Enhancement of Functions of Tokaido Shinkansen Earthquake Disaster Prevention System

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The Tokaido Shinkansen has always had the most advanced technologies for preventing earthquake disasters. For example, the world's first mechanical alarm seismoscope with a fully automated process from issue the earthquake detection to alarm was installed in November 1965—one year after the Tokaido Shinkansen opened. However, in view of recent remarkable advances in seismology and earthquake engineering, the present earthquake disaster prevention system of the Tokaido Shinkansen is changing greatly. This article outlines the new earthquake rapid alarm system (TERRA-S) put into operation and plans for future improvements.

Outline of Earthquake Disaster Prevention System

System configuration

The Tokaido Shinkansen earthquake disaster prevention system consists of an earthquake alarm system designed to remotely and quickly detect a major earthquake occurring somewhere, plus wayside seismographs designed primarily to sense actual quakes along the line. The system is composed of 14 remote seismographs installed at points away from the tracks; 25 substation devices that evaluate whether or not to stop supplying power to trains based on information supplied by the remote seismographs; two terminal devices for monitoring the remote seismographs and substation devices by the dispatcher, etc., and three relay stations for relaying information between the remote seismographs, substation devices, and monitoring terminals. Two types of wayside seismographs—electrical and mechanical acceleration seismographs—are installed alongside the substation devices (Fig. 1). The locations of the 14 remote seismographs are shown in Figure 2.

Functions of earthquake alarm system

When a major earthquake occurs somewhere away from the Tokaido Shinkansen, it is detected by the nearest remote seismograph, which estimates the earthquake magnitude and epicentre using the initial P-wave and transmits the results to the associated substation device via the relay station. Based on information from the remote seismograph, the substation device evaluates whether an alarm should be issued. If an alarm is issued, the substation device transmits a signal to cut the power, causing an application of the train emergency brakes (Fig. 3).

Functions of wayside seismographs

When an earthquake occurs somewhere along the Tokaido Shinkansen, the nearest wayside seismograph senses the quake before the P-wave reaches a remote seismograph. The wayside seismograph automatically issues an alarm if the seismic acceleration exceeds a set limit (40 gal), stopping the train.

In addition to issuing the earthquake alarm, an important role of wayside seismographs is monitoring the quake from its detection until its termination, calculating the maximum acceleration, and transmitting this information to the dispatcher. The dispatcher decides how operations should respond based on the magnitude and epicentre announced by the Japan Meteorological Agency after the earthquake and the maximum acceleration, etc., recorded by the wayside seismograph.

Enhanced Earthquake Rapid Alarm System

An earthquake alarm system was introduced to the Tokaido Shinkansen in

Figure 1 Tokaido Shinkansen Earthquake Disaster Prevention System Configuration

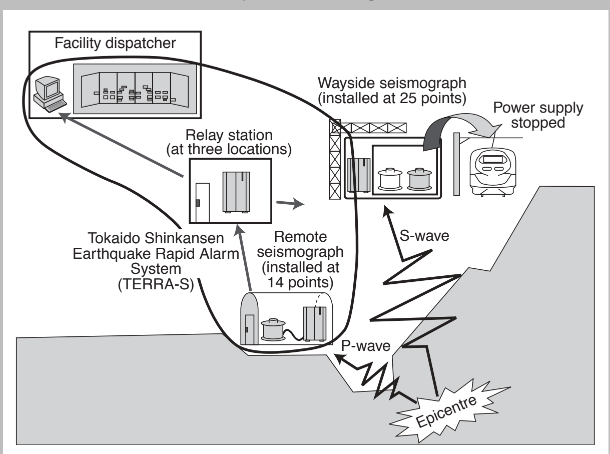


Figure 2 Locations of Remote Seismographs

Figure 3 Functions of Earthquake Alarm System and Wayside Seismograph

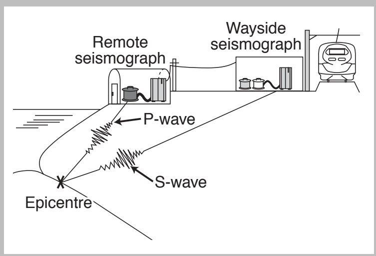
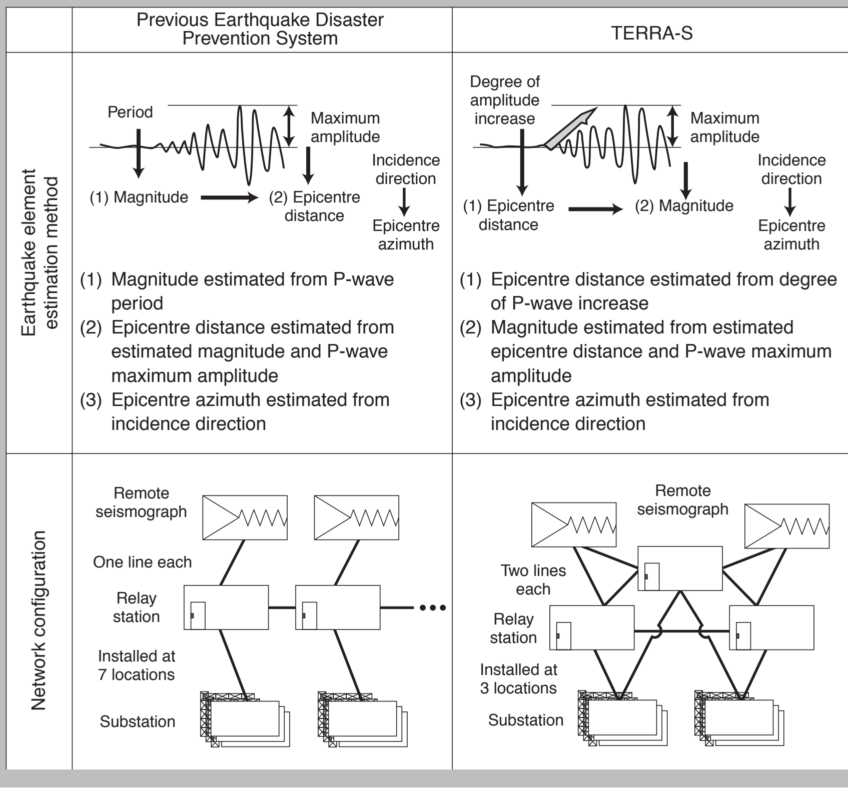


Figure 4 Comparison of Former and New Systems



1992 and it has been an important system for protecting the Tokaido Shinkansen from earthquakes. In the 10 or more years since the introduction, significant technical improvements have been made to estimate the earthquake parameters from its P-wave. Recently, JR Central built a new Tokaido Shinkansen Earthquake Rapid Alarm System (TERRA-S) using the improved techniques. The new system was put into operation on 30 August 2005 and its main characteristics are described below.

Faster estimation

In view of its purpose, clearly it is better to issue an earthquake alarm as fast as possible. The conventional remote seismographs estimate the earthquake magnitude from the period of the initial P-wave, and the epicentre distance from the estimated magnitude and maximum amplitude of the initial P-wave. As a result, it took about 3 s from the instant the earthquake was detected until completion of the estimation. The remote seismographs used for the new system adopt a new earthquake element estimation method co-developed by the Railway Technical Research Institute (RTRI) and the Meteorological Agency. New it takes about 2 s from first detection of an earthquake until completion of estimation of the earthquake elements, cutting the current required time by about 1 s (Fig. 4).

Improved accuracy

The accuracy of the earthquake alarms includes not only ‘properly issuing an alarm when an earthquake that will affect railway structures has occurred’ but also ‘not issuing an alarm for an earthquake that will not affect any railway structures.’ Thanks to the introduction of the new earthquake element estimation method mentioned above, it should become possible to reduce unnecessary alarms by nearly 50% while improving the accuracy of earthquake alarms.

Faster and more reliable information transmission

Unlike the earthquake observation system, the earthquake alarm system must transmit appropriate information even during an earthquake, as well as right after the earthquake. Moreover, in view of the nature of earthquake alarms, the information must be transmitted as speedily as possible. As shown in Fig. 4, the new network is configured with redundancy so that even if one communication line or one relay station fails, the remote seismograph can continue sending without interruption.

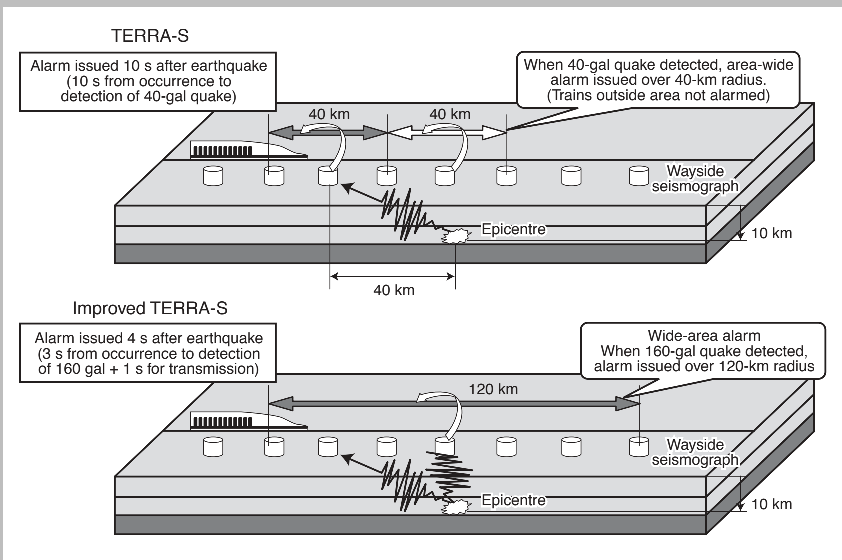
Enhanced Functions of Wayside Seismographs

In addition to the enhancement TERRA-S described above, the wayside seismographs—the other major component of the earthquake disaster prevention system—are being enhanced with completion scheduled in FY 2005.

Addition of wide-area alarm to wayside seismographs

Needless to say, if a major earthquake hits a large city, the area above the epicentre

Figure 5 Outline of Wide-area Alarm Function



can be devastated. From experience, such earthquakes can even cause considerable damage even at places tens of kilometres from the epicentre, depending upon the fault direction, ground conditions, etc. If a seismograph was at the epicentre and if it could issue an alarm over a wide area around the epicentre, it would be possible for places away from the epicentre to receive the alarm some 10 or so before the main shock arrives.

This improvement of the wayside seismographs adds a new function to react to an earthquake with the epicentre right under the track. If the wayside seismograph detects a quake exceeding 160 gal, it assumes it is on the epicentre and issues an alarm over a 120-km radius—wider coverage than before (Fig. 5).

New quake index with strong damage correlation

The improved function of the wayside seismographs is not limited to expanding the area receiving an earthquake alarm. It also improves the accuracy of the predicted quake effect by calculating the seismic intensity, which is more strongly correlated to structural damage than maximum acceleration and allows better operation control after an earthquake.

Faster earthquake alarms from wayside seismograph

Wayside seismographs were introduced on the Tokaido Shinkansen as soon as it opened. Although a number of improvements were made to the original wayside seismographs (changed monitored frequency band to increase correlation with structural damage and introduced electronic seismograph), the

Figure 6 Comparison of Alarm Timing between Horizontal and Three-component Accelerations

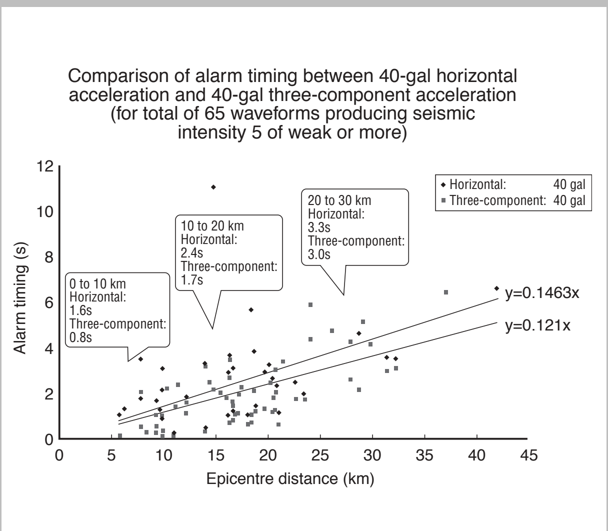


Figure 7 Maximum Value of Horizontal and Three-component Acceleration

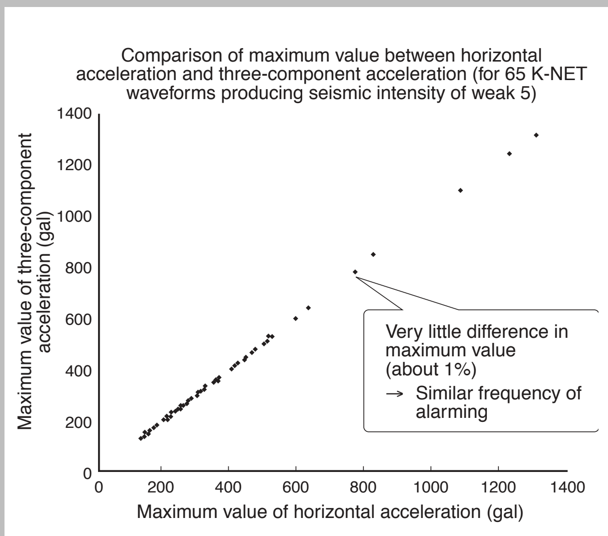


Figure 8 Installation of Additional Remote Seismographs and Wayside Seismographs

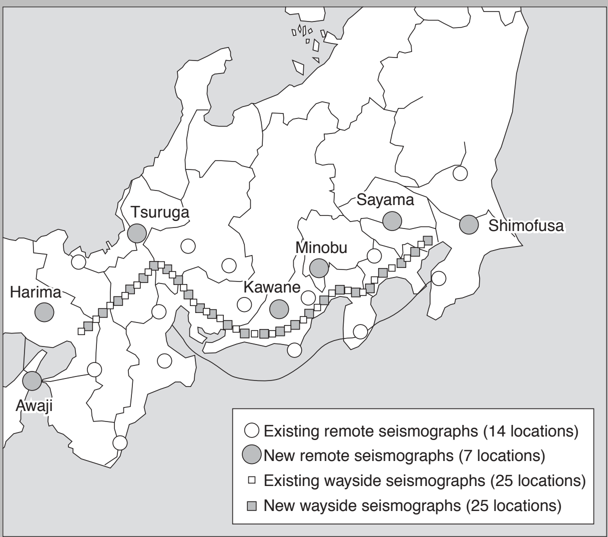
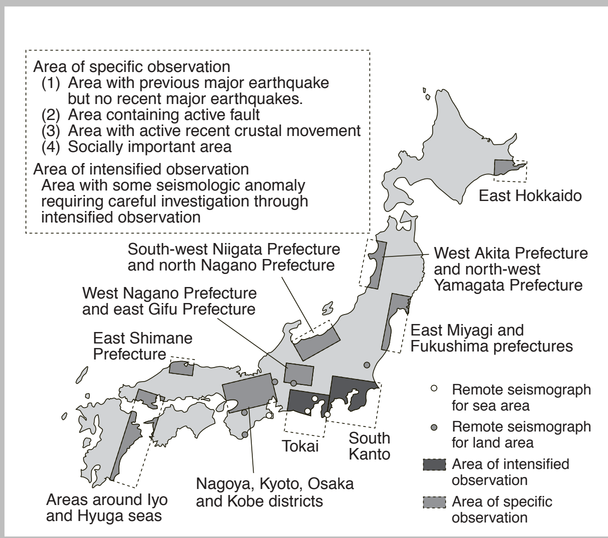


Figure 9 Areas of Specific Intensified Observation and 14 Earthquake Detection Points



horizontal acceleration of 40 gal has remained the set alarm level.

In planning the present enhancement of wayside seismographs, we studied what effect would be produced if the quake index for issuing an alarm was changed from horizontal acceleration to a three-component acceleration including vertical motion. As a result, we found:

- Compared to 40 gals as the reference value, three-component acceleration quicken the alarm by a maximum of several seconds (Fig. 6).
- Comparing the ultimate maximum value between horizontal acceleration and three-component acceleration, the value of the three-component acceleration is naturally larger than that of the horizontal acceleration. However, the average difference is only 1% (Fig. 7).

Based on these findings, we found that using three-component acceleration with the same alarm level of 40 gals, alarms could be speeded up without increasing the alarm frequency.

Additional Wayside and Remote Seismographs

The enhancement of TERRA-S and wayside seismographs described so far concerns the functions of the individual devices. Considering the earthquake disaster prevention system as a whole, it is possible to further enhance the functions by installing more wayside and remote seismographs. The expansion plans for both types of seismographs are described below and are scheduled for completion by late FY2006; the expansion of remote seismographs is scheduled for completion around mid-2007 (Fig. 8).

Additional wayside seismographs

At present, there are 25 wayside seismographs installed at intervals of about 20 km. In the present functional enhancement plan, a new wayside seismograph will be installed about midway between every two existing wayside seismographs, offering a total of 50 wayside seismographs at intervals of about 10 km.

When the additional wayside seismographs are installed, the narrower interval will make it possible to speed up alarms by about 1 s. In addition, since the additional wayside seismographs enable more detailed post-quake information, it is possible to shorten the time required to confirm the safety of wayside facilities.

Installation of additional remote seismographs

The present earthquake rapid alarm system has remote seismographs installed at 14 points surrounding the Tokaido Shinkansen. In the present functional enhancement plan, seven more seismographs will be installed where the current interval is longer than elsewhere, giving a total of 21 remote seismographs. Twelve of the existing remote seismographs are installed at points in some of the ‘areas of specific observation’ or ‘areas of intensified observation’ specified by the Coordinating Committee for Earthquake Prediction and two are installed where the next Tonankai earthquake is likely to occur (Fig. 9). Therefore, they are concentrated in specific areas, but the additional remote seismographs will make it possible to issue alarms faster for nearby earthquakes.

Optimized Control

The enhancement of various functions described so far contributes both to improvement in train safety during an earthquake and to optimized post-earthquake control. This section discusses the new method of operation control using the earthquake disaster prevention system after the functional enhancement.

Operation control based on measured seismic intensity

Generally, the greater the maximum seismic acceleration, the more damage to structures. However, the probability of earthquake damage is not determined only by the maximum acceleration. Other factors such as quake period and seismic duration cannot be neglected. The SI value and measured SI have both been proposed as indexes that take these factors into account. There is very little difference between them from the standpoint of assessing the structural damage.

For the Tokaido Shinkansen, we plan to adopt measured seismic intensity (SI) as the new index because it is widely known by the general Japanese public and because the value announced by the Meteorological Agency can be substituted directly if our seismographs fail. As described, the ability to calculate SI is being added to the wayside seismographs. Post-earthquake operation control based on measured seismic intensity started at the end of FY 2005 when the functional enhancement of the wayside seismographs was completed. This new operation control method should help reduce the frequency of track patrols too.

Interval between wayside seismographs and regulatory value

Even when the same quake index is used, the reference value for operation control differs with the interval between seismographs. At a long interval between seismographs, there is a risk that the actual quake midway between the seismographs is greater than the reading. Therefore, the regulatory value must be set on the safe side.

With the present 20-km interval between wayside seismographs, when measured seismic intensity is used as the quake index, the reference value for track patrolling must be stricter by one rank than the measured seismic intensity—the low limit at which structural damage can occur. When the installation of additional wayside seismographs is completed and the interval decreases to 10 km, it should be possible to raise the reference value. In future, we intend to study the optimum way of setting regulatory values.

Conclusion and Future Prospects

The new TERRA-S should make a greater contribution to the safety and stability of the Tokaido Shinkansen. We are confident that when the planned functional enhancement is completed, TERRA-S will be the world's most advanced earthquake disaster prevention system.

However, learning a lesson from the major earthquake in Niigata Prefecture on 23 October 2004 that derailed a shinkansen on the Joetsu Shinkansen and shocked many people (see pp. in this issue), we will never be completely satisfied with past achievements and will continue upgrading our earthquake disaster prevention system. ■

Further Reading

Establishment of Earthquake Rapid Alarm System on Tokaido Shinkansen (in Japanese), 60th JSCE Annual Meeting, 2005.

New Earthquake Data Estimation Strategy for Rapid Earthquake Detection (in Japanese), RTRI Report, 2002.

Rapid Earthquake Data Estimation Strategy using P-wave Envelope Figure (in Japanese), *Jishin*, 2004.

How to Operate under Earthquake Restrictions (in Japanese), *JR East Technical Review*, 2003.

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