Recent Research and Development in Railway Dynamics

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Railway Dynamics is the research field for finding out technical solutions for dynamic problems caused by the characteristics of the railway system. RTRI has been tackling many problems in the field of railway dynamics. To accelerate this research and development, RTRI has been developing organized simulation tools in the form of a “Railway Simulator” using high performance computing technologies, since 2010. This simulator mainly focuses on interaction in boundary regions such as wheel/rail/track/structure, pantograph/catenary, and so on. This paper describes current research activities including the development of the railway simulator for the purpose of achieving a safer and more reliable railway system.

Keywords: railway dynamics, dynamics, simulation, contact phenomena, running safety, earthquake

1. Introduction

Railway is a transportation system used for carrying passengers or freight by wheeled vehicles on rails. It is mainly characterized as a transportation system without intentional steering, allowing safe and precise operation. Nonetheless, since rails and track greatly affect the kinematic performance of vehicles, proper maintenance is essential. According to the RTRI definition, “Railway Dynamics” covers all areas related to dynamic subjects and dependent on railway characteristics, and R&D is geared to improving safety, convenience, maintainability, and acceptability.

Railway Dynamics aims to solve dynamic interactions. Rails play a role of supporting and guiding vehicles. Interaction between wheels and rails controls the dynamic character of rolling stock, as well as causing long-term deterioration of wheels and rails (Fig. 1). Tracks which are the structure holding the rails to the line, generate interaction between vehicles and structures (e.g. viaducts, bridges, and tunnels). Such interacting forces may accelerate the subsidence of ballasted track and induce cracks on structures. As for overhead contact lines, interaction between contact wires and pantographs may produce wear of contact wires and contact strips, as well as reducing current collection quality.

Dynamic interaction stems from a vast array of parameters. Therefore, numerical simulation is useful for precise examination of these phenomena. In some cases, observing phenomena through experiments or real-vehicle tests is difficult in practice. In such cases numerical simulation is only means to obtain an effective solution. Improving and mainstreaming numerical solution tools is therefore a central part of Railway Dynamic research. Based on this priority, RTRI has been developing the “Railway Simulator” lead by the Railway Dynamics Division. Some phenomena resulting from dynamic interaction and underlying long-term deterioration induced in vehicles and facilities do not have well-established physical models which would allow their proper simulation. These cases require fundamental experimentation and observations of the phenomena in real situations to gain appropriate understanding of the

Fig. 1 Examples of damage and deterioration related to wheels and rails

physical mechanisms at play.

This paper introduces recent R&D results related to Railway Dynamics and describes the current state of development of the Railway Simulator that numerically reproduces the dynamic interaction inherent in railways.

2. Railway Simulators

In order to improve the quality and efficiency of research activities related to railways, RTRI is pursuing the development of the Railway Simulators which will be able to reproduce various phenomena arising from train operation, on a computer. Work in this area has reached Phase 1 at present, which is implementation of its core system.

The core systems of the Railway Simulators comprises some simulator groups, that is, a “virtual railway testing tracks”, an “airflow/aeroacoustics simulator”, and

an “earthquake-disaster simulator” . The virtual railway testing tracks are sets of simulation tools for reproducing the dynamic behavior of tracks on a computer, vehicles and overhead contact lines in normal train operation. A simulator to analyze wheel/rail rolling contact behavior [1, 2] based on large-scale FEM contained in the virtual railway testing tracks can emulate phenomena for damage deterioration related to wheels and rails, shown in Figure 1. Such damage-deteriorative phenomena between wheels and rails are also deeply related to the long-term degradation of ballasted track which supports the rail. A ballast analysis model [3, 4, 5, 6] is being developed in parallel that reproduces the dynamic behavior of ballasted track coupled with the rolling contact behavior simulator described above. This model, calculating the elastic behavior of sleepers and individual ballast stone through Quadruple Discrete Element Method (QDEM), can estimate precisely the behavior of sleepers and ballast stones when a train passes (Fig. 2). While it is now at a stage where a ballasted track with one sleeper can be simulated, a wider range extended in the rail direction will be covered soon, being expected for the development of an effective countermeasure for ballast settlement.

The airflow/aeroacoustics simulator is composed of two simulators, namely an airflow simulator for analyzing the flow field around an object and an aerodynamic-noise simulator for calculating the aerodynamic-noise intensity [7]. The airflow simulator employs a Cartesian Mesh Method to mitigate time-consuming meshing operations as part of the flow-field analysis. Large-scale computers are required for performing high-precision flow-field calculations via the Cartesian Mesh Method, therefore this program makes highly efficient use of super computers. Figure 3 shows the prediction results of aerodynamic noise of a cylinder. This figure indicates that simulated aerodynamic noise by the airflow/aeroacoustics simulator is equivalent to that by the aeroacoustics simulator in combination with a conventional CFD solver using boundary-fitted grids.

The earthquake-disaster simulator forecasts damage to railway structures when an earthquake occurs at an arbitrary location in Japan. It consists of simulation tools for estimating seismic propagation from the epicenter and for predicting damage to railway structures due to seismic

Fig. 2 Example of ballast behavior analysis by Quadruple Discrete Element Method

(a) Result of flow field analysis (vortex structure)

(b) Comparison of aerodynamic noise between prediction and experiment

Fig. 3 Analysis results of flow-field and aerodynamic-noise of a cylinder by using Cartesian Mesh Method

waves. By simulating damage to railway structures under various scenarios, this method can be widely applied to prioritise where seismic countermeasures should be applied, or to gauge the expected effectiveness of such countermeasures.

Phase 1 of the Railway Simulator development was completed by the end of fiscal year 2014, with Phase 2 commencing in fiscal year 2015. Phase 2 will include work focusing not only on existing dynamic simulators but also other simulators for train operation, passenger behavior, and the communication environment for railway operations. More integrated simulation tools will also be designed by building cooperative computational environments for the simulators.

3. Fundamental studies related to Railway Dynamics

3.1 Contact phenomena

While simulation is a significantly powerful research tool as stated in the previous chapter, it is only possible using established physical models available for the phenomena in question. Among tribological phenomena such as contact and abrasion, however, there are many unsolved issues, which require on-site observations and fundamental experimentation.

In wet running conditions, where the wheel/rail contact surface is covered with a film of water from rain or snow, for example, the adhesion coefficient drops due to the lubrication effect of the water film, thereby making the wheels prone to slipping or sliding. Measures in this case rely on pre-estimation of the adhesion coefficient which is complex, given by the many parameters involved. RTRI conducted research into the various parameters affecting the coefficient by utilizing a test device (Twin-disc Rolling Contact Machine: Fig. 4 (a)) owned by RTRI [8]. Results

(a) Adhesion estimation with the twin-disc rolling contact machine

(b) Motion simulation of water drop colliding with wall

Fig. 4 Fundamental studies for solving adhesion characteristics in wet conditions between wheels and rails

from these experiments were successful and led to a study on the influence of surface roughness and contact temperature on the adhesion coefficient between wheels and rails in wet conditions and is reported on in this special issue [9].

In parallel with these experimental trials, RTRI is also working on a study of numerical simulation to predict the behavior of the water film between wheels and rails using the Particle Method. Although this simulation program just has started (Fig. 4 (b)), it is expected to be a powerful tool complementing the aforementioned experiments, to understand further underlying phenomena.

3.2 Vehicle running safety

When a train runs on a track containing large planar displacement like emerging from the exit of a transition curve with a sharp bend, the outer-track wheel of the wheel-set at the head of each vehicle in the traveling direction may sometimes exhibit a large drop in wheel load. This is because the vehicle load acting on one bogie is supported by 3 wheels (so-called 3-point support) at a location where the planar displacement is large.

When a large lateral pressure acts on the wheel while in this state, it may climb over the rail, leading to possible derailment. As a practical countermeasure to this, RTRI is developing a bogie which can control the decrease in wheel load [10]

A feature of the new bogie is a rotatable side beam positioned against the cross beam as shown in Fig. 5 (a). As the left and right side beams can rotate independently in the pitching direction, each wheel can catch up with the large planar displacement, thereby suppressing the wheel-load reduction. Since this bogie has the same structure and parameters as a conventional bogie, except for the rotation-

(a) Bogie frame structure

(b) Suppressive effect of wheel-load reduction (Roll rig test)

Fig. 5 Bogie structure to control the decrease in wheel-load and its wheel-load reduction effect

al mechanism in the side beams, the reliability for safety on normal operations is also high.

Figure 5 (b) shows the result of investigations into the suppressive effect of the wheel-load reduction ratio through rolling tests on RTRI's rolling stock testing plant. Results revealed that the wheel-load reduction ratio with the new design was 40 %. At present, two bogies of this type were manufactured for mounting on the same vehicle, being tested for various running conditions.

3.3 Response analysis of structures in earthquakes

Response estimation of structures is important because serious damage of structures by earthquakes creates a significant impact. While a large interactive force may be expected in large-scale earthquakes between vehicles and structures, there has been no means to evaluate its influence.

Hence, the effect of vehicle vibration due to earthquakes on seismic response of structures was studied in detail through numerical simulation, and an estimating procedure that is reasonable and also simple was proposed by generalizing simulation results [11, 12]. As an assessable means for actual design, an equivalent inertia method (static analysis) for the general static seismic design and an equivalent weight method for dynamic design including special-long bridges were proposed (Fig. 6). Estimation of structural seismic response becomes a reality through utilizing these procedures, economical structural design and high-precision seismic diagnosis for existing structures can be actualized.

(a) Dynamic interaction of vehicle/structure in earthquakes

(b) Concept of equivalent weight method

Fig. 6 Seismic design of structures considering influence by dynamic behavior of train

4. Conclusion

This paper reports the developmental status of the Railway Simulator that numerically reproduces dynamic interactions inherent in railways, also introducing some of the recent R&D results related to Railway Dynamics.

As stated at the beginning, the essential mission of the Railway Dynamics is to solve the dynamic interactions. Application of the Railway Simulator will accelerate the resolution of dynamic interaction phenomena in the boundary regions (vehicle/track/structure, overhead wire/pantograph, etc.) inherent in railways, also being expected to contribute to the establishment of effective suppressive measures for long-term deterioration phenomena induced by such dynamic interactions.

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