Newsletter on the Latest Technologies Developed by RTRI

Railway Technology Avalanche

September 19, 2008 No.24

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.
URL: http://www.kenf.or.jp/en/

GENERAL INFOMATION

ARTICLES

Research and Development for the Safety of Railways against Natural Disasters

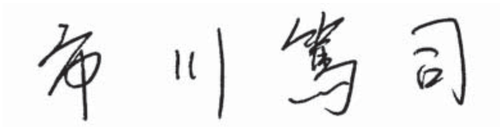
Atsushi ICHIKAWA
Director, Research and Development Promotion Division

In recent years, heavy rains, strong winds, earthquakes and other natural disasters have frequently occurred in various areas around the world. Railways in Japan have also experienced a series of large-scale disasters. Railway structures, for example, have been seriously damaged by heavy rains. Shinkansen cars were derailed in one large earthquake, and some railway cars have been overturned by strong winds. In response to these disasters and accidents, the Railway Technical Research Institute (RTRI) has been active in promoting research and development to ensure the safety of railways.

To prevent damage due to strong winds, the RTRI has been developing methods to observe wind-force phenomena, investigate the effect of windbreaks and calculate the aerodynamic forces that affect railway cars on bridges and embankments. For this purpose, the RTRI implements on-site measurement and tests using large-scale wind tunnel test apparatus. Through these research and development activities, the RTRI plans to propose basic technologies to protect trains from strong winds within a few years.

To minimize earthquake-related damage to structures, the RTRI and Railway companies are now developing a low-cost, highly effective earthquake-proof reinforcing technology. Applying the results obtained so far from this development, Railway companies are now executing reinforcing work for existing railway lines. In parallel, we are developing guards to prevent derailment in earthquakes as well as guards to keep cars on the track even if their wheels derail. Some of the results of such development have already been applied to existing railways.

Given the abnormal weather conditions caused by global warming, it is anticipated that serious natural disasters will continue to occur in the future. This makes it increasingly important to promote research and development on the safety of trains against natural disasters. The author wishes this subject be addressed in conjunction with railway engineers in different countries.



Technical Discussion of LRT without Contact Wires

Toshihiro HAMAMOTO
Director, Sales, Marketing and Business Development Division

1. Introduction

LRT that is free of contact wires (referred to below as *contact-wire/battery hybrid LRT*) enables further savings in energy and maintenance for LRT systems while improving city landscapes. Since the Railway Technical Research Institute (RTRI) succeeded in trial operation of a battery-driven tram in August 2003 at the test track on its premises, it has promoted research and development of a number of related technologies. These include the signal system required for the commercialization of LRT that is free of contact wires and a guidance system from the viewpoint of universal design.

2. Workshops for technical discussion of LRT

To comprehensively introduce the results obtained so far from research and development of element technologies to existing tramway business promoters and autonomous bodies who are discussing the introduction of LRT, the RTRI decided to sponsor and manage workshops for technical discussion of LRT for the three-year period from fiscal 2005 to 2007.

The RTRI acted as secretariat for the workshop committee led by the University of Tokyo's Professor Yoshihiro Suda and composed of members from universities, the Ministry of Land, Infrastructure, Transport and Tourism, the National Police Agency, ten tramway business promoters and nine autonomous bodies.

The themes on the agenda were as follows:

1. LRV without contact wires
2. Simplified signal systems
3. Operation control and guidance systems
4. A compound traffic system

The committee also performed feasibility studies on the construction of new lines, the operation of battery-driven trams on parts of electrified sections, and the extension of such an operation mode to clarify cases where LRT without contact wires would be advantageous from the viewpoint of economy.

3. The contact-wire-free Hi-tram LRV

Under contract with the New Energy and Industrial Technology Development Organization (NEDO), the RTRI placed an order with a car builder for the manufacture of a hybrid test tram-train known as the Hi-tram. The vehicle is driven with power supplied from on-board batteries and/or through contact wires from external power sources.

The tram was completed last autumn and was subjected to various tests, including a quick-charge test from rigid contact wires on the premises of the RTRI. From November 2007 to March 2008, the tram was subjected to running tests to check the effects of energy saving and durability at extremely low temperatures in Sapporo (on the northernmost commercial streetcar line in Japan) in cooperation with Sapporo City's Transport Bureau.

4. Conclusion

The RTRI has promoted technical discussion for three years, not only on the new LRV tram but also on a new LRT system as a whole. The institute will strive to enhance the LRT system to create an innovative and efficient transport network through technical development, thereby aiming at the commercialization of LRT without contact wires - a technology developed in Japan.

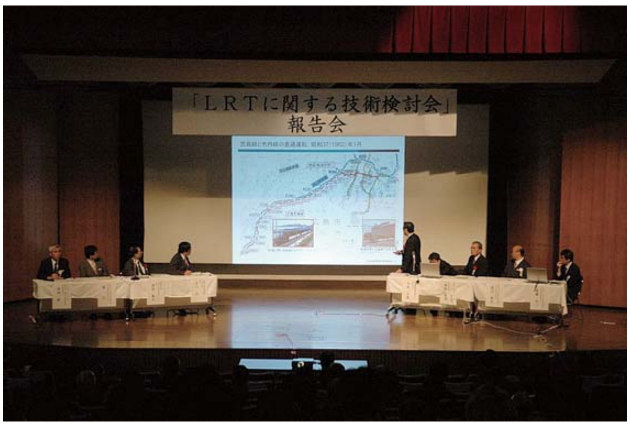
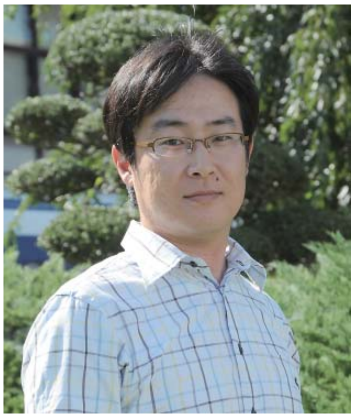


Fig. 1 Reporting session (panel discussion) at the workshop for technical discussion held last autumn

Fig. 2 The Hi-tram under a running test in snowy conditions in Sapporo

Development of a Damage Detection System for Structural Members in the Ground

Hirokazu OHMURA
Researcher, Foundation and Geotechnical Engineering, Structures Technology Division



Viaducts with a rigid-frame structure are common on railways. Their foundations, underground beams and pier substructures are normally built in the ground, but for bridge piers in running water, their substructures are submerged below the surface. It is difficult to visually check the conditions of structures existing in the ground or in water.

To facilitate the inspection and diagnosis of hidden pier sections and other bridge substructures for which visual observation is difficult, the Railway Technical Research Institute (RTRI) developed a damage detection system with an RF-ID tag that can transmit attribute information on an object using a non-contact method.

This system uses a sensor unit composed of stainless-steel strain gauges that are attached on the reinforcement of the pier members of rigid-frame viaducts. When the system is applied to a bridge under construction, it detects the load increase by degrees during the construction work and contingent loads after it has been put into service in terms of the strain generated in the primary reinforcement. The detected strain values are stored in the RF-ID tag and sent wirelessly to an outside monitoring system. The developed RF-ID tag sensor system, which does not have a battery power source, is constructed as a contactless passive system capable of receiving power from outside by electromagnetic induction (Figs. 1 and 2). With this system, inspectors can acquire information on the object structure contactlessly from an RF-ID tag buried at eye level. Strain is detected as resistance by the strain gauges, read by a portable reader/writer (R/W) held aloft from outside, displayed and stored on a PC (Figs. 1 and 3).

The damage detection system thus developed was subjected to a monitoring test after installation on the pier foundation of a viaduct construction project (near Musashi-sakai station on the Seibu Tamagawa line and Musashikoganei station on the Chuo line of the East Japan Railway Company) and checked for its applicability to construction work. The RF-ID tag is sheathed with high-strength mortar to enable installation in covering concrete. The procedure for installation is to treat (grind) the surface of a reinforcing bar, weld strain gauges to paste on it, adjust the wiring of leads and affix the RF-ID tag. It takes approximately one hour to install a set of system components during the processes from reinforcing bar fabrication to form assembly without disturbing the bridge construction work (Figs. 4 and 5). After installation on the viaducts listed above, the system components were loaded with viaduct beams, slabs and tracks in succession for half a year. The RTRI confirmed the applicability and validity of the damage detection system by obtaining stable measurement values, including those for changes in the load from all sensors during this period. By applying this system, therefore, it is now possible to check whether structural members in the ground are damaged and to evaluate the degree of damage if they are subjected to an earthquake or contingent force. This does not require excavation of the surrounding ground.

This system was developed jointly by the RTRI and Toshiba Plant System Co. using a subsidy from the Ministry of Land, Infrastructure and Transport.

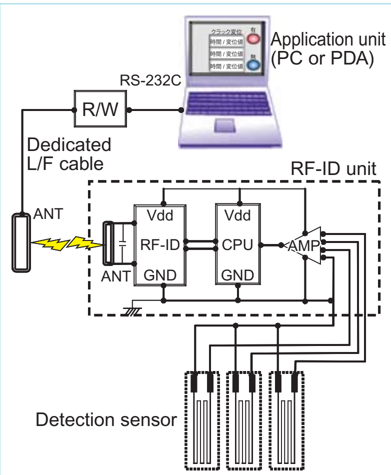


Fig. 1 Basic system composition

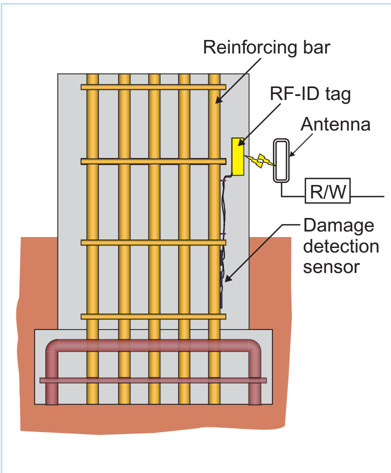


Fig. 2 Data collection

Fig. 4 Installation of detection sensors (to collect data from a rigid-frame viaduct)

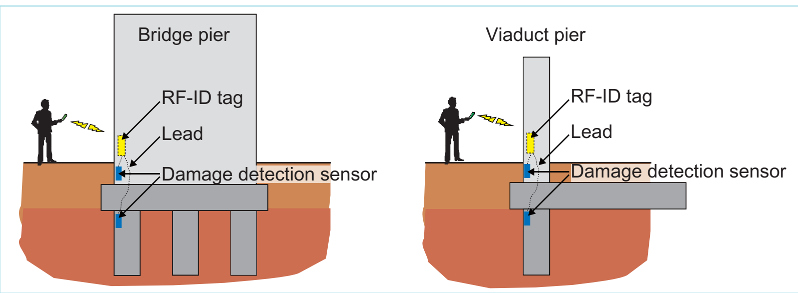


Fig. 3 Installation of damage detection sensors

Fig. 5 Installation of sensors

Preventing Fatigue Breakage of Contact Wires

Atsushi SUGAHARA
Senior Researcher, Laboratory Head, Current Collection Maintenance, Power Supply Technology Division

Contact wires are subject to a bending strain every time a pantograph slides along them. As the bending strain increases with an increase in train speed, it may cause fatigue breakage of the contact wires. This paper describes measures implemented to prevent fatigue breakage, such as measurement of the bending strain in contact wires and evaluation of the fatigue properties of contact wire materials.

The strain in contact wires is measured with a strain gauge fixed to the top surface as shown in Fig. 1. Since overhead contact wires normally carry a high voltage, the measurement signal is transmitted through a radio telemetry device. In the measurement process, a strain waveform in response to the passage of a pantograph is obtained, typically with the form shown in Fig. 2.

In evaluating the measured strain, the value of 500×10^{-6} is taken as the maximum allowable strain[1]. This value is the fatigue limit of a typical contact wire made of hard-drawn copper under no tensile load, which is compensated by the decrease in the fatigue limit due to the mean tensile stress imposed by the tensile load. The mean tensile stress assumes the value at the wear limit of the contact wire, or the maximum value generated in actual applications.

On the other hand, the fatigue properties of newly-developed materials for contact wires are often measured by implementing fatigue tests applied with an actual tensile load. The example introduced below uses high strength copper-tin alloy contact wires (SN-W contact wires). In a high-speed train application on the Shinkansen, the high-strength SN-W contact wires are manufactured by increasing the tin component of the conventional wear-resistant copper-tin alloy contact wires (SN contact wires with a tin component of 0.3%) to 0.35%, thereby increasing the degree of work hardening. Table 1 shows the characteristics of SN-W and two other types of wire.

Figure 3 shows a conceptual drawing of a fatigue test device for a contact wire, which is used to excite a contact wire vertically at the centre under a tensile load to generate bending strain repeatedly and measure the cumulative excitation frequency until it breaks or reaches the fatigue life.

Figure 4 shows the results of the fatigue tests, in which the mean tensile stress is set in consideration of a wear limit. That is, the mean tensile stress is set at a value not exceeding the tensile strength of contact wires divided by 2.2, the safety factor applied to copper and copper alloy contact wires in Japan. Figure 4 indicates that the fatigue resistance of SN-W contact wires is slightly higher than that of hard-drawn copper contact wires, as the evidence for the generally accepted view that fatigue resistance is correlated with tensile strength and other properties.

Regarding the SN-W contact wires, the author determined two semi-logarithmic approximate expressions, one in the long-life region and the other in the short-life region, to combine as a presumed 50% probability line for fatigue breakage. In the long-life region, the author also determined the standard deviation $\hat{\sigma}(\varepsilon_a)$ of strain amplitude ε_a from the approximate expression to draw a (approximate expression - $3.09\hat{\sigma}$) line or presumed 0.1% probability line for fatigue breakage. This is illustrated in Fig. 5. Strictly speaking, however, many more measurements are required to estimate the values of extremely small probabilities. The strain amplitude is 728×10^{-6} at the intersection between the 0.1% probability line for fatigue breakage and the line of cumulative excitation frequency of 10^7. When the cumulative frequency of excitation is regarded as the total number of pantographs that have slid along the contact wires, the strain amplitude of 700×10^{-6} seems allowable for SN-W contact wires with some margin, as the contact wires reach the wear limit before the cumulative excitation frequency of 10^7.

The Railway Technical Research Institute will collect data further on the fatigue of different contact wire materials and implement tests to study the effect of strain waveform on the fatigue life.

1) Railway Bureau of Ministry of Transport and Railway Technical Research Institute: "Manual for Speed-up Tests of Conventional Lines" (in Japanese), 1993

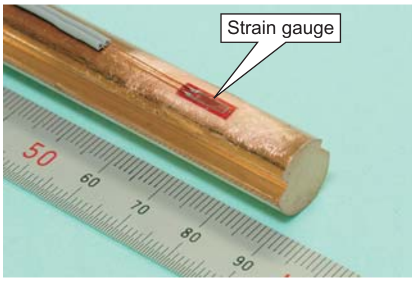


Fig. 1 A strain gauge fixed to a contact wire

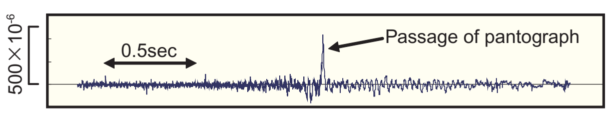


Fig. 2 A strain waveform in a contact wire

Table 1 Properties of three types of contact wires (comparison at a nominal sectional area of 170 mm²)

	SN-W	SN	Hard-drawn copper
Cross section (mm²)	169.7	169.4	170.0
Mass (kg/km)	1509	1506	1511
Minimum breaking load (kN)	74.5	58.8	57.8
Conductivity (%IACS)	≧70	≧70	≧97.5

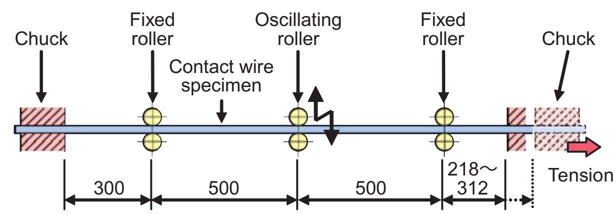


Fig. 3 Contact wire fatigue test device

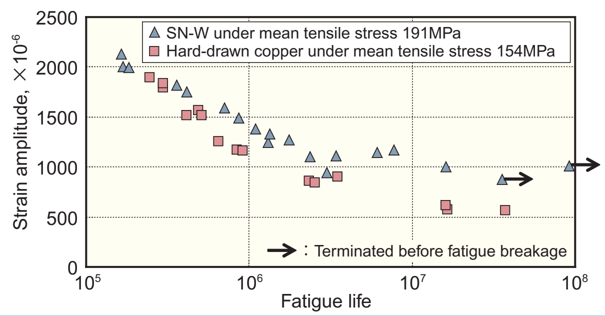


Fig. 4 Results of fatigue tests

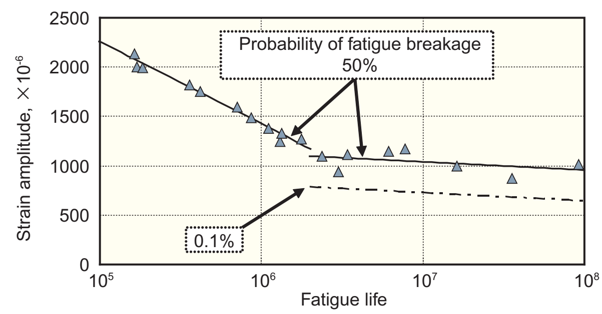


Fig. 5 Approximation of fatigue life property of SN-W contact wire

Research to Evaluate the Remaining Service Life of Aged Rails

Hiroo KATAOKA
Senior Researcher, Track Structures & Components, Track Technology Division

The maintenance of rails incurs enormous expenses, and to prevent rail failure, a number of railway operators in Japan replace them periodically based on the accumulated passing tonnage. As the introduction of lightweight vehicles and rail grinding operation has reduced rail failure at joints in recent years, it is now considered possible to extend the periodicity of such rail replacement. There are several types of rail failure, and cracks at the rail foot are difficult to detect. Star cracks (a type of damage found on rails) at the boltholes of fishplated joints are also often overlooked. The Railway Technical Research Institute (RTRI) has therefore decided to review the periodicity of rail replacement focusing on rail foot cracks (in the case of long-rails or continuous welded rails (CWR)) and star cracks at the boltholes of fishplated joints.

To evaluate the remaining life of rails, the RTRI implemented fatigue tests on welded parts and fishplated joints of rails that had been used in the field. The average accumulated passing tonnage of the rails tested was 380 million tons with Shinkansen CWR. The corresponding figure for rails used in 1,067-mm-gauge sections was 540 million tons with CWR and 330 million tons with fishplated joints. Based on the results of fatigue testing, the RTRI determined the S-N curves of laid rails (see Figs. 1 to 4).

In this context, a dynamic analytical model has already been developed to calculate the bending stress at welded parts, and the RTRI used this model in the study to evaluate the life of CWR. To analyze the dynamic stress at fishplated joints, another model is also available that combines a beam model to calculate the dynamic wheel load on the rail under investigation and a solid model to calculate the stress in the rail using the wheel load thus calculated as an external force. The RTRI verified the appropriateness of these models by implementing on-site measurement.

By applying these study results, the RTRI calculated the stress in the rails under different track and rolling stock conditions, and estimated the remaining life of the rails from the S-N curves and stress values thus obtained.

The RTRI also evaluated the remaining life of the welded parts of rails with boltholes. These rails were once used with fishplated joints, and were later welded to form CWR. Comparison of the remaining life between rails with cracks at the rail foot and those with cracks at their boltholes suggests that the latter retain a longer service life.

After evaluating the remaining life of different types of rail, the RTRI has confirmed that the periodicity of rail replacement can be extended (see Figs. 5 and 6). To achieve this, however, grinding is required for CWR to remove surface irregularity of the rail top. On the other hand, contact between the fishplate and the rail in fishplated joints should be controlled to avoid excessive wear. After discussing these points, several railway operators in Japan have already extended the periodicity of rail replacement in CWR sections.

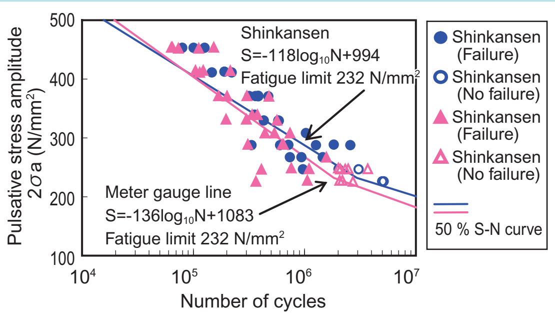


Fig. 1 S-N curve of laid rail of CWR at 50% fracture probability

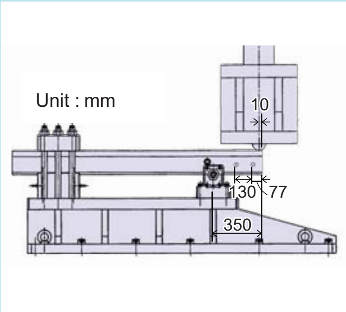


Fig. 2 Bending fatigue test of fishplated joint rail

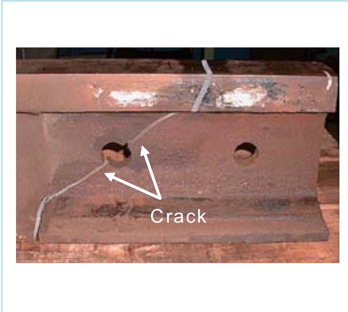


Fig. 3 Example of rail broken in fatigue test

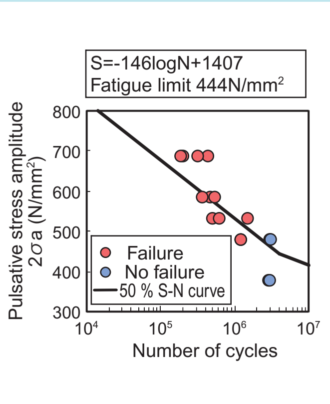


Fig. 4 S-N curve of laid jointed rail at 50% fracture probability

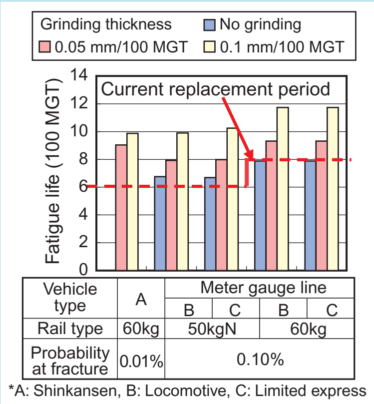


Fig. 5 Example of evaluated fatigue life of CWR

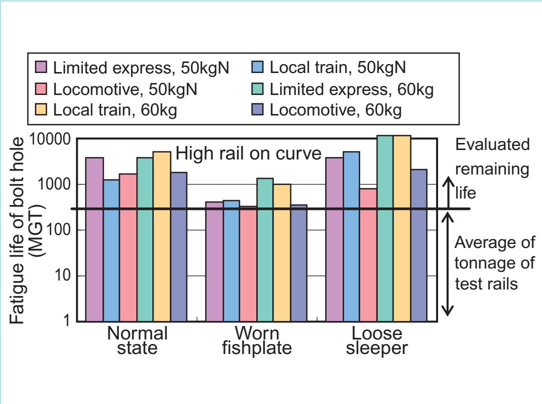


Fig. 6 Example of evaluated fatigue life of bolt holes (Probability at fracture:0.10%)

Train Operation Control Indices for Use during Earthquakes in Japan

Masahiro KORENAGA
Researcher, Earthquake Disaster Prevention, Disaster Prevention Technology Division

1. Train operation control indices for use during earthquakes

When an earthquake occurs, train operation is suspended quickly within the appropriate area from the viewpoint of ensuring safety. In the wake of earthquakes, however, train operation is resumed as soon as possible once safety has been confirmed. In this context, railways in Japan principally use the three earthquake motion indices outlined below as criteria to judge whether train operation should be suspended when an earthquake occurs and the timing with which service can be resumed.

(a) Peak ground acceleration (PGA)

Peak ground acceleration (PGA) is widely used as a criterion for train operation control during earthquakes. Railways in Japan use PGA values obtained by compounding the vectors of two horizontal components of measured acceleration filtered to accurately reflect the effect on railway structures.

(b) Value of spectrum intensity

Spectrum intensity (SI) is a numerical value to express the degree of movement in normal structures subjected to earthquake. It is defined as the average velocity response spectrum in the range of the period from 0.1 to 2.5 sec with a damping constant of h = 0.2. An approximate expression has been proposed to calculate SI on a real-time basis using a seismometer.

(c) Instrumental seismic intensity

The seismic intensity scale used by the Japan Meteorological Agency is one of the most widely known earthquake motion indices in Japan. In the past, the scale was estimated from the physical perception of the staff in charge at the agency and damage conditions at earthquake-stricken sites based on criteria regarding the intensity of quakes. Nowadays, however, calculation methods have been proposed, and intensity is now measured automatically using new seismic intensity meters developed simultaneously to enable the measurement of seismic intensity in objective terms.

2. Statistical features of the earthquake motion indices

As criteria for train operation control in Japan, railway operators now increasingly use the SI value and the instrumental seismic intensity, which show a close correlation with earthquake-related damage to structures. However, the index used for this purpose depends on each railway operator. The RTRI has determined the statistical relationships between PGA, SI and instrumental seismic intensity using about 2,400 sets of earthquake data observed with seismometers at public organizations (see Figs. 1 to 3 for the relationships found). The relational expressions thus obtained for earthquake motion indices can be used to discuss the criteria for train operation control during earthquakes.

For high-speed railways such as Shinkansen in particular, the decision on whether to suspend train operation must be made quickly. Shinkansen trains therefore utilize an early earthquake disaster prevention system developed by the RTRI that uses an algorithm to estimate earthquake details (the position of the epicenter and the magnitude) based on P-wave data from the first few seconds of the tremor. Under this system, the area affected by the earthquake is evaluated quickly and appropriately based on the limited information available for estimation. To address this limitation, the RTRI has proposed attenuation relations of PGA, SI and instrumental seismic intensity composed of the two parameters of magnitude and epicentral distance (Fig. 4). It has also proposed a technique to estimate the area affected by an earthquake based on the empirical relationship between the magnitude and the area affected as predetermined from past earthquake damage to railways (Fig. 5). This technique is called the M-Δ method, and is also currently used for the Shinkansen early earthquake disaster prevention system. The damaged area according to the M-Δ method corresponds to that at a seismic intensity of 5 Lower (an instrumental seismic intensity of 4.5 to 5.0) estimated by the attenuation relation mentioned above.

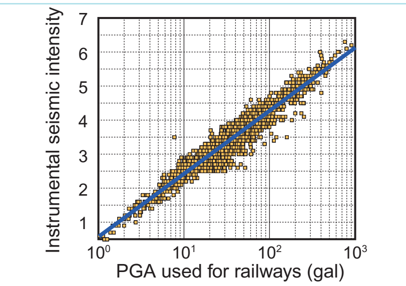


Fig. 1 Relationship between the peak ground acceleration and the instrumental seismic intensity used in railways

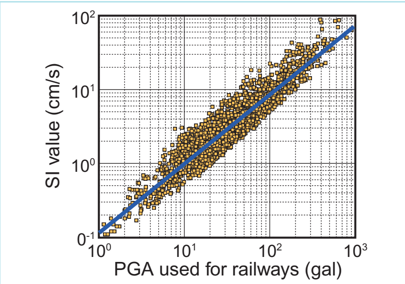


Fig. 2 Relationship between the peak ground acceleration and the SI value used in railways

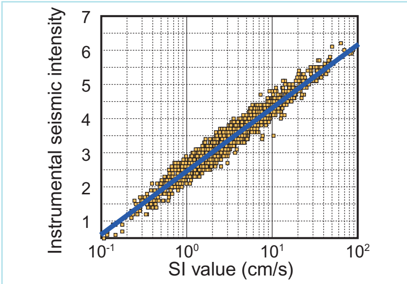


Fig. 3 Relationship between the SI value and the measured seismic intensity

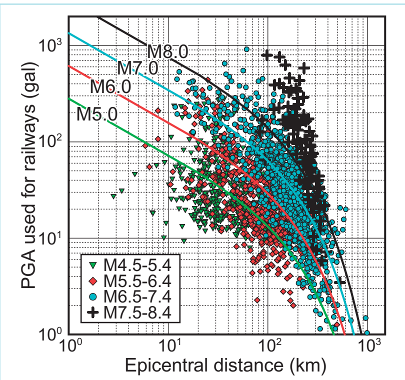


Fig. 4 Attenuation with distance of the peak ground acceleration used for railways

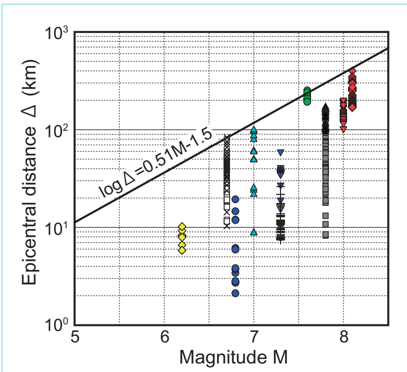


Fig. 5 Relationship between earthquake magnitude and the epicentral distance from the damaged site