Train Operation Control Indices for Use during Earthquakes in Japan

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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.

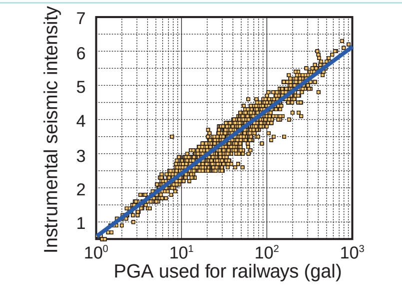

Fig. 1 Relationship between the peak ground acceleration and the instrumental seismic intensity used in railways

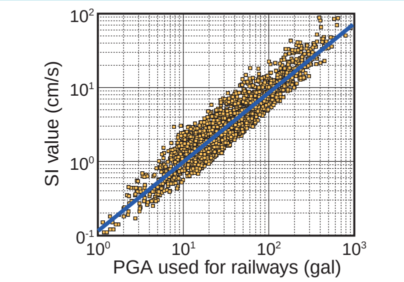

Fig. 2 Relationship between the peak ground acceleration and the SI value used in railways

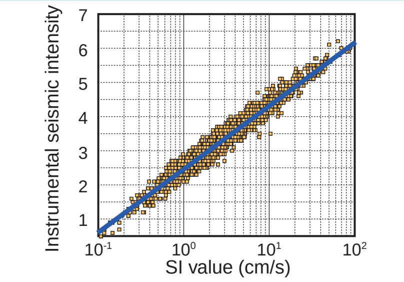

Fig. 3 Relationship between the SI value and the measured seismic intensity

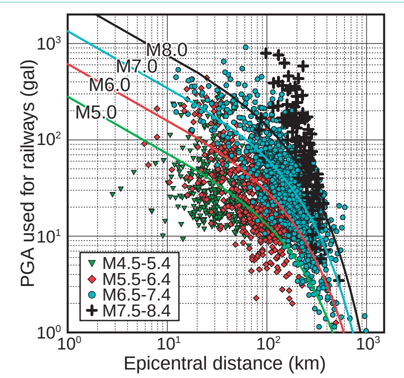

Fig. 4 Attenuation with distance of the peak ground acceleration used for railways

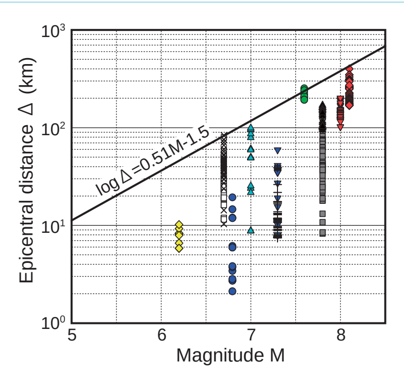

Fig. 5 Relationship between earthquake magnitude and the epicentral distance from the damaged site