Special feature: Are its lessons being adequately applied? Follow-up on the ten-year anniversary of the Hanshin-Awaji Earthquake

- Are we prepared for future massive earthquakes? -

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Earthquake-resistant reinforcement of existing structures

Since the Hanshin-Awaji Earthquake, efforts have been made to reinforce existing structures that were built in earlier eras and have relatively low earthquake resistance with regard to massive earthquakes. With the spread of a performance-based approach to structural design in recent years, new technologies have been developed and introduced which make it possible for these kinds of reinforcement projects to meet high performance requirements under difficult restrictions and economic considerations.

Concerning earthquake-resistant reinforcement measures for small and medium-size bridges, the area which encompasses the broadest scope, the main measures are reinforcement of bridge supports, installation of systems to prevent bridge collapse, and replacement of bearings and expansion devices. There are several technologies for reinforcement of bridge supports, including methods for additional installation of concrete, steel plate, carbon fiber sheeting, or spiral bar. Systems to prevent bridge collapse include elements such as structures for the prevention of bridge collapse (with failsafe functions to ensure that the relative displacement of the bridge's girders due to major deformation and displacement during a large earthquake would not exceed the girder suspension length), structures to limit displacement (using anchor bar angle stoppers and projections to control relative displacement of the substructure and superstructure when the bearings collapse), and structures to prevent grade differences. Technologies are being developed to solve the problems of restrictions that are unique to existing structures by achieving seismic isolation through the use of laminated rubber bearings and the like when replacing bearings.

Earthquake-resistant reinforcement measures have not yet been implemented for many bridges that are particularly long or show complex behavior. However, in some of these cases, reinforcement methods are being studied or work has already begun. In earthquake-resistant reinforcement measures for particularly long bridges, after studying the earthquake-resistant performance of the bridge as an overall system, it is both effective and economically advantageous in many cases to adopt methods that reduce the earthquake response through the use of technologies for seismic isolation and damping, such as replacing the bearings with seismic isolation bearings, changing to a multipoint elastic suspension structure, or installing low surrender point steel members and dampers. Minato Bridge

(Photograph 1) is one example of a particularly long existing bridge where reinforcement work is currently underway.[1]

Photograph 1. Minato Bridge

Strong motion seismograph network (K-NET and KiK-net)

The National Research Institute for Earth Science and Disaster Prevention has established a strong motion seismograph network for nationwide monitoring of strong ground movements and instituted a system for the rapid announcement of its findings. The network consists of Kyoshin Net (K-NET), with about 1,000 observation facilities to obtain surface records at intervals of about 20 kilometers (Photograph 2, left), and KiK-net, a strong motion seismograph network to obtain surface records at about 700 locations. This kind of monitoring system with uniform, high-density, nationwide coverage is unparalleled anywhere else in the world. Digital acceleration records (two horizontal components and one vertical component) have been obtained for many damaging earthquakes since the Hanshin-Awaji Earthquake. From several hours to several days after an earthquake, these records are made available to the general public through the Internet. This data has become indispensable for many research activities, including hypocenter fault modeling and studies to determine the mechanisms of structural damage. Figure 1 is a distribution map of earthquake monitoring points. F-net, as shown in the figure, is an earthquake monitoring network that is capable of recording earthquake movements over a wide frequency range, from rapid movements of the earth's surface to very slow movements.

Photograph 2. K-NET monitoring point (left), electronic standard point (right)

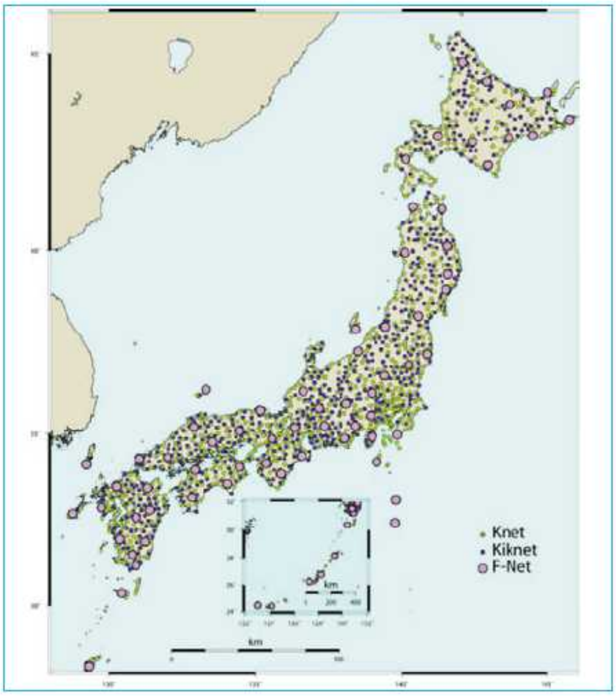
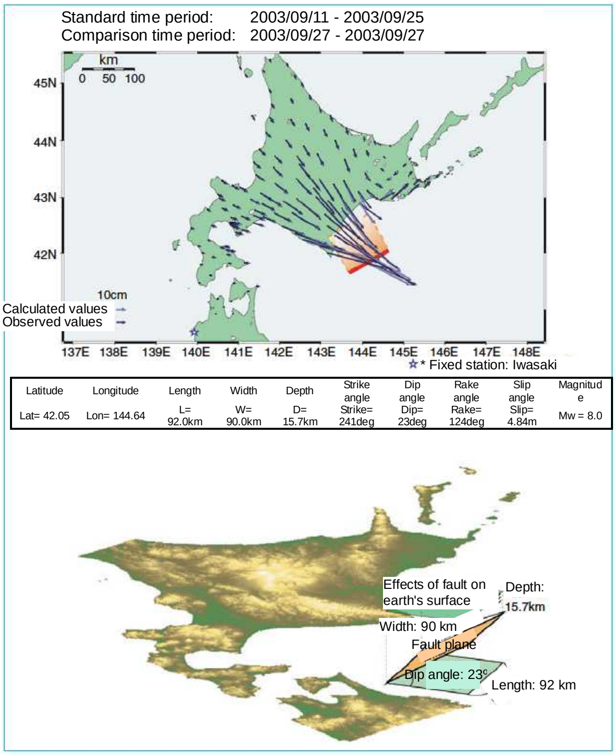


Fig. 1. Distribution map of earthquake monitoring points of the National Research Institute for Earth Science and Disaster Prevention

GPS continuous monitoring system, GEONET

The GPS Earth Observation Network System (GEONET) is a system developed by the Geographical Survey Institute for the continuous monitoring of position information from standard points, using radio waves from GPS satellites. A GPS continuous monitoring network was already in use at about 200 locations since 1994, before the Hanshin-Awaji Earthquake; and the system was expanded to its present scale after that earthquake disaster. There are about 1,200 monitoring points nationwide (Photograph 2, right), position information is gathered from each point once per second and analyzed at the Geographical Survey Institute in Tsukuba. The resulting information on movements of the earth's crust is then made available to the general public.



Latitude	Longitude	Length	Width	Depth	Strike angle	Dip angle	Rake angle	Slip angle	Magnitude
Lat= 42.05	Lon= 144.64	L= 92.0km	W= 90.0km	D= 15.7km	Strike= 241deg	Dip= 23deg	Rake= 124deg	Slip= 4.84m	Mw = 8.0

Fig. 2. Movements of the earth's crust due to the earthquake off Tokachi, Hokkaido (September 26, 2003) and model of presumed fault[4]

Figure 2 shows movements of the earth's crust in an earthquake off Tokachi on September 26, 2003, along with a model of the presumed fault based on inversion analysis. This position information is available to the general public within two to five hours. In addition to earthquakes, the data also includes aftereffect movement (slow sliding after an earthquake) and slow slip (movements of the earth's crust when slow movement occurs at plate boundaries without causing an earthquake). It is used in fault modeling, study of earthquake cycles, and other areas of research. Figure 3 shows the Kobe-Niigata high-strain rate zone (a structural zone where many inland earthquakes have occurred in the past), which was identified on the basis of this data.

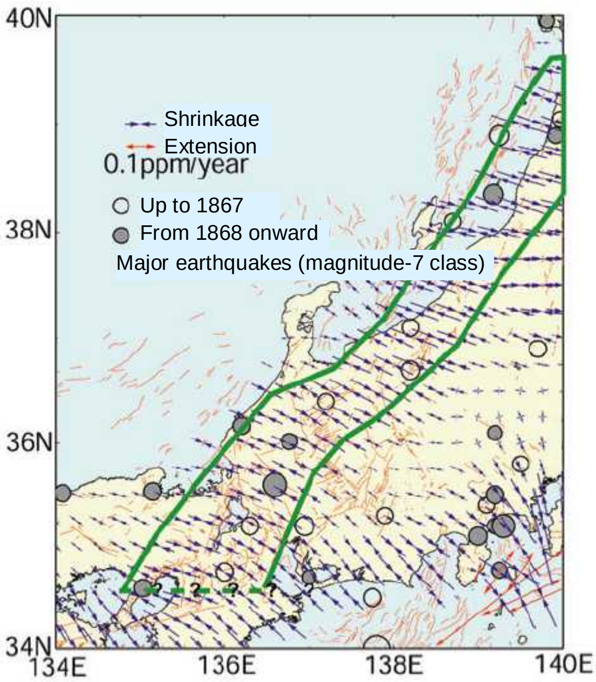


Fig. 3. Kobe-Niigata high-strain rate zone[2]

Urgent earthquake bulletins

Urgent earthquake bulletins are issued before the principal shock of an earthquake arrives, using information on seismic waves from monitoring points near the hypocenter to estimate the hypocenter, earthquake scale, time of principal shock arrival at various locations, intensity, and so on. These bulletins, issued by the Japan Meteorological Agency, are expected to play a role in preventing and reducing earthquake damage by means of measures taken in advance. Figure 4 illustrates the utilization of these urgent bulletins. Figure 5 shows the amount of advance warning from the time an urgent bulletin was issued until the time that the principal shock arrived in the case of an actual earthquake (M7.4 earthquake off Tokaido at 11:57 PM on September 5, 2004).

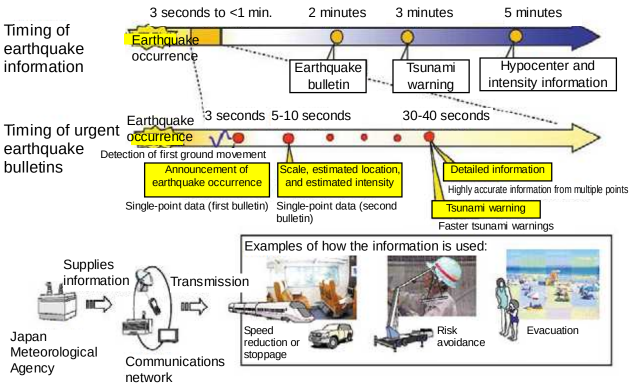


Fig. 4. Utilization of urgent earthquake bulletins[3]

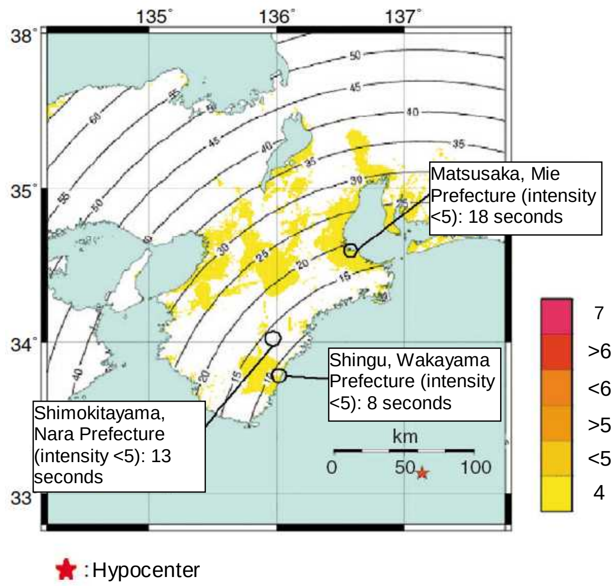


Fig. 5. Time from urgent earthquake bulletin until arrival of principal shock[3] (M7.4 earthquake off Tokaido at 11:57 PM on September 5, 2004)

Since February 25, 2004, the Japan Meteorological Agency has been cooperating with other agencies in a test operation of the urgent earthquake bulletin system in order to verify strategies for the use of these bulletins, from the following three standpoints.

(1) Strategies for use in automatic control systems:
Control of trains, elevators, etc.

(2) Strategies for use in risk avoidance behavior by residents, etc.:
Informing persons in buildings and notifying local governments

(3) Verifying use of information supply system:
Testing information supply with cell phones, satellite communications, etc.

Full-scale 3D test facility (E-Defense)

A full-scale, three-dimensional test facility (E-Defense) is being constructed by the National Research Institute for Earth Science and Disaster Prevention in Miki, Hyogo Prefecture. This facility is expected to be completed in 2005. Its purpose is to experimentally determine the ways that actual structures fail during earthquakes, along with the extent of failure and the reasons for failure, in order to contribute to the establishment of design methods for structures that protect human life.

The main component of E-Defense is a shake table, measuring 15 x 20 meters, which creates the same complex, three-dimensional movements as an actual earthquake. It will be possible to place full-size structures, up to 1,200 tons in weight, on the shake table and subject them to earthquake movements greater than those of the Hanshin-Awaji Earthquake. This will be the largest shake table in the world. In two horizontal directions and in the vertical direction, respectively, it will be capable of generating a maximum acceleration of 0.9 G and 1.5 G, maximum speed of 200 cm/s and 70 cm/s, and maximum displacement of ±1 m and ±50 cm (with a 1,200-ton load).

Many experiments are being planned for after E-Defense is completed, including joint efforts by industry, government, and academia for tests to determine the earthquake resistance of existing wooden structures and verify the effects of earthquake-resistant reinforcement, as well as the development and verification of new bridge structures and earthquake-resistant reinforcement technologies for bridge supports (Fig. 6).

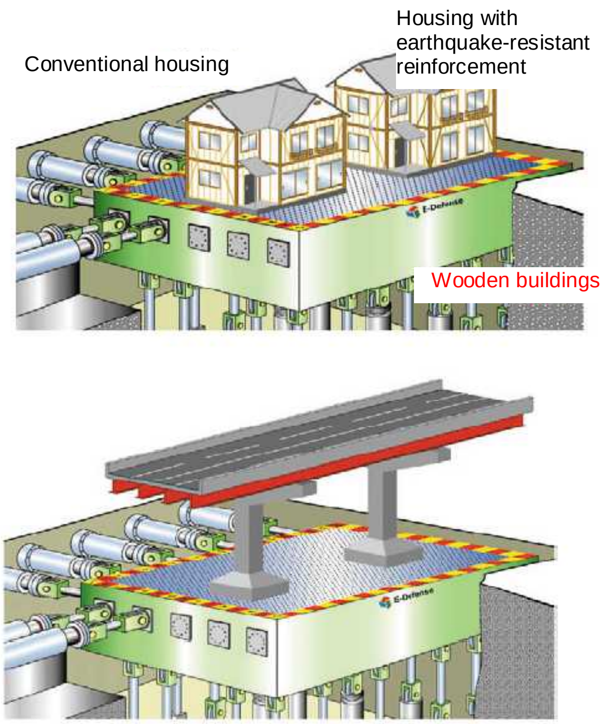


Fig. 6. Full-size destructive testing of wooden buildings and bridge structures

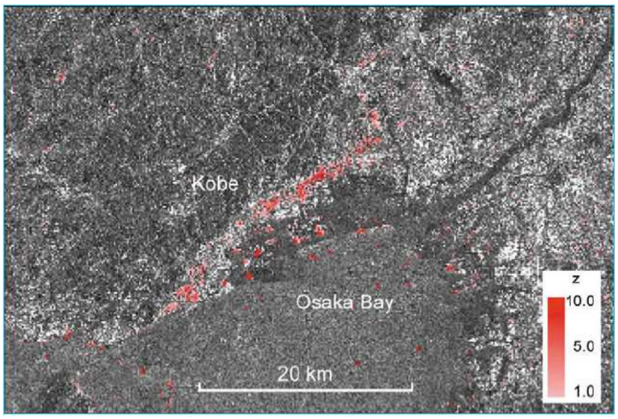


Fig. 7. Example of damage detection during the Hanshin-Awaji Earthquake[5]
Red portions indicate areas where heavy damage is assumed.

__Remote sensing (laser images for damage detection)__

Synthetic aperture radar (SAR) measurement is a microwave-based remote sensing technology which can function day or night, regardless of cloud cover. The Earthquake Disaster Mitigation Research Center of the National Research Institute for Earth Science and Disaster Prevention has developed a method for automatic detection of damage regions by comparing SAR images, obtained with satellite-mounted synthetic aperture radar units, before and after an earthquake. This method is based on the fact that backscatter strength (strength of microwave reflection) decreases in regions where there has been a significant extent of building collapse. Figure 7 is an example showing detection of the earthquake disaster zone in the Hanshin-Awaji Earthquake. The applicability of damage detection methods based on absolute-value measurement of surface changes has also been confirmed in recent earthquakes in Turkey, India, and Iran. It is anticipated that this will be used as an early assessment method in large-scale disasters in developing countries as well.

References

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