Measurement and Discrete Three-Dimensional Modeling Techniques of Dynamic Behavior of Ballasted Track

Akira AIKAWA
Senior Researcher, Track Dynamics, Railway Dynamics Division

The ballast in ballasted track consists of an assemblage of ballast particles having irregular shapes, each subject to minor frictional phenomena including rotation, slippage and crushing caused by dynamic and impact loads of high-speed trains. The effect of the phenomena over a long period of time causes localized and uneven plastic deformation inside the ballast aggregate. This phenomenon is governed by the dynamic characteristics of the discrete aggregate of ballast particles that form a skeletal structure. An effective way of investigating the mechanism of ballast breakdown caused by running loads, therefore, is to reproduce the behaviour of particles subjected to dynamic and impact loads by using a discontinuous model simulating the microstructure of particle assemblage.

The Railway Technical Research Institute (RTRI) has created a three-dimensional dynamic model of a discontinuous structure to reproduce the assemblage composed of ballast particles in detail. By applying the three-dimensional distinct element method to this model, the authors are now implementing dynamic response analysis for structural elements of the track against running train loads.

For this purpose, the authors first measured the profiles of about 4,000 ballast particles with a contact-type three-dimensional digitizer and represented them as polyhedron models by using a newly developed automatic polyhedron-generating algorithm (Fig. 1). After adjusting the grain size distribution of about 28,000 polyhedron models, the authors performed a simulation to compact ballast particles by dynamic loads and created a ballast structure, again by applying the three-dimensional distinct element method. The authors then created models of the structural elements of the track including sleepers, each as a three-dimensional distinct element model to simulate the detailed structure of ballasted tracks (Fig. 2).

The authors then used the three-dimensional distinct element method to input a rail seat force measurement waveform obtained at a welded rail joint when a limited express train running at 78 km/h was modelled as a moving load. Figure 3 shows the distribution of the translational and rotational velocities of the ballast particles near the bottom of the right side rail in the loading and unloading processes. This figure indicates that the ballast directly beneath the sleepers conspicuously translates and rotates in both processes, with the ballast near the sleeper ends exhibiting concentrated rotational motion.

In this manner, the above-mentioned dynamic model of a discontinuous structure that minutely reproduces an assemblage of particles enables quantitative assessment of rotation, frictional slippage and other complicated behaviours specific to particles. It also reproduces the contact force between particles, and the internal stress and history of movement of ballast particles, which are not normally observable or measurable in tests. This means that it is possible to evaluate in quantitative terms the dynamic performance, deformation features, energy dissipation characteristics and frequency dependency of ballast particles based on the results of numerical analysis.

After developing a “sensing sleeper” with a number of ultra-thin impact force sensors attached to its underside, the authors are now measuring the pressure distribution on the bottom surface of the sleeper by using it to quantify the actual phenomena in the field and determine relevant parameters. The authors are also measuring three-dimensional translational and rotational behaviours of ballast particles with a “three-dimensional sensing stone” having two built-in tri-axial acceleration sensors.

In the next step, the authors will improve the precision of the model developed to investigate the deterioration of ballasted track and discuss methods to evaluate the measures so as to reduce maintenance costs.

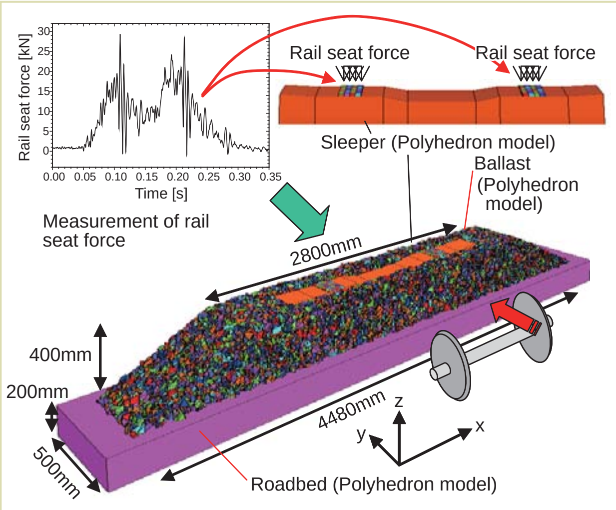

Fig. 2 Three-dimensional DEM model analysis

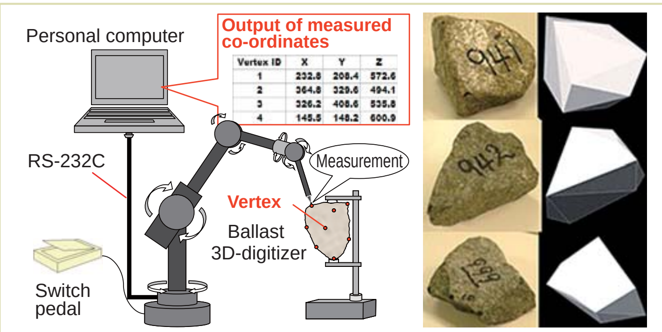

Fig. 1 Digitization of grain shape

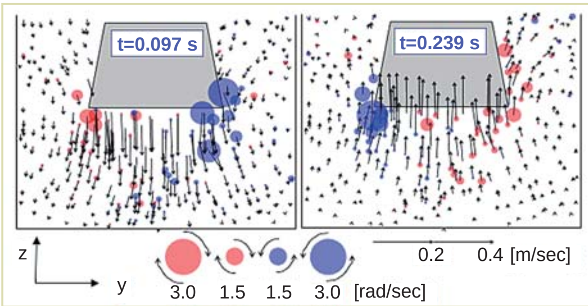

Fig. 3 Translational/rotational velocities of ballast particles under the right side rail (simulation)