wheel circumferential speed, and conveys it to the WSP algorithm. The WSP algorithm outputs the exhaust, hold, or air supply operation (determined from the slide detection conditions) to the WSP dump valve of the Real Machine Section as a command. The simulator has a loop in which the Computer Section computes the speed information again after reading the BC pressure changed by the operation of the WSP dump valve of the real machine. It continues looping until the vehicle stops (i.e. vehicle speed = 0 km/h), and computes the stopping distance, which is the distance along which the vehicle travelled during the period from the start of braking to its stop.

Comparison between Test Methods and Adhesion Condition

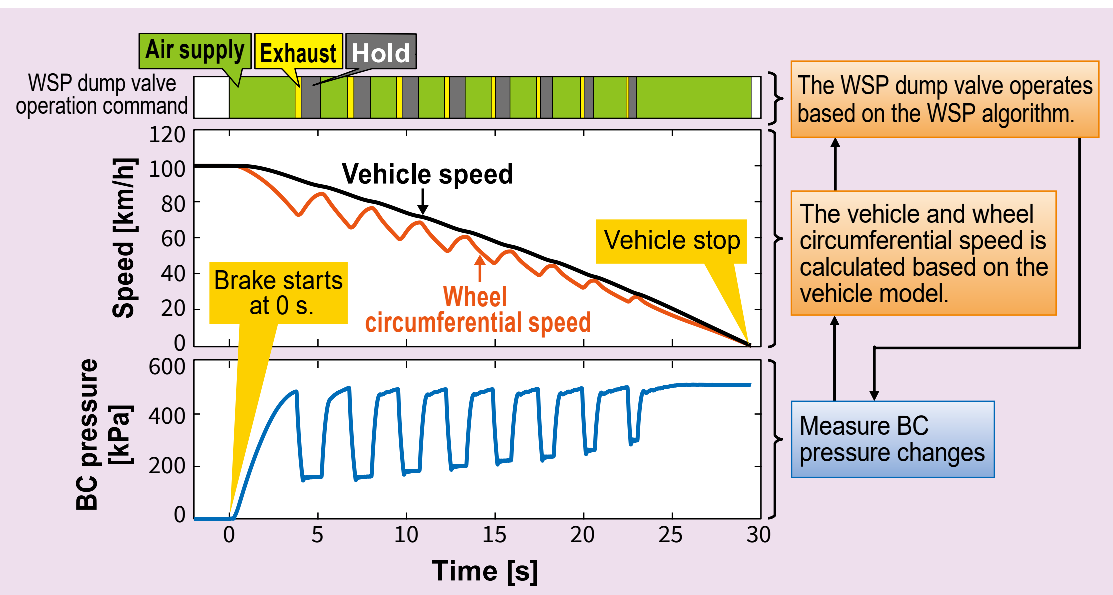
The performance of WSP is obtained as a result of the mutual influence of the WSP algorithm, adhesion condition, and BC pressure behavior. A simulation can evaluate these influences accurately and efficiently.

While the on-track test is the most realistic and convincing test method, it has limits to how much WSP performance can be evaluated with a limited number of tests.

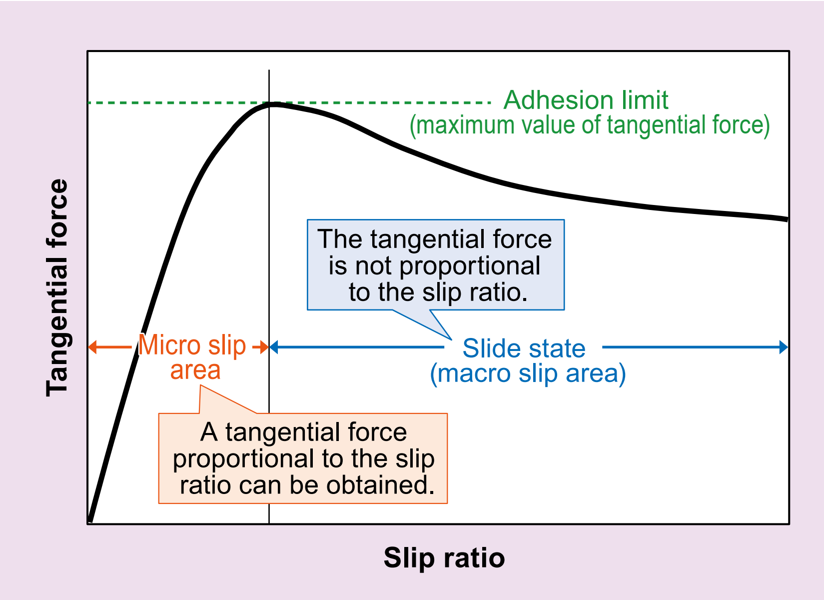
By contrast, the WSP Simulator allows the tester to set the BC pressure behavior and the adhesion condition among the three factors that affect the performance. The tester can specify, as a known amount, the adhesion condition that is liable to fluctuate and difficult to reproduce in the on-track test. Thus, this simulator is useful, for example, for comparing the performance when different WSP algorithms are applied to the same adhesion condition.

As seen from the comparison between the two methods, it is important to give the WSP Simulator an adhesion condition that is as close as possible to the on-track test. From the results of various research that analyzes the mechanism of adhesion between the wheel and rail (e.g. [1] and [2]), we refer to the findings such as detailed theoretical models and approximate values of experimental results and set the adhesion condition suitable for the test purpose.

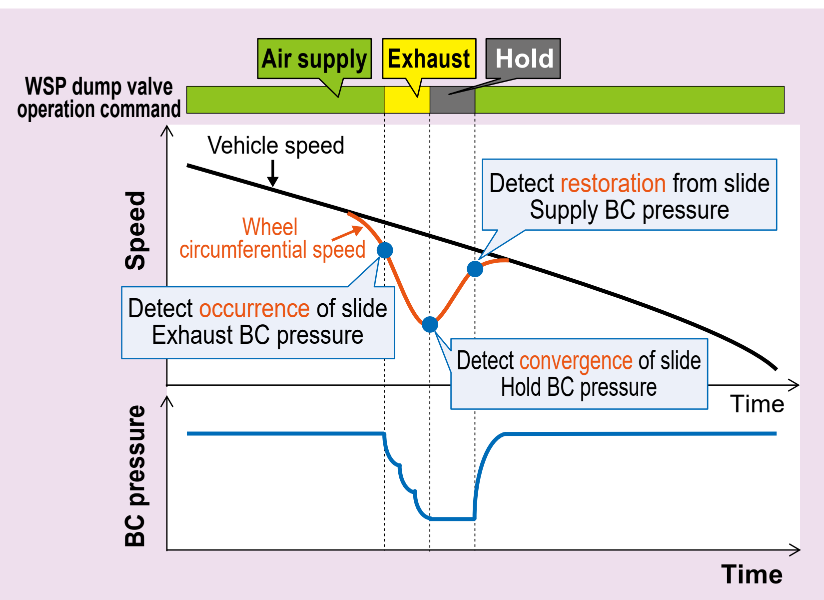
For the adhesion condition, this paper applies the relationship between the slip ratio and tangential force in Relationship between the slip ratio and tangential force, which is known as a general characteristic. The slip ratio, obtained by dividing the



WSP Simulator output example



Relationship between the slip ratio and tangential force



Overview of slip ratio WSP

difference between the vehicle speed and wheel circumfer-ential speed by the vehicle speed, is one of the indices showing the magnitude of the slide at that time.

In the WSP Simulator, the adhesion condition is given by quantifying the relationship between the slip ratio and tangential force intended by the tester (e.g. the adhesion limit value, the slip ratio that reaches the adhesion limit, and the tangential force behavior in slide state).

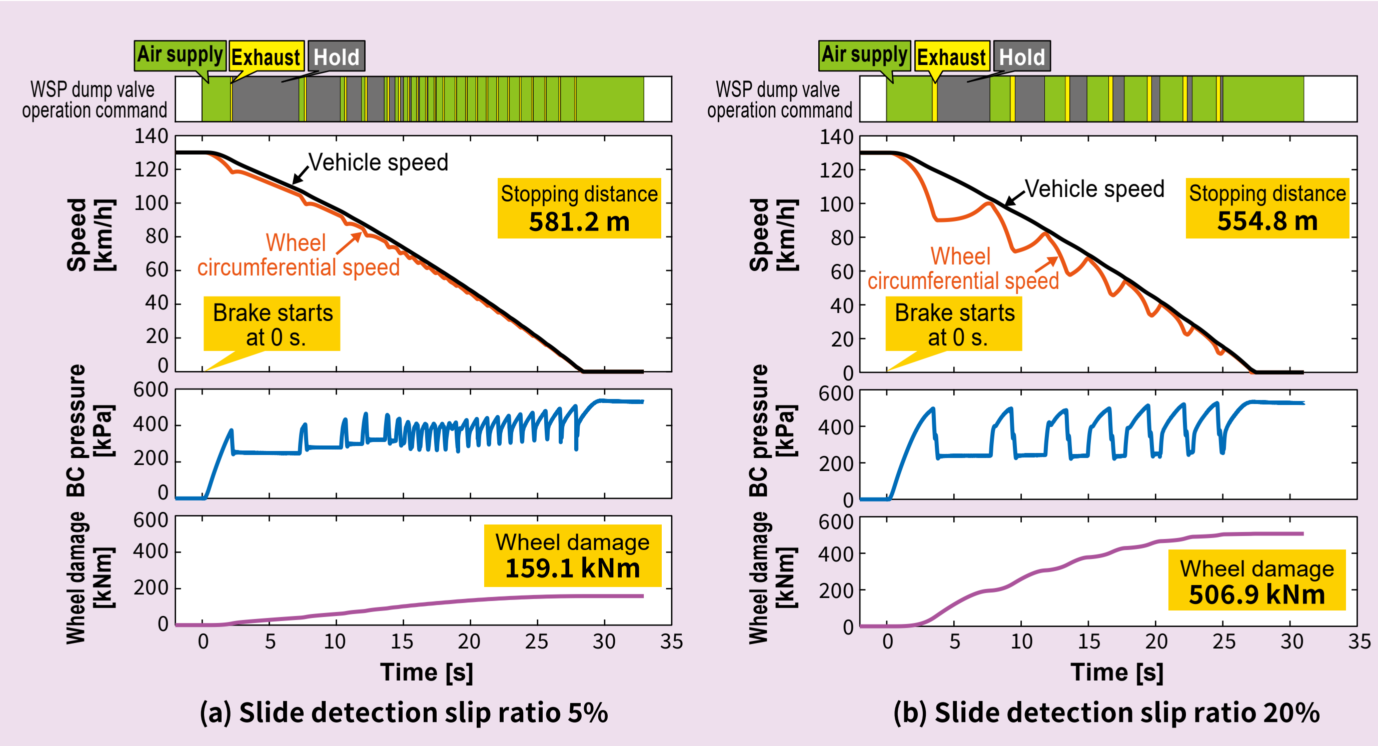
Performance Evaluation Indices

What is good performance WSP? As for evaluation indices to judge good or bad, since an increase in the stopping distance has a particular effect on safety, we choose it herein as the most important evaluation index.

Next, the physical quantity defined as the amount of wheel damage [3)] is used as the evaluation index for wheel flat prevention. It corresponds to work due to friction between the wheel and rail during a slide. It is 0 if no slide occurs; the value increases as the slide continues. It is calculated from speed information and braking force.

Test Results and Evaluation Examples

This section shows an example of an evaluation performed with the WSP Simulator. Overview of slip ratio WSP overviews the WSP algorithm (slip ratio WSP) to be evaluated. Once the slip ratio reaches the specified threshold, it detects the occurrence of a slide and exhausts the BC pressure, detects that the slide has turned to convergence, and maintains the BC pressure. Then, after detecting the restoration from the slide and supplying the BC pressure, it repeats the previous steps. As for the threshold value of the



Test results from changing the slide detection slip ratio

slip ratio at which to detect a slide, the following two were evaluated: (a) 5% (reducing the allowable slip ratio, with priority given to wheel flat prevention) and (b) 20% (not loosening the brake as far as possible, with priority given to the not increasing the stopping distance).

Test results from changing the slide detection slip ratio shows the results of operating the brake from a speed of 130 km/h with the BC pressure behavior and adhesion condition in common. As a result, the stopping distance was 581.2 m in condition (a) and 554.8 m in condition (b); the wheel damage was 159.1 kNm in condition (a) and 506.9 kNm in condition (b). In this example, we conclude that condition (a) is superior in terms of load on the wheel, but (b) is superior if safety is considered to be the highest priority (e.g. for emergency braking).

Conclusion

We expect to utilize the WSP Simulator as a new development tool for the WSP algorithm and as a method to reduce the number of trials during the on-track test by checking the performance of this algorithm before performing that test. In the future, we will improve its modeling accuracy and expand its functions to make it a more user-friendly simulator.

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Evaluating Train Vehicle Running Safety on a Bridge in the Event of an Earthquake

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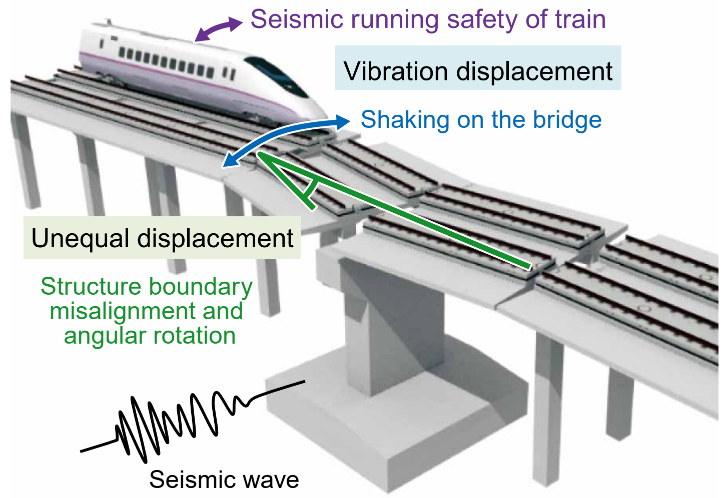
The 2004 Niigata Prefecture Chuetsu Earthquake, the 2011 off the pacific coast of Tohoku earthquake, and the 2015 Kumamoto earthquakes caused railway vehicle derailments (Shinkansen train derailed by the 2004 Niigata Prefecture Chuetsu Earthquake). Multifaceted measures are being promoted throughout the railway system to prevent derailments in future earthquakes. Vehicle derailment behavior is affected not only by the magnitude and characteristics of earthquake motion, but also by the effects of structures, tracks, and vehicle vibration characteristics. Thus, evaluating it accurately requires a cross disciplinary outlook. After outlining the technology to simulate the vehicle derailment behavior considering these effects, this paper introduces a newly proposed, simple evaluation method for seismic running safety on a bridge that takes into account the nonlinear behavior of structures.

Shinkansen train derailed by the 2004 Niigata Prefecture Chuetsu Earthquake

(Source: "The Railway Accidents Analysis Report" (Japan Transport Safety Board) (http://www.mlit.go.jp/jtsb/railway/rep-acci/RA2007-8-1.pdf; as of October 13, 2021))



Vibration displacement and unequal displacement

Introduction

Vehicle derailment behavior in an earthquake, influenced by many factors, presents a complex mechanism. Nonetheless, thanks to vigorous R&D since the 2004 Niigata Prefecture Chuetsu Earthquake, simulation technology has been advanced, and causes of these derailments have been individually elucidated and the behavior has been quantified.

Most vehicle derailments during earthquakes so far have occurred on bridges and viaducts. It is known that derailment is greatly affected by vibration amplification and unequal displacement; the former of which is caused by the bridge shaking more than the ground surface, hence, amplification and the latter of which is caused by misalignment against the adjacent bridge due to the different earthquake shaking (Vibration displacement and unequal displacement)[1].

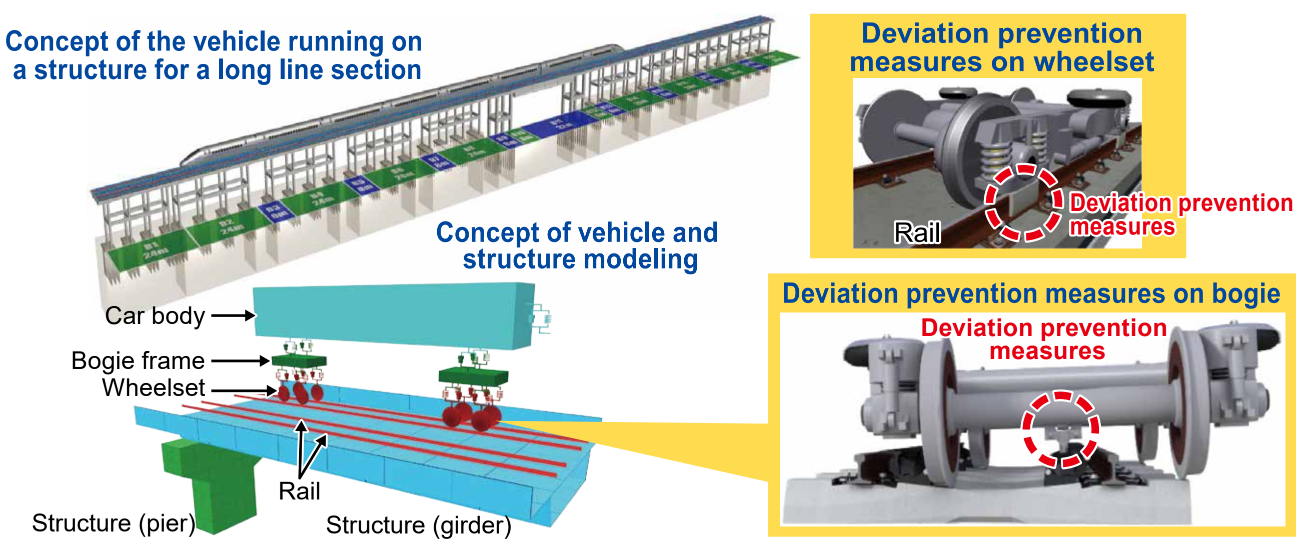
It is known that embankment sections and tunnel sections have a low possibility of derailing a train during an earthquake. This is because embankments and tunnels have less amplification of earthquake shaking than on bridges. In addition, they have an advantage over bridge sections in that they have less track misalignment.

Evaluating seismic running safety in an earthquake by dynamic simulation of a vehicle/bridge

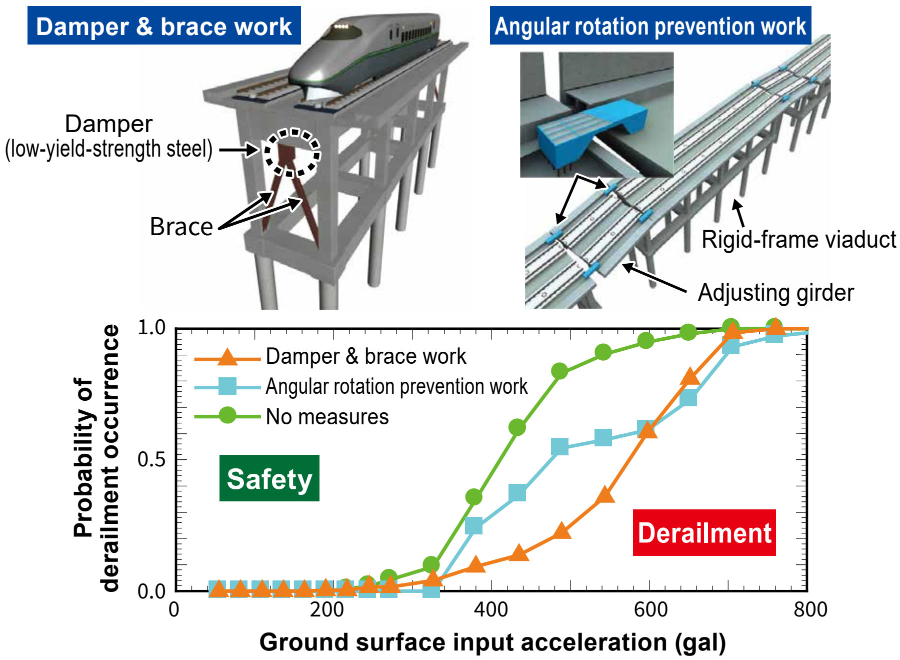
To elucidate the derailment behavior of railway vehicles running on bridges in earthquakes, we need to perform detailed numerical simulations using a computer. To do this, we need to consider not only vehicles but all the dynamic behavior of track surfaces and bridges on which the vehicles run.

RTRI has been developing the dynamic interaction analysis program DIASTARS for vehicles and structures (Dynamic interaction analysis program considering the vehicle-structure dynamic interaction)[2]. It can simulate the behavior of vehicles and structures, taking into account the interaction forces between wheels and rails. As in Dynamic interaction analysis program considering the vehicle-structure interaction, DIASTARS is used for vehicle running analysis in an earthquake for long line sections and for the performance evaluation of deviation prevention measures following the derailment.

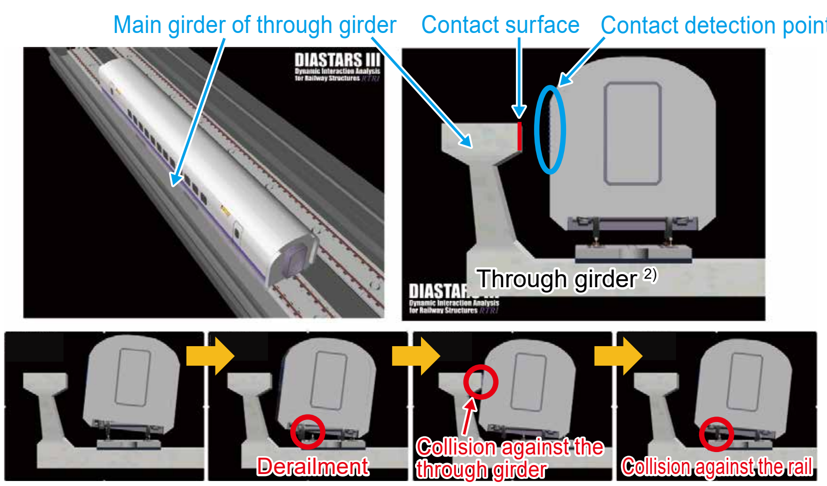
Probability of derailment occurrence shows an example of performance



Dynamic interaction analysis program considering the vehicle-structure dynamic interaction



Probability of derailment occurrence



Contact analysis of vehicle-structure interaction

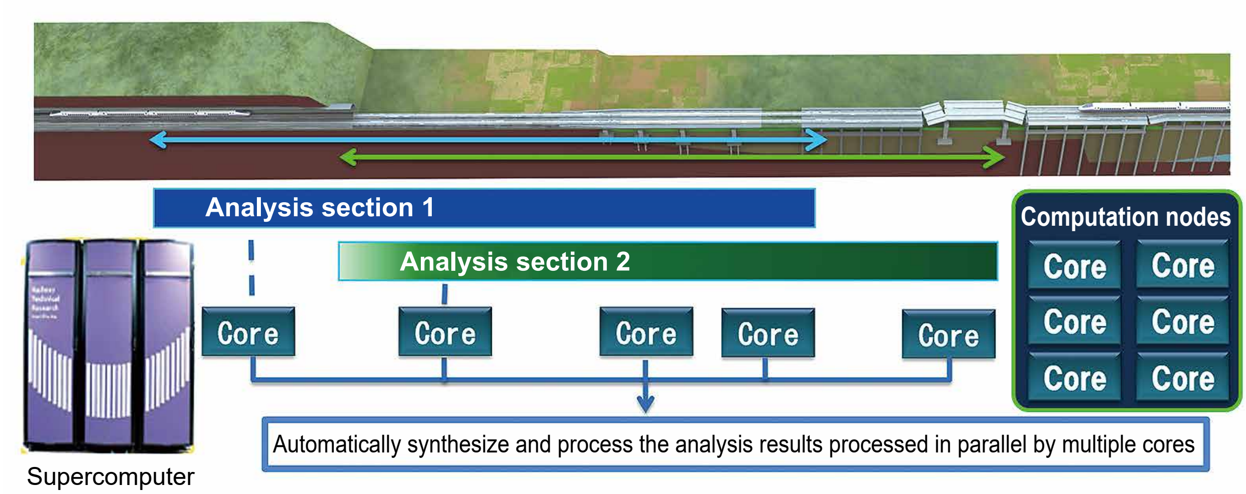
evaluation for damper & brace work and angular rotation prevention work, which are countermeasures to reduce the probability of derailment during earthquakes. Damper & brace work is a construction method that reduces the response in an earthquake by placing steel materials diagonally, like braces, to increase stiffness and combining dampers, which are members absorbing the earthquake motion energy. Angular rotation prevention work is a construction method that reduces the deviation at the boundary by connecting the viaduct in the track direction. In this example, note the 400 gals (≈ 0.4 times the gravitational acceleration) point of the ground surface input acceleration (*1) on the horizontal axis in the figure. With no prevention measures, the probability of derailment damage (*2) was approx. 45%, whereas with the introduction of angular rotation prevention work, it decreased to approximately 30% and, with the further introduction of damper & brace work, it decreased to approximately 10%. (*1: maximum acceleration on the surface of the earth due to the earthquake; *2: percentage of the wheelsets that derailed in series of trains running in the line section.)

Because it can also continuously analyze the dynamic behavior before and after the derailment, in recent years DIASTARS has also been used for R&D aimed at elucidating the behavior of vehicles after a derailment and evaluating the performance of countermeasure work to prevent deviation. For example, it enables performing numerical analysis in consideration of contact between deviation prevention measures installed on the bogie or wheelset of the vehicle and the track structure (Dynamic interaction analysis program considering the vehicle-structure interaction) and contact between the car body and track structure. Contact analysis of vehicle-structure interaction shows an example of an analysis of how the vehicle derails due to shaking by earthquake motion and the car body collides with the main girder of the through girders located on the side of the track.

For configuring the computation process, as in Dynamic interaction analysis of long line section by parallel computation of supercomputer, the analysis section is divided into multiple smaller sections, and the running analyses of the respective sections are concurrently processed on multiple processors in a supercomputer to significantly speed up the process. This allows us to exhaustively capture the effects of various parameters such as vehicle speed, running position, and magnitude of earthquake motion, enabling us to consider the whole of a long line section and detailed phenomenon elucidation.

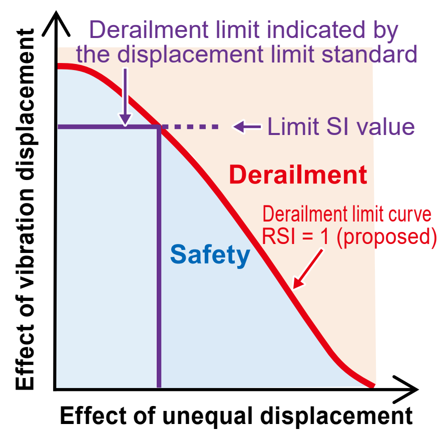
New Evaluation Method for Seismic Running Safety for Large Scale Earthquakes

RTRI has proposed a new evaluation method for seismic running safety, considering the nonlinear behavior of bridges in large scale earthquakes (Evaluation method of seismic running safety considering the nonlinear behavior



Dynamic interaction analysis of long line section by parallel computation of supercomputer

of the bridge)[3]. This method determines the possibility of vehicle derailment by calculating the running safety index (RSI), which is an index that takes into account the effects of vibration displacement and unequal displacement. Specifically, if RSI > 1, it determines that the possibility of the derailment is high, and RSI < 1 it determines that the vehicle running is safe. RSI evaluates seismic running safety by focusing on the effect of vibration displacement on the vertical axis, independently of the effect of unequal displacement indicated on the horizontal axis. The proposed RSI is an index that simultaneously considers the effect of vibration displacement focusing on the acceleration of the top of the structure and the effect of unequal displacement due to angular rotation of the bridge boundary. The effectiveness of the RSI index and the derailment limit curve as shown above was found by performing the precise simulation of vehicle running in an earthquake for several hundred thousand cases that assume a wide range of conditions, by using DIASTARS on a supercomputer as described above. The RSI values (the range below the red curve in Evaluation method of seismic running safety considering the nonlinear behavior of the bridge) are effective also for nonlinear responses in large scale earthquakes and, therefore, can be applied to a wider range than displacement limiting standards that require the assumption of linear responses (the purple line range in Evaluation method of seismic running safety considering the nonlinear behavior of the bridge). In addition, the validity of the RSI was validated for multiple long line sections after it was verified that the result of simulation by DIASTARS and the result of the evaluation by RSI matched with each other regarding the derailment position and the derailment limit.



Evaluation method of seismic running safety considering the nonlinear behavior of the bridge

Conclusion

We think that if we can develop a bridge that does not let vehicles derail in an earthquake, it will be the ideal form of a railway bridge, but to realize this would require future technological development.

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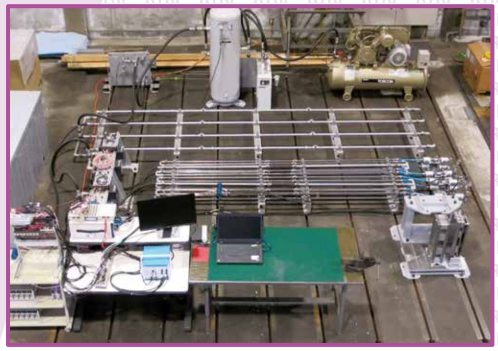

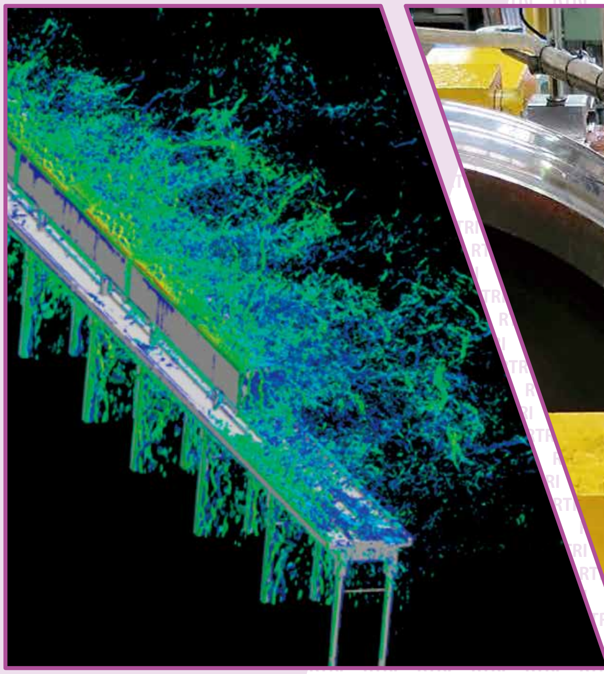

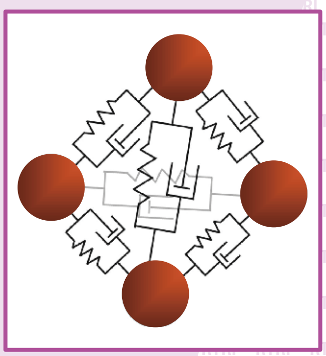

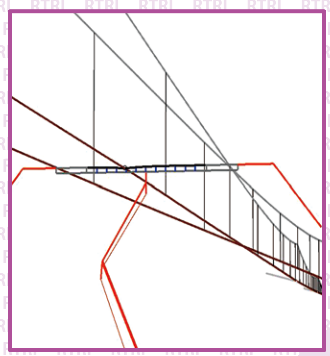

Railway Technical Research Institute