Technology

Railway Technology Today 10 *(Edited by Kanji Wako)*

Minimizing the Effect of Natural Disasters

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Introduction

Japan is situated in one of the most active crustal zones in the world. The country's extremely diverse topography and geology combine to create generally unstable conditions, including frequent earthquakes. The weather, too, can be unmerciful, bringing heavy rain and snow. It is not surprising that a wide variety of natural disasters strike different parts of Japan each year.

The nationwide rail network needs protection from natural disasters. This article looks at efforts taken by Japanese railways, and research conducted by the Railway Technical Research Institute (RTRI), to prevent damage caused by heavy rain and snow, gale-force winds, major earthquakes and other natural disasters.

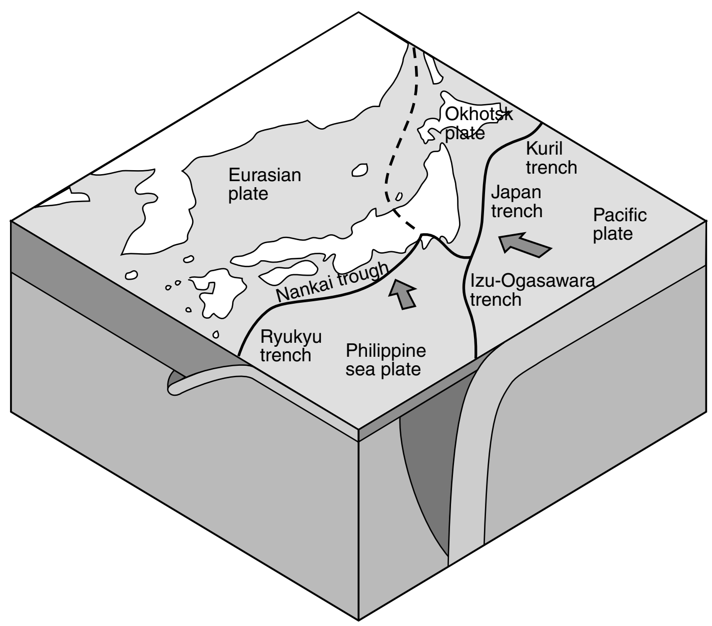
Geology and Weather—Formidable Forces

The earth's crust is divided into more than 10 plates of different sizes. The plates rise from submarine ridges, move laterally at a speed of 1 to 10 cm per year, then sink into oceanic trenches. The Japanese archipelago is located along several plate boundaries. As Figure 1 shows, the Japanese islands are subjected to tremendous stresses caused by the collision of four massive plates.

The archipelago's configuration was determined by these forces. Violent upthrusts throughout the entire island chain during the Quaternary period, about 2 million years ago, produced topographical features with generally steep gradients, and geological formations of faulted, weak rock that extends far below the surface. Japan is still subject to great crustal stresses today as the many active volcanoes and frequent earthquakes indicate. As a result, Japan's geological makeup is quite different from that of many continental areas where strata often date back to pre-Mesozoic times and the land is relatively stable.

Rain and snowfall are heavy in Japan because it stretches from the monsoon climate zone to the sub-arctic. Mean annual precipitation (total rainfall and snowfall) is about 1700 mm, or twice that of much of Europe and the USA. And because Japan's landmass is elongated and narrow, with steep mountain ranges, there is a relatively high tendency—four times greater than in Europe and the USA—for rain and meltwater to wash away the ground. Weathering and erosion result in extensive surface degradation, causing frequent landslides and other disastrous events.

Figure 1 Japan's Proximity to Four Tectonic Plates and Plate Movement



Natural Disasters and Their Impact on Railways

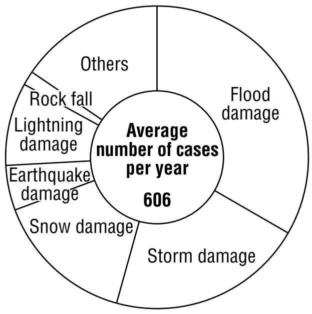
Figure 2 shows the number of times since 1966 that natural disasters (not including earthquakes) have damaged railway tracks in Japan. About 30 years ago, there were about 8000 incidents annually. But this figure has declined substantially since then, to stand at about 1000 incidents now.

Figure 3 shows a breakdown of different natural forces that have interrupted train operations over the last 10 years. Flood damage caused by typhoons and localized downpours occupies a prominent position, followed by storm and snow damage.

Steps to mitigate the effects of natural disasters have helped reduce the number of times railway operations have been interrupted, but natural forces still cause derailments and accidents that kill and injure passengers each year, so further measures are required.

Figure 2 Incidence of Damage to Japanese Railways by Natural Disasters

Figure 3 Different Natural Forces Interrupting Train Operations in Last 10 Years



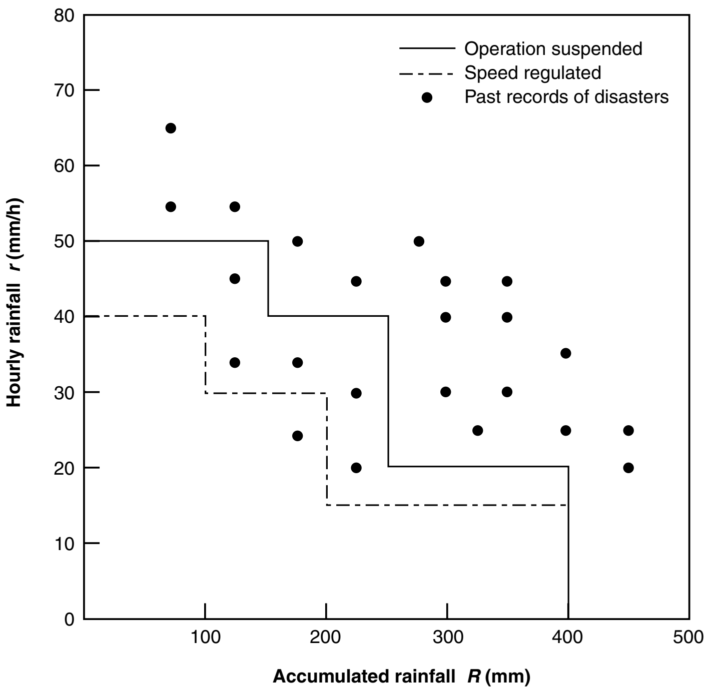
Protective Measures

To limit the impact of natural disasters on railway operations, we need to be able to predict time, location, and type. But we are dealing with natural phenomena that are extremely hard to predict accurately, even with today's advanced technology. So Japanese railways have concentrated their efforts on achieving safety and uninterrupted operations by combining the following three types of measures:

• Strengthening infrastructure and installing protection devices

Railways try to mitigate the forces of nature and prevent track damage in a number of ways, particularly by strengthening infrastructure. Tracks for shinkansen and other lines laid in the relatively recent past are generally designed to withstand the forces of nature. However, most conventional lines were built decades ago and have many sections that cannot withstand natural forces.

Figure 4 Typical Train Operation Controls



These sections are being reinforced gradually.

Typical measures, discussed later in more detail, include slope protection, erection of avalanche fences and wind barriers, and seismic reinforcement of infrastructure. These measures are the most effective possible but would be prohibitively expensive if applied to every section of every track, explaining why priority is given to track sections that are at most risk of natural disasters.

• Train operation controls

When natural forces are strong enough to indicate the possibility of damage to track or trains, trains are run at slower speeds or operations are suspended. Indices indicating accumulated rainfall (absolute rainfall) and hourly rainfall (rainfall intensity) are generally used to express both of these factors in combination.

Figure 4 gives an example of train operation controls applied to reduce the risks associated with rain. Rainfall amounts and indices indicating reduced speeds and interrupted service are shown. Rising river indices are based on actual water levels, wind indices are based on instantaneous wind speed, and seismic indices are based on the seismic motion at ground level. The important question regarding these train operation controls remains; how to determine the values that govern operations? In actual practice, they are determined through experience, taking into account data from previous disasters.

• Disaster detection

If natural forces create conditions that could interfere with train operations, systems can quickly detect these conditions to stop the train and prevent damage. For example, devices are installed to detect rock falls and avalanches, and the Urgent Earthquake Detection and Alarm System (UrEDAS) has been developed. Both are discussed below.

In some cases, one can detect signs that warn of future trouble—for example, a partial land slippage or changes in underground water level can indicate an imminent landslide. We can use measuring devices to predict and detect such an occurrence. But the installation of such devices and measurements and observations require significant manpower and expense, so these devices are installed only in a limited number of locations.

Embankment collapse caused by heavy rain (RTRI)

Safeguarding Trains from Heavy Rainfall

Heavy rain can seriously disrupt rail services. Rainwater can flood tracks, wash away ballast and collapse slopes (e.g. embankment slopes, cut slopes, and natural slopes). Flooding rivers can scour bridge and revetment foundations. Rock falls are another serious problem encountered on slopes, although they do not necessarily occur during heavy rainstorms.

Various preventive structures are installed along the track to prevent these problems (Fig. 5). Such structures are often the most effective, but, as previously mentioned, they require huge expense. Another reason why they are not the answer to every problem is that they are not disaster-proof if the natural force is stronger than the design force. This means that we must also use train operation controls and, where necessary, detection devices even after erection of protective structures.

Slope failure is the most common problem associated with heavy rainfall, so measures to prevent rain damage begin by preventing slope failure. However, before deciding which preventive measure would be most effective, we must first evaluate how much rainfall will trigger a slope collapse. Preventive structures and train operation controls will be effective countermeasures to heavy rainfall only if we can make such a prediction with a high degree of exactitude.

To increase prediction accuracy, RTRI recently devised a new risk estimation method for slope failure during heavy rainfall. Risk estimations are made for three types of slope failure: embankment collapse, surface collapse on cuttings, and deep collapse on cuttings. The estimated slope failure risk value is expressed using the term 'critical rainfall'.

Figure 6, which indicates both hourly and accumulated rainfall, plots sample results obtained through this risk estimation method. The critical rainfall curve indicates withstanding force, with the highest withstanding force in the upper right of the figure. When the actual rainfall is more than the values plotted on the curve, the risk of collapse is great. This risk estimation method has already been adopted by the JR group of companies, which are now using it to estimate slope failure risks.

The extent to which a soil slope collapses is closely related to the amount of rain, but this is not necessarily the case with falling rocks, which may fall even during fine weather. Train operation controls are therefore not very effective in preventing damage caused by falling rocks. Protective barriers and detection devices are more effective. Such devices consist of cables laid near track areas where there is a risk of falling rocks. When a cable is severed by a falling rock, an alarm is activated and the train is stopped.

Safeguarding Trains from Heavy Snowfall

Snow can seriously interfere with train operations. Trains may be stopped by snow accumulating on the tracks and turnouts, or by drifting snow or avalanches. Avalanches and snow drifts can derail a train, snow can damage rolling stock, snow adhering to rolling stock may fall off while the train is in motion and cause an accident, and railway structures may collapse under the weight of snow.

A number of structures can be erected to prevent these and other problems (Fig. 7). The snow can also be removed before it becomes a serious nuisance using rotary snowplows or Russel (pushing) snowplows. In addition, winter schedules can be

Figure 5 Major Structures to Prevent Damage by Landslides and Flooding

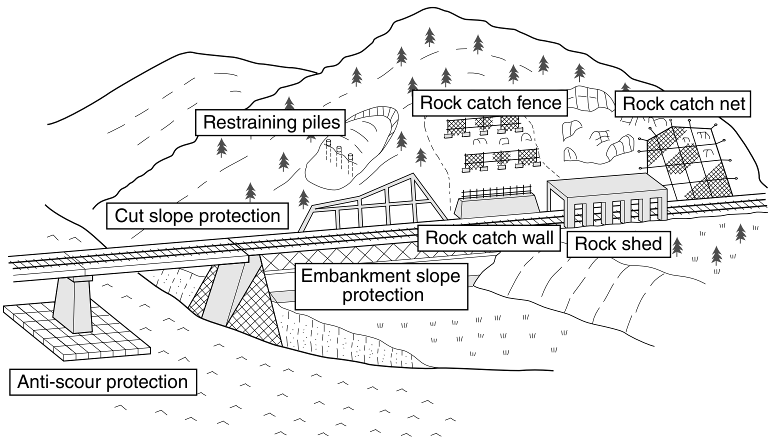


Figure 6 Critical Rainfall Curve

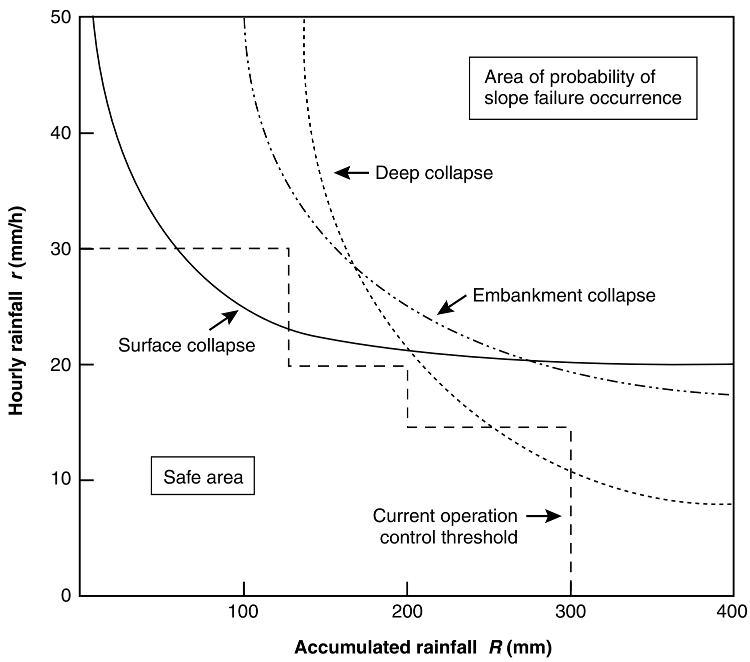
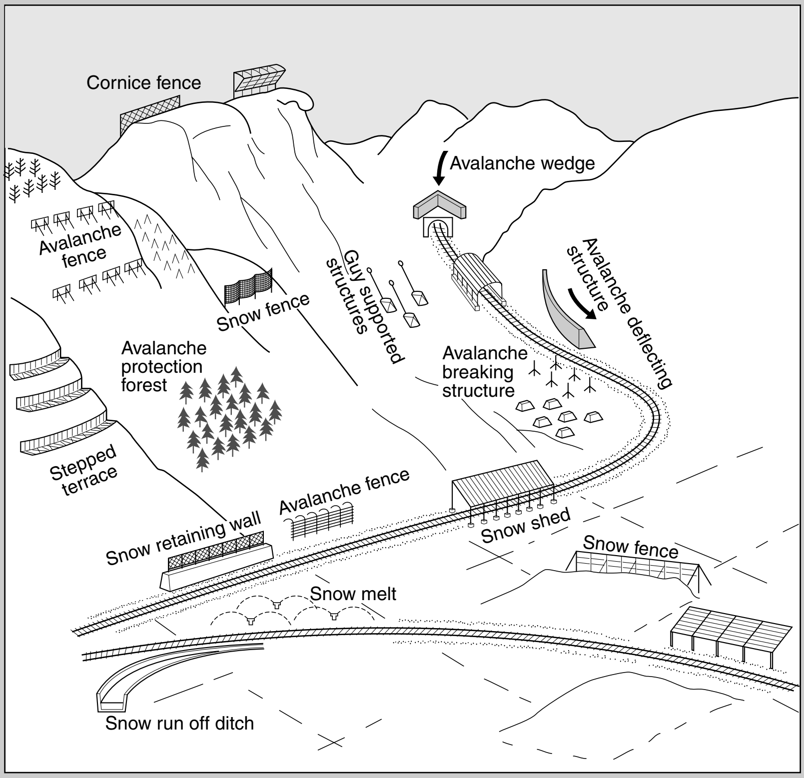


Figure 7 Major Structures to Prevent Snow Damage



Testing avalanche detection and alarm system at Shiozawa Snow Test Site. Pole in middle for avalanche detection (RTRI)

devised to permit the alternate use of snowplows and trains on the same track. Train operation controls can be implemented on a phased basis, depending on the amount of snow on the tracks and snow removal conditions.

Avalanche risk is evaluated from the air using helicopters, and on the ground during patrols. When an avalanche is anticipated, especially during the snowmelt season, special surveillance measures are taken to protect rail operations. A different problem is seen in tunnels—freezing of leaking water. To prevent this, structures equipped with thermal insulators are being developed and installed.

The following measures are taken to protect shinkansen from snow damage. In the case of the Tokaido Shinkansen line, sprinklers spray water on ballasted track during snowfalls. This makes snow wet, otherwise it would fly up when trains speed by, and prevents snow from adhering to rolling stock.

The Tohoku and Joetsu shinkansen lines run through areas subject to greater snowfalls. Ballasted track sections are shorter there, and rolling stock is designed to inhibit snow adherence. Viaducts on the Tohoku Shinkansen line have been constructed to withstand snow depth equivalent to the annual return in a 10-year period. On the Joetsu Shinkansen line, water sprinklers melt snow on track sections in the plains and on long, tunnel-free sections in mountainous areas. Snow sheds and snow shelters have been constructed over shorter sections between tunnels.

Interruption of rail services caused by heavy snow (RTRI)


Typical wind barrier (JR Hokkaido)

Wind-tunnel test on aerodynamic forces of gale-force winds on rolling stock (RTRI)

RTRI is now developing an avalanche detection and alarm system for railway tracks. We have completed basic research on a system that will be extremely accurate in detecting the occurrence of avalanches and evaluating their size, and that will issue alarms when required. Our prototype experiments have indicated that the system can perform these functions and we have every reason to believe that it will be put to practical use soon.

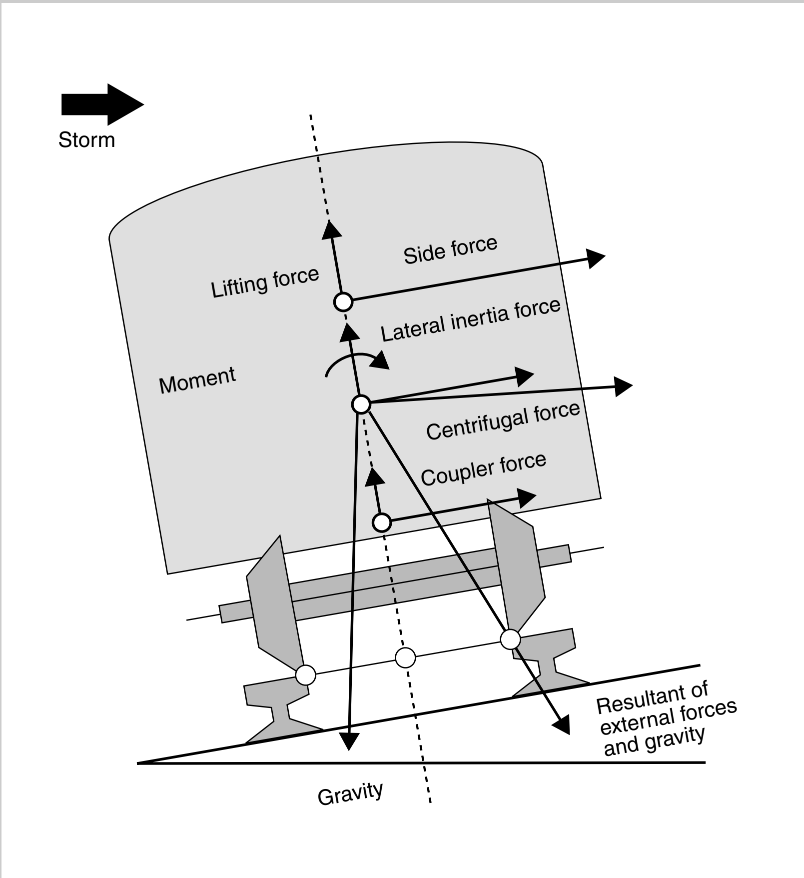
Safeguarding Trains from Gale-force Winds

The greatest danger posed to a train by gale-force winds is derailment. Wind is said to have caused 29 derailments during the more than 120 years of rail transport in Japan.

Other external forces also come into play, especially lateral inertia force and centrifugal force. These external forces can combine with gravitational force to exert a pressure that is directed toward the leeward side of the wheels. This pressure pushes the wheels away from their point of contact with the rails, causing the train to derail (Fig. 8).

One way to prevent this is to reduce aerodynamic forces acting on rolling stock. Another way is to measure wind speeds

Figure 8 External Forces on Rolling Stock and Critical Conditions for Overturn (typical)



with trackside anemometers, and to stop train operations on wind-prone track sections when wind speeds indicate a need to do so. The first approach involves installation of wind fences or windbreaks. The second approach involves use of train operation controls, which generally stop services when the instantaneous wind speed reaches 30 m/s, or 25 m/s in areas where even greater caution is warranted. Once the train is halted, operation guidelines call for it to stay halted for a full 30 minutes, and then to proceed only if conditions indicate that wind speeds are dropping.

RTRI is conducting wind-tunnel tests to determine the extent to which various rolling stock shapes, and the various shapes of structures like bridges and embankments, can determine the intensity of wind-generated aerodynamic forces against moving rolling stock. We are also examining wind conditions along track sections to discover the various characteristics of wind. The results of this research will be used to establish safe and effective train operating control norms.

Safeguarding Trains from Earthquakes

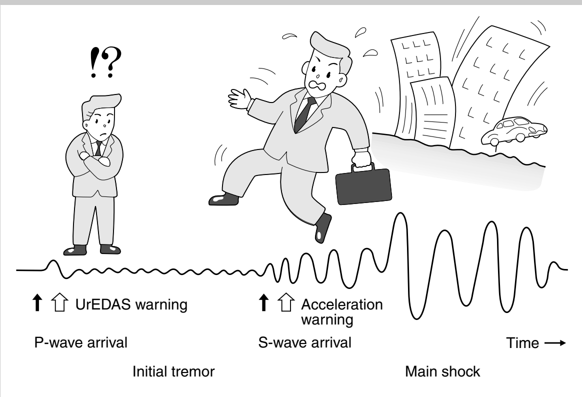
Japan is one of the most earthquake-prone countries in the world. A recent example is the Great Hanshin Earthquake that struck the Kobe region in January 1995, causing considerable damage to railway infrastructure, including the San'yo Shinkansen line.

Measures to protect railways from earthquakes include: (1) strengthening infrastructure and equipment so that they can withstand the anticipated earthquake motion; and (2) stopping the train as soon as an earthquake occurs, in order to minimize damage.

The second measure involves installation of trackside seismometers and the application of train operation controls. The controls vary according to detected seismic motion. Train operation controls generally call for reduced speed when the earthquake acceleration is between 40 and 79 gals, and a rapid stop when the acceleration is 80 gals or greater. The objective is to prevent the train from entering a zone that has been damaged by an earthquake. But the problem remains that the train must travel some distance while the ground is shaking before coming to a complete halt. Thus, this type of precaution may be inadequate, especially in the case of a fast shinkansen. To address this issue, RTRI developed the above-mentioned Urgent Earthquake Detection and Alarm System (UrEDAS), which is designed to detect earthquake forces more rapidly and transmit alarms more accurately. As Figure 9 shows, the system detects an earthquake by picking up small seismic waves called P-waves, which are the first to reach the Earth's surface. The system then immediately estimates the epicenter and the magnitude of the earthquake, and then uses this data to determine risk levels. If the risk is great, the system transmits alarms to areas that could be affected. The object here is to halt trains, or at least reduce their speed, before the main shock arrives and causes damage. When UrEDAS was first installed in 1992, it covered the entire Tokaido Shinkansen line. It has now been installed on all shinkansen tracks.

The other earthquake countermeasure—strengthening infrastructure and equipment—follows seismic design standards established by the Japanese government. Work has been carried out to increase the earthquake resistance of new structures and equipment, and of

Figure 9 Principle of Urgent Earthquake Detection and Alarm System (UrEDAS)



Viaduct collapsed during Great Hanshin Earthquake (RTRI)

Seismometer (left) installed at UrEDAS site (middle) and data processing unit at Seismic Data & Analysis Center (Photos: RTRI)

existing structures and equipment in areas where it is thought a major earthquake could strike.

However, the motion of the 1995 earthquake in the Kobe area greatly exceeded any earthquake movement expected at the time. Therefore, RTRI revised its seismic design principles. Two notable results of this revision are: (1) in the past, any study of extremely strong earthquake motion focused on interplate earthquakes, but consideration is now also given to earthquakes along inland active faults; and (2) structural design is based on the principle that structures must not collapse during an earthquake even though they may sustain damage. Decisions regarding structural seismic capacity are based on each structure's importance.

Conclusion

It is impossible to prevent an act of God from inflicting damage on railway infrastructure, but appropriate measures can make infrastructure less vulnerable.

First, for any protective measure to be effective, railways must always remain aware of conditions on and near their tracks, and must take appropriate steps whenever there is a risk of disaster. Japanese railway companies inspect their tracks and equipment on a regular basis, and information obtained from these inspections is used when devising protective measures. Inspections are conducted mainly by engineers, but new techniques, such as remote sensing, have also been used recently.

Effective train operation controls require continuous and accurate assessment of meteorological conditions. Over the years, this has meant trackside installation of rain gauges, anemometers and other devices. In some cases, such devices can now be accessed online, making it possible to collect data in real time. Greater precision is also achieved using data from Japan's Meteorological Agency. We must also increase the reliability of technologies used to predict natural disasters, and develop other effective and economical means to safeguard railways from the forces of nature. RTRI is conducting serious research to tackle these issues. ■

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