Newsletter on the Latest Technologies Developed by RTRI

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Railway Technical Research Institute
2-8-38 Hikari-cho, Kokubunji-shi
Tokyo 185-8540, JAPAN
URL: http://www.rtri.or.jp

Editorial Office: Ken-yusha, Inc.
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The Progress of the RTRI's Five-Year Master Plan

Yuji NISHIE
Director, Planning Division

The Railway Technical Research Institute (RTRI) is currently promoting a variety of projects based on the RESEARCH 2005 Five-Year Master Plan launched in 2005.

As basic policies, the Master Plan manifests such subjects as the creation of railway technologies in the 21st century, maximization of the integrated power of the RTRI as a group of railway engineers, quick response to the needs of railways, inheritance and dissemination of railway technologies, accumulation of basic technologies, and transmission of information on developmental activities.

In line with these policies, the RTRI has four targets: realizing a highly reliable system of railways, providing passengers with convenient travel, establishing railways with low construction and operation costs, and achieving harmony between railways and the environment.

To attain these targets, the RTRI currently implements activities in three areas: research for the future of railways, technological development for practical purposes, and research to solidify the basis of railway technologies.

The RTRI has promoted research and development quite successfully in the past during the period of this Master Plan. In the meantime, however, the social and economic environment surrounding railways has started to undergo rapid change.

On the Joetsu Shinkansen line, a train derailed in the Mid Niigata Pref. Earthquake of 2004. In 2005, a derailment/overturning accident involving a commuter transport train occurred on the Fukuchiyama line, and another derailment/overturning caused by gusting winds also happened with an express train on the Uetsu line in the same year. In the wake of these successive accidents, concern among the Japanese public about the safety and reliability of railways has increased considerably. In administrative terms, on the other hand, the Ministry of Land, Infrastructure, Transport and Tourism (MLITT) integrated the Aircraft and Railway Accidents Investigation Commission (ARAIC) and the Investigation Division at the Marine Accident Inquiry Agency (MAIA) in October 2008 to create the Japan Transport Safety Board (JTSB) and bolster the structure that supports accident surveys and investigations. Furthermore, the global economy is becoming increasingly chaotic, with the problems of resources and energy - including global warming, soaring crude oil prices and the exhaustion of rare metals - becoming ever more serious. In December 2008, the government enacted three laws to restructure corporations in the public interest; the RTRI will also be required to respond appropriately to these laws.

Amid these ever-changing circumstances, the RTRI is preparing the Master Plan for 2010 and thereafter. As part of this process, the RTRI will discuss measures to maximize the potential of railways and meet the requirements of a globalized society and a nation in which the effects of falling birth rates and longer life expectancy are becoming increasingly evident.

UIC Panel of Structural Experts Meeting and Exchange Seminar in Japan

Nobuyuki MATSUMOTO
Deputy Director, International Affairs Division

The Railway Technical Research Institute (RTRI), an affiliate member of the UIC, concluded the Research Collaboration Agreement with the UIC in 1994. The Institute has sent staff to the Global Dimension of UIC since 1997, and has participated in its numerous technical committees and joint research projects. The author has also been a member of the Panel of Structural Experts (PoSE), which is one of the committees under the Infrastructure Forum.

With such a close relationship in the background, fifteen members of PoSE visited Japan for the first time from September 16 to 20, 2008 for their biannual committee meeting and the Railway Bridge & Tunnel Exchange Seminar.

The seminar was held for the first time as a UIC activity in Asia to promote technical exchanges between European and Asian railway civil engineers. The RTRI hosted the seminar with the cooperation of Korea Railroad (Korail), Japan Railway Companies and the Japan Railway Construction, Transport and Technology Agency (JRTT). It was a full-day seminar held in one of RTRI's conference facilities, and fourteen presentations were given by the participants. European engineers made seven presentations, including an outline of the present status of Eurocodes and the Sustainable Bridges Project - part of the Sixth EU Framework Programme. Japanese engineers made six presentations; three JR companies from the main island of Japan (EJR, CJR and WJR) introduced their recent research and development activities, and JRTT introduced the features of the Shinkansen structures. The RTRI gave an outline of *the Design Standard for Railway Structures and Commentary* and covered recent research topics on structural technology, while Korail made a presentation on bridge replacement. Fruitful expert discussions were also conducted at the seminar. The proceedings of the event was published, and can be accessed on the UIC website. At the end of the session, a UIC representative announced that such exchange seminars would be held once every four years in non-European areas.

After the committee meeting and the exchange seminar, PoSE members took part in an inspection tour to three construction sites. They visited an EJR elevated viaduct construction site for continuous grade separation, as well as two tunnel construction sites of Odakyu Electric Railway Co., Ltd and Hanshin Electric Railway Co., Ltd.

The RTRI is very happy to have hosted such an exchange seminar in Tokyo, and plans to promote joint research projects and technical exchange meetings with railway-related research organizations overseas to further extend its contribution to world railways.

A Study of Evaluation Methods for Railway Signalling Systems from the Viewpoint of Availability

Koji IWATA
Senior Researcher, Train Control Systems, Signalling and Telecommunications Technology Division

High levels of safety are required for railway signalling systems, for which various measures based on the fail-safe concept are taken to prevent failures because any failure has the potential to cause a serious accident. An International Standard, IEC 62278, has been instituted recently to view the reliability (R), availability (A), maintainability (M) and safety (S) of railway signalling systems. In some cases, it was necessary to analyze and evaluate the signalling systems from the viewpoint of availability, in addition to safety, which is the most important matter for consideration. For this reason the Railway Technical Research Institute (RTRI) is studying a method to improve the availability of signalling systems, while maintaining safety standards at the same level or even improving them (Table 1).

This method characteristically evaluates the measures needed to attain the target availability in terms of reducing the frequency of failure occurrence and cutting downtime of the signalling systems. For the purpose of this study, the author transforms the equation (1) that defines the availability of a system into the equation (2), considering that the frequency of failure occurrence λ per unit time is equal to the reciprocal of the mean time between failures (MTBF). Note also that the frequency of failure occurrence (λ) is in inverse proportion to the downtime of the system (MTTR) when availability remains unchanged.

$$A=\frac{\mathrm{MTBF}}{\mathrm{MTBF}+\mathrm{MTTR}} \quad \cdots\cdots(1)$$

$$\lambda=\frac{1-A}{A}\,\frac{1}{\mathrm{MTTR}} \quad \cdots\cdots(2)$$

The equation (2) indicates that there are two ways of attaining the target availability; one is to reduce the frequency of failure occurrence and the other is to cut the downtime of the signalling systems. These equations clarify that the purpose of the measures to be taken is to reduce the frequency of failure occurrences or to cut the downtime of the systems.

To validate the effectiveness of this method, the author carried out a case study of a railway line section around 50km long, with 15 stations equipped with interlocking, and operated by 101 trains per hour during peak hours on quadruple track at a typical station. The failure data used is based on the railway safety database which is managed by the Railway Technology Promotion Center, RTRI, and the period for analysis is about 5 years. The author set the target availability based on the decrease in the number of passengers affected by system failures, which is assumed to be proportional to the length of downtime.

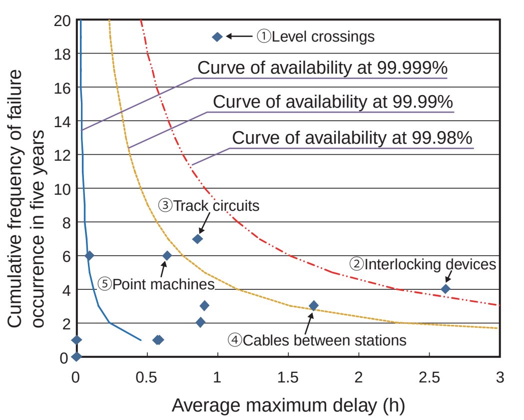
Figure 1 shows the availability of system components of the line, in which the y-axis represents the frequency of failure occurrence and the x-axis the average maximum delay of affected trains, which corresponds to the downtime. The availability is higher for the components in the bottom left area in Fig. 1 and lower for those in the top right area. The three curves in Fig. 1, from left to right, indicate that the availability is 99.999%, 99.99% and 99.98%, respectively. The points marked in Fig. 1 indicate the values of availability of different components installed along the line. More specifically, availability is worst with level crossings, but it is better with interlocking devices, track circuits, cables between stations and point machines. As this evaluation aims to improve railway signalling systems, the author excluded from the analysis failures due to external disturbances or unknown causes and selected interlocking devices and point machines as the key components in this study.

In choosing measures to be taken for the selected components, the author assumes that a longer component vector of improvement in availability results in a smaller number of measures needed to achieve the improvement efficiently. As a best option for interlocking devices and point machines for example, the author selected two measures: "simplification of wiring" for interlocking devices and "enhancement of status monitoring" for point machines (Fig. 2). A combination of these two measures enables availability of about 99.92% to be attained efficiently, as indicated by the bold arrow mark in Fig. 2. In this manner, measures can be selected to efficiently attain the target availability for railway signalling systems as a whole.

The author will apply the above technique to other lines in the future and will propose measures to effectively improve railway signalling systems.

Table 1 Procedures to evaluate railway signalling systems from the viewpoint of availability

【Step 1】 Current status evaluation	【Step 2】 Setting of target values	【Step 3】 Determination of measures to be applied to attain the target availability
• Current availability (frequency of failure occurrence, downtime)	• Target availability	• Selection of target components for improvement and their effectiveness • Shortening the downtime • Improvement of reliability (decrease in the frequency of failure occurrence) • Improvement of maintainability (decrease in the frequency of failure occurrence) (by improved precision of detection)
• Effect on the current train schedule (number of trains cancelled or delayed)	• Target number of trains cancelled or delayed	• Effectiveness from the viewpoint of a whole signalling system • Frequency of failure occurrence after improvements • Downtime after improvements
• Current cost	• Target cost	



Note: Circled figures indicate the sequence of improvement.

Fig. 1 Availability of system components

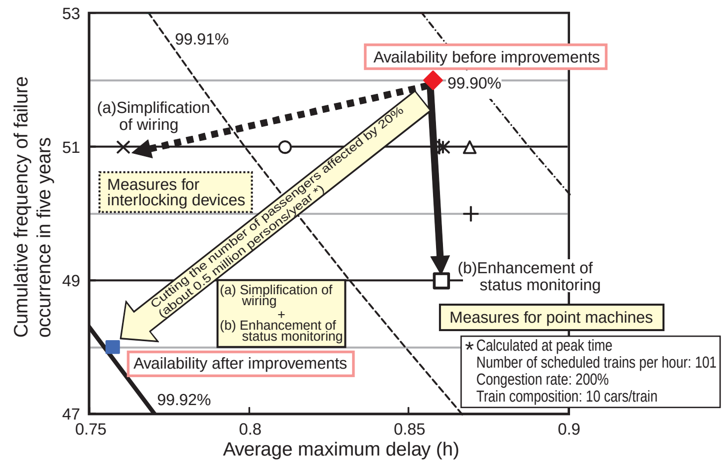


Fig. 2 Study of the application of combined measures to more than one component (Combination of measures for point machines and interlocking devices)

A Method for Failure Detection Based on Monitoring Data from Existing Facilities

Naoya OZAKI
Researcher, Facilities Management Systems, Transport Information Technology Division

We have been studying technologies for detection of failures and ways in which alarms can be triggered based on data obtained from existing facilities and sensors. However, it is often the case that no method can be found for directly sensing the conditions of target objects or phenomena that we wish to detect. In such cases, two options can be considered. One is to install new sensors to detect the target objects or phenomena directly. The other is to determine the existence of failures from existing data which is considered to relate to or depend on the phenomena and occurrences.

The option of installing new sensors to monitor failures allows them to be detected directly. This option offers the advantage that processing of the information to determine the existence of a failure is simpler when compared with indirect detection method. The disadvantage is that the sensors attract an installation cost and an increase in maintenance costs. In contrast, the option of detecting failures using data available from existing facilities incurs no additional costs, although some care is needed to determine whether or not failures are occurring. Having considered these factors, we performed an empirical study to approach this problem using the latter option.

The concept of failure detection is as shown in Fig. 1. First, data is collected during normal conditions (normal data). Next, the range of values that may be regarded as normal through statistical analysis techniques is determined, based on the normal data obtained. Then, if the observed data falls within the range, the data is considered to be normal. If it falls outside the range, the data is considered to be unusual. This is a basic concept that can be applied to any facilities. For example, we have investigated whether or not the breakage of crossing rods can be detected from the level of electric current used to operate existing automatic barrier machines. Since there are so many crossings, the installation of sensors to each automatic barrier machine would incur significant cost. Also, the situation in which a crossing rod is broken would lead to passers-by being exposed to danger, and accordingly detection of the failure is required as quickly as possible. Therefore, we think that, if the failure can be detected by measuring the electric currents operating automatic barrier machines, safety can be improved at low cost.

In this study, we carried out a test in which five situations were simulated by the operation of two automatic barrier machines (Fig 2), each of which was supplied by a different manufacturer. We analyzed whether or not the breakage of crossing rods can be detected using the electric current data obtained in the test. In order to evaluate the effectiveness of the fault detection, we tested three methods: (1) using average values of electric currents; (2) using maximum values of electric currents; (3) using electric currents in time-series from the start of operations. As a result, in the discrimination method (3), we were able to detect failures correctly from electric current values of the automatic barrier machines (Table 1). Since our method has only been applied to a limited number of devices, we will continue to carry out more case studies in order to ascertain the effectiveness of our method.

Since the use of sensornet has attracted considerable attention, and the deployment of it is increasing, we will be able to acquire data for a range of facilities in the near future. We expect that the scope of this technique will continue to increase.

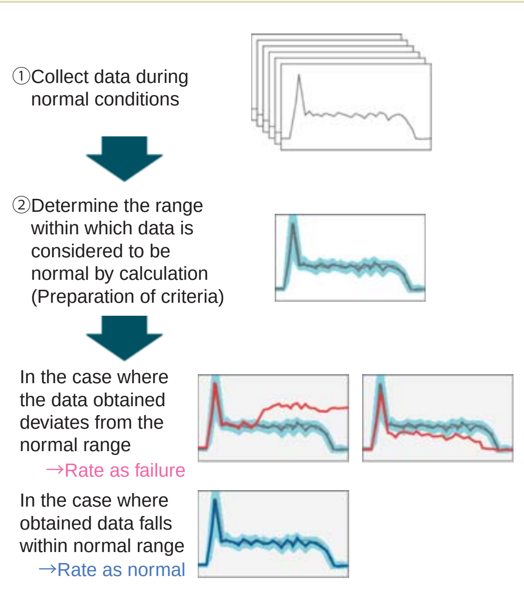


Fig. 1 Concept of failure detection

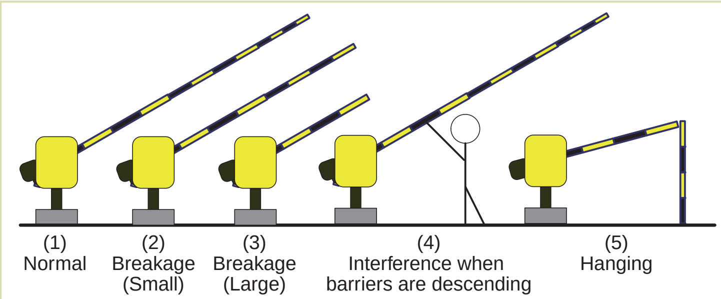


Fig. 2 The contents of a simulation test for breakage of crossing rods / interference when barriers are descending

Table 1 The result of rating using electric currents time-series data

	Crossing A				Crossing B			
	Automatic barrier machine 1		Automatic barrier machine 2		Automatic barrier machine 3		Automatic barrier machine 4	
	Ascending	Descending	Ascending	Descending	Ascending	Descending	Ascending	Descending
Breakage (Small)	◎	◎	◎	◎	◎	◎	◎	◎
Breakage (Large)	◎	◎	◎	◎	◎	◎	◎	◎
Hanging	◎	◎	◎	◎	◎	◎	◎	◎
Interference when barriers are descending	–	◎	–	◎	–	◎	–	◎

◎: 100% rated ○: One rating of normal case as failure
△: One rating of failure case as normal ×: Two or more erroneous ratings

Long-Term Field Durability Testing and Practical Application of Shelling Damage-Resistant Bainite Rail

Yukio SATOH
Senior Researcher, Frictional Materials, Materials Technology Division

A principal factor governing the life of rails is rolling fatigue damage (known as shelling), which tends to occur in rails on which trains operate with a high degree of frequency. Shelling damage can cause rail failure if left unattended for long periods, meaning that railways incur enormous maintenance costs in replacing failed rails and detecting cracks and other faults in them. Against this background, the Railway Technical Research Institute (RTRI) has developed bainite rail (a new rail made of bainitic steel aimed at improving shelling damage resistance) and succeeded in putting it into practical use after checking its characteristics through a long-term durability test in the field, which is outlined below.

The development of shelling damage-resistant rails was previously implemented under a policy aimed at suppressing rolling contact fatigue - a cause of shelling damage - by increasing the strength of rails. Based on this concept, a number of high-strength rails were manufactured on a trial basis and tested after being laid in the field. However, attempts to use these rails failed, as no model survived durability testing without shelling damage. In view of the lack of success in previous developments, the author discarded the conventional policy of increasing rail strength and adopted a new concept aimed at expediting rail wear to an appropriate extent to promote the self-removal of the rolling contact fatigue layer that causes shelling damage (see Fig. 1 for a conceptual drawing of the new developmental policy). In consideration of the laboratory test results, the author set the target rail wear rate of the rail under development at 1.2 times or more that of the standard carbon rails used in the section where specimens of the new rail were tested for durability.

The author selected bainitic steel as a material to satisfy the new concept of development, and had bainite rail specimens manufactured. After implementing laboratory tests to check the performance of the specimens with respect to the specifications and standards to be met for use in the field, the author subjected them to field testing for about 10 years on a narrow-gauge trunk line featuring high-frequency train operation to check their durability and suitability for practical use. For this durability test, the author set five hardness levels within the JIS specification range for the rails tested, and grouped them into three categories: high-hardness bainite rail (HLC, MLC), medium-hardness bainite rail (LC) and low-hardness bainite rail (N1E, N2W).

In the test, the author was able to examine the appropriate level of hardness to attain the targeted wear rate under actual conditions in the field and confirm that the tested rails had shelling damage-resistant features when used as tracks for train operation (see Fig. 2 for the strength levels and symbols of the tested rails).

The durability test proved that the wear amount of bainite rails is scattered in comparatively wide ranges up to an accumulated passing tonnage of about 150 million gross tons (MGT) (in the initial wear zone). However, it becomes smaller thereafter as the accumulated passing tonnage increases (in the stationary wear zone) (see Fig. 3 for the wear amount of different rails). In the stationary wear zone, the volume of wear on the low-hardness bainite rails is 1.2 times or more that found on the standard carbon rails. A survey implemented at an accumulated passing tonnage of about 215 MGT showed that shelling damage had occurred on all the specimen rails except the low-hardness bainite type (see Table 1 for the occurrence of shelling damage on different specimens). The field test was extended up to an accumulated passing tonnage of 320 MGT (over 10 years).

Through this study, the author was able to prove that low-hardness bainite rails offer excellent resistance against shelling damage compared with existing standard carbon rails, and succeeded in putting bainite rails into practical use.

Bainite rails are now used in areas covered by JR Hokkaido and JR East over a total length of about 44 km.

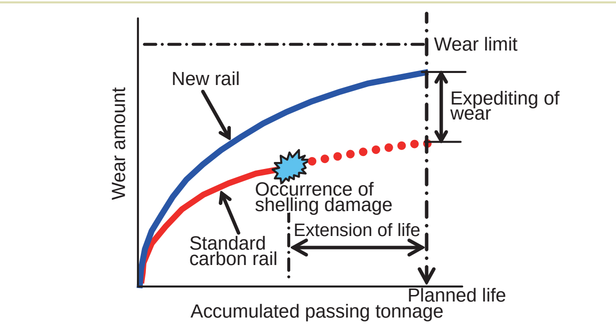


Fig. 1 Conceptual scheme of the new development policy

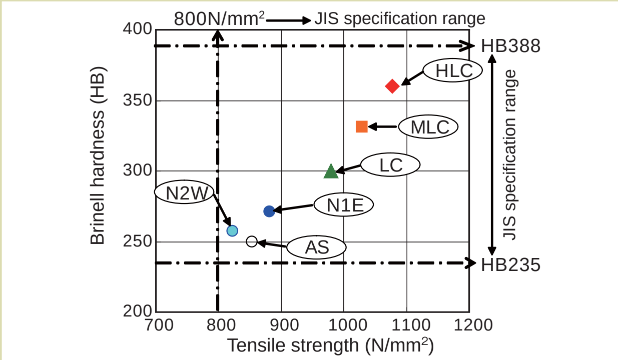


Fig. 2 Strength levels and symbols of specimen rails

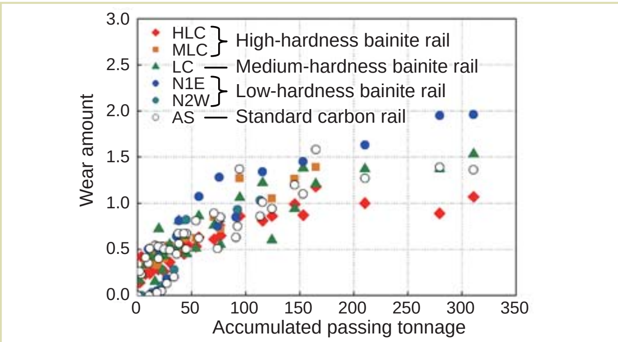


Fig. 3 Volumes of wear on specimen rails

Table 1 Occurrence of shelling damage

Specimen rail	Shelling damage
High-hardness bainite rail	Occurred
Medium-hardness bainite rail	Occurred
Low-hardness bainite rail	No occurred
Standard carbon rail (reference rail)	Occurred

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.

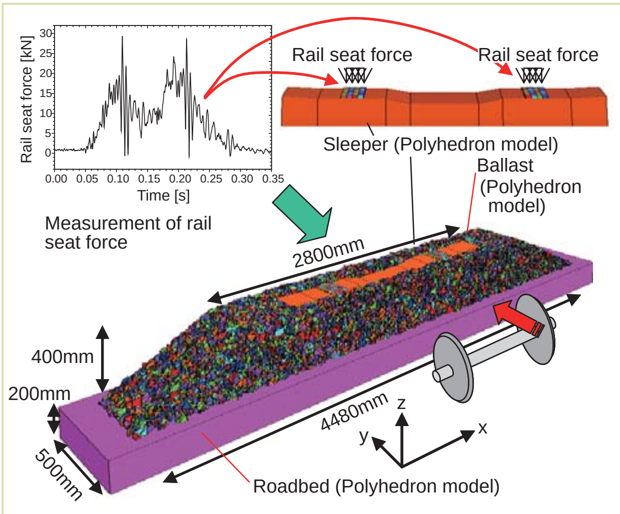
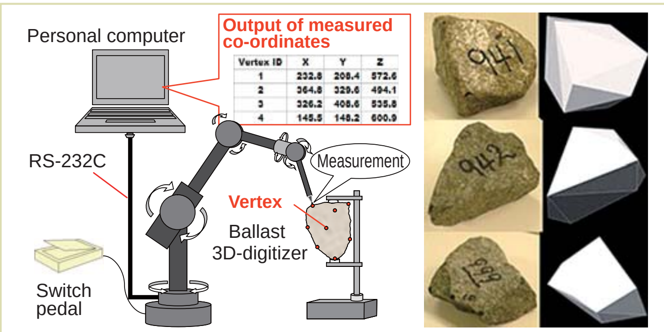


Fig. 2 Three-dimensional DEM model analysis



Vertex ID	X	Y	Z
1	232.8	208.4	572.6
2	364.8	329.6	494.1
3	326.2	408.6	535.8
4	145.5	148.2	600.9

Fig. 1 Digitization of grain shape

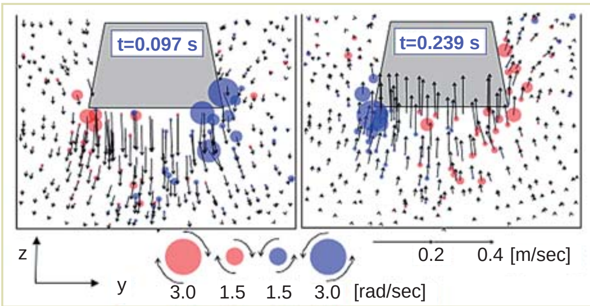


Fig. 3 Translational/rotational velocities of ballast particles under the right side rail (simulation)