KNOWLEDGE NOTE 1-1

CLUSTER 1: Structural Measures

Structural Measures against Tsunamis
Structural Measures against Tsunamis

Structures such as dikes play a crucial role in preventing disasters by controlling tsunamis, floods, debris flows, landslides, and other natural phenomena. However, structural measures alone cannot prevent all disasters because they cannot mitigate damages when the hazard exceeds the level that the structures are designed to withstand. The Great East Japan Earthquake (GEJE) demonstrated the limitations of Japan’s existing disaster management systems, which relied too heavily on dikes and other structures. Damage can be kept to a minimum by multilayered approaches to disaster mitigation that include structural and nonstructural measures and that ensure the safe evacuation of residents.

Dikes, dams, and other structures are regarded as core measures in disaster risk management in Japan. Japan has constructed dikes to mitigate flooding for nearly 2,000 years. The first dike system was constructed in the Yodogawa River in Osaka in the fourth century. The Japanese used dike systems to protect crucial areas, such as castles and residential areas, in the middle and early modern periods. The government established after the Meiji Revolution in the late nineteenth century has promoted structural measures to control floods, high tides, landslides, and tsunamis by employing modern technology introduced from the Netherlands and other Western countries. Disaster damage had substantially decreased because of concentrated investment in structural measures (KN 6-1).

Surrounded by seas, Japan has an extremely long, geographically complex coastline of approximately 35,000 kilometers. People, productive assets, and social capital are concentrated on small coastal plains over a limited land area. Not only are Japan’s coastal areas situated where earthquakes are exceptionally common, but they are also subject to harsh natural events, such as typhoons and winter ocean storms. Historically, the country has suffered severe damage from tsunamis, storm surges, ocean waves, and other natural phenomena. To protect life and property concentrated near its coastline, the country has been developing coastal and port facilities for the last half century.
FINDINGS

COASTAL STRUCTURES IN THE REGION AFFECTED BY THE GREAT EAST JAPAN EARTHQUAKE

When the tsunami hit eastern Japan in March 2011, 300 km of coastal dikes, some as high as 15 meters high, had been built (figure 1). Prefectural governments, which have the main responsibility for building the dikes (supported by national subsidies that cover two-thirds of the cost), built 270 kilometers of the total, with the national government building the remaining 30 km. The national government also had developed technical standards, guidelines, and manuals for use in the design and construction of coastal structures. In response to the economic damage caused by the GEJE – ¥300 billion ($3.75 billion) in destroyed dikes—the government has invested several hundred billion yen in dike construction in the Iwate, Miyagi, and Fukushima prefectures. It has also invested ¥400 billion ($5 billion) in constructing bay mouth breakwaters in major ports, such as Kamaishi, Kuji, and Ofunato, to protect them from tsunamis. A cost-benefit analysis of these investments appears in KN 6-1.

The disaster-affected region had frequently sustained devastating damage from tsunamis, including the Sanriku tsunamis of June 1896 and March 1933, and a tsunami caused by a massive earthquake off the coast of Chile in May 1960. The 1933 Showa Sanriku Tsunami was the first disaster to provoke modern tsunami countermeasures at the initiative of the central and prefectural governments. Those countermeasures included mainly relocation to higher ground and the building of dikes, albeit at just five sites (box 1).

The Chilean Earthquake Tsunami of 1960 prompted extensive construction of coastal dikes in the region. The dike height was initially based on the height of the 1960 tsunami but was revised several times thereafter to take into account other major tsunamis that had

BOX 1: The enormous tsunami walls of Taro, Miyako City, Iwate Prefecture

The people of the Tohoku region have built and maintained tsunami dikes for decades. Following the Meiji Sanriku Tsunami of 1896, the village of Taro was hit by a 15-meter tsunami that washed out 285 houses and killed 1,447 people. The 7.6-meter Showa Sanriku Tsunami of 1933 also hit Taro, washing out all 503 houses and killing 889 of the village’s 2,950 residents. Because insufficient high ground could be found for 500 houses, the village chose to build dikes. Construction began in 1934 using borrowed money and took more than three decades to complete. The largest dike was 2,433 meters long and 7 meters high (10.65 meters above the sea level). It was 3 meters wide at the top and as much as 25 meters wide at the base. The March 11 tsunami swept over this dike before destroying it, leaving a path of death and destruction across the community.
occurred in the previous 120 years, as well as predictions of future storm surge levels. These dikes are designed to withstand the largest of the predicted tsunami heights and storm surge levels. In Iwate and northern Miyagi, the heights were based on historical records, whereas in southern Miyagi and Fukushima they were based on the predicted storm surges. Methods of risk assessment are explained in KN 5-1.
HOW STRUCTURES PERFORMED AGAINST THE GEJE TSUNAMI

Some towns in the region were well protected by the structures in place, even though the tsunami caused by the earthquake far exceeded their design height. In Iwate’s Fudai Village, the 15.5-meter floodgate, built in 1984, protected the village and its 3,000 inhabitants. The village was severely damaged by the Meiji Sanriku Tsunami of 1896 (height 15.2 meters), the Showa Sanriku Tsunami of 1933 (11.5 meters), and the Chilean Earthquake Tsunami of 1960 (11.5 meters). The mayor of the village in the early 1980s was convinced that a 15-meter tsunami would hit the village again at some point, and built the 200 meter-wide floodgate about 300 meters inland from the mouth of the Fudaigawa River, which runs through the village. Although the 20-meter-high GEJE tsunami did top the floodgate, the gate kept the water from reaching the town center (figure 2). The topography of Fudai Village, being surrounded by cliffs with a narrow opening to the sea, was a major factor in enabling the construction of such a high gate.

The dikes also served to protect communities in areas where the tsunami was lower than the dike (northern Iwate, Aomori, Ibaraki, and others), as shown in the example of Hirono Town (figure 3).

Certain breakwaters were also effective in mitigating damage from the tsunami. The breakwater at the mouth of Kamaishi Bay in Kamaishi City, Iwate, was completed in 2009, at a total cost of some ¥120 billion ($1.5 billion). It was the world’s deepest breakwater. Although destroyed by the GEJE tsunami, it reduced its force, and therefore its height, by

FIGURE 2: Inundation area in Fudai Village, Iwate

Source: MLIT.
about 40 percent and delayed its arrival by some six minutes, allowing more time for people to evacuate to higher ground (figure 4).

The GEJE tsunami destroyed many coastal structures. Of the 300 km of dikes along the 1,700 kilometer coast of the Iwate, Miyagi, and Fukushima prefectures, 190 kilometers were destroyed or badly damaged. In many cases the tsunami was twice the height of the dikes (figure 1). All 21 ports along the Pacific coast in the Tohoku region (from Aomori to Ibaraki) sustained extensive damage to their breakwaters, quays, and other coastal facilities, suspending all port functions.

Run-up from the tsunami caused significant damage along major rivers in the region. Traces of the run-up were found as far as 49 kilometers upstream from the mouth of the Kitakami River. Ishinomaki City in the Miyagi Prefecture, where the Kitakami flows out to the sea, experienced severe tsunami run-up in addition to the direct attack along the coast. Approximately 73 square
kilometers along the river, or about 13 percent of the entire city, were inundated (figure 5). The city suffered badly, with 3,280 dead and 539 missing (as of March 11, 2012). 20,901 houses were completely destroyed, and 10,923 houses badly damaged (as of October 21, 2011).

NEW THINKING ABOUT STRUCTURAL MEASURES IN LIGHT OF THE GEJE

The GEJE exposed the limitations of disaster risk management (DRM) strategies focused disproportionately on structural measures. Dikes and breakwaters built before the GEJE were designed to protect against relatively frequent tsunamis, and were effective in preventing damage from those of limited height. In the GEJE, however, the height of the tsunami far exceeded predictions. Although the structures helped to reduce water levels, to delay the arrival of the tsunami, and to maintain the coastline, many of them were breached, resulting in enormous inland damage.

Planning for the largest possible event is a significant policy shift in Japan’s thinking about DRM. Building 20- or 30-meter tsunami dikes is neither realistic nor financially, socially, or environmentally practical. But lives can and must be protected by other means, notably multi-layered approaches that combine structural and nonstructural measures to ensure the safe
FIGURE 6: **Countermeasures against level 1 and level 2 tsunamis**

<table>
<thead>
<tr>
<th>Tsunami to be considered</th>
<th>Required performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1 tsunami</td>
<td></td>
</tr>
<tr>
<td>Largest in recent history (return period of approx. 100 yrs.)</td>
<td>Disaster prevention • Protect human lives • Protect properties/economic activities</td>
</tr>
<tr>
<td>Level 2 tsunami</td>
<td></td>
</tr>
<tr>
<td>Maximum level (return period of approx. 1000 yrs)</td>
<td>Disaster reduction • Protect human lives • Mitigate economic loss • Prevent major secondary disasters • Enable early recovery</td>
</tr>
</tbody>
</table>

Source: MLIT.

FIGURE 7: **Structure of a highly resilient breakwater**

Source: MLIT.
evacuation of residents (KN 6-5). Nonstructural measures are discussed in the knowledge notes of cluster 2. Planning for the new generation of multilayered DRM approaches is based on a comprehensive assessment of historical records, documents, and physical traces of past tsunamis, and by drawing on the latest seismological research and simulations.

Since the GEJE, the Japanese government has taken a two-level approach. Level 1 includes tsunamis that occur as frequently as every 100 years and that cause significant damage, whereas level 2 covers the largest possible tsunami, which has an extremely low probability of occurrence (once every 1,000 years) but that has the power to cause devastating destruction (figure 6). Conventional structural measures such as dikes and breakwaters protect human lives and property, and stabilize local economic activities, in the face of level 1 tsunamis. To withstand level 2 tsunamis, however, coastal structures must be improved to be more resistant to collapse and to reduce the likelihood of their complete destruction through scouring (figure 7). Some 87 percent of dikes that had been reinforced against scouring were not damaged in the GEJE, although the tsunami spilled over them.

The government has issued new guidelines for rebuilding river and coastal structures, taking into consideration their appearance as well as local characteristics, ecosystems, sustainability issues, and financial feasibility.

**OPERATION OF FLOODGATES AND INLAND LOCK GATES**

Although floodgates and inland lock gates can protect against tsunamis, their operation posed problems during the GEJE. Such gates should be closed before the tsunami arrives, but in the case of the GEJE tsunami this operation could not be completed in time, and a number of volunteer fire fighters and other workers were killed in the process. In addition, many gates were left open because equipment failed or because operators were caught in traffic jams and could not reach the site. Other gates became nonfunctional owing to power losses.

In December 2011, the Flood Prevention Act was amended to require local governments to ensure the safety of volunteer firefighters and other workers who operate floodgates, inland lock gates, and similar facilities. In March 2012, MLIT and the Fire and Disaster Management Agency issued the following recommendations to local governments and other concerned organizations:

- Remove unnecessary floodgates and ensure that the remaining floodgates can be operated automatically, semi-automatically, or by remote control.
- Keep inland lock gates closed at all times. Introduce automatic floating gate systems or install ramps or steps.
- Install emergency power supplies and make facilities earthquake-resistant.
LESSONS

The enormous tsunamis experienced in the GEJE have revealed the limitations of DRM measures that rely too heavily on structures. Structural measures cannot completely prevent tsunami disasters.

Many dikes and breakwaters were destroyed by tsunamis. They were nevertheless effective to some extent in reducing inundation areas and mitigating damage.

It is important to learn from past disasters and to revise countermeasures accordingly. In the GEJE-affected areas, various structural measures had been implemented in light of historical disasters, and they were successful in mitigating damage until the GEJE.

Scenarios that envision the greatest possible hazard should be taken into consideration when designing DRM measures. An appropriate combination of structural and nonstructural measures is required in order to achieve maximum mitigation of damage.

Structural measures should be designed to prevent damage to human lives and properties caused by level 1 events and to mitigate damage from level 2 events.

Though it is unrealistic to build structures large enough to protect against the largest conceivable events, the resilience of conventional structures must be enhanced. These should be built to mitigate damage even when the hazard level exceeds their design specifications. It is possible for structures to “fail gracefully” (meaning that they do not fail completely failure or collapse), thereby delaying the onslaught and reducing the energy of tsunamis. The concept of failure should be incorporated into the design to take into account unforeseen events.

Coastal facilities such as floodgates should be designed so that they can be properly managed even in the event of power failure and in the absence of operators. Standardized guidelines should be established for their safe operation in emergencies.

RECOMMENDATIONS FOR DEVELOPING COUNTRIES

Prepare for disasters by integrating structural and nonstructural measures. DRM measures should account for two levels of hazard. Level 1 events are relatively frequent and produce major damage; level 2 events, the largest possible disasters, have an extremely low probability but produce devastating impact. Every possible structural and nonstructural measure should be employed to protect against level 2. Structural measures should be designed to protect people, property, and socioeconomic activities against level 1 and to mitigate damages at level 2.*

* The two-level approach has already been adopted in the design of other key infrastructure, such as dams and flood-prevention dikes. Dams typically consider the maximum probable flood or a flood with a 10,000-year return period when designing structural safety, and a 100–200 year flood for flood-control operations. For flood-prevention dikes to protect some critical areas of Tokyo and other locations, the government has increased design standards beyond the norm of 100–200 year floods.
Provide technical and financial support for local governments. The central government plays a crucial role in reducing disaster risks across the country. The central government should encourage local governments to promote structural measures by providing financial support and guide them in meeting minimum requirements for structures by producing technical guidelines and manuals. Also, the central government should provide the local governments with technical support, such as conducting training for technical staff in planning, design, operations, and maintenance.

Consider designs and improvements to enhance the resilience of structures and to prevent sudden and complete failure. Extraordinary external loads caused by earthquakes, floods, and other events should be considered in designing structures such as dams and dikes, which should be designed in a way so that they will mitigate damage even when the hazard level exceeds their design levels. Their effectiveness in mitigating damage should be ensured even in the event of their technical failure.

Raise dike levels in a phased manner, considering the country’s financial and social conditions. Safety standards and structural design upgrades against level 2 events should reflect the concentration of population and economic assets in the protected areas. Although it may not be possible to build dikes capable of withstanding level 2 disasters, appropriate and feasible targets for dike design safety should be identified.

Assure reliable operation of key facilities during emergencies. The safe and reliable operation of infrastructure must be ensured in emergency situations. Structural measures such as floodgates cannot provide reliable protection if they cannot be operated under extreme conditions, such as power failures and the absence of operators. Multiple layers of operation should be assured. A sufficient number of qualified operators should be available during disasters, but not necessarily onsite. Developing manuals and conducting regular drills are required during normal times. The danger to which operators are exposed should be minimized.

KEY REFERENCES


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KNOWLEDGE NOTE 1-2

CLUSTER 1: Structural Measures

Building Performance
The strong main shock of the Great East Japan Earthquake (GEJE) of March 11, 2011, caused little damage to buildings. Buildings designed under the current building code and those with base isolation fared well. However, seismic design guidelines for nonstructural members had not been considered adequately, which resulted in problems such as the collapse of ceiling panels. Soil liquefaction occurred in reclaimed coastal area along Tokyo Bay and riverside areas. The key lessons of the GEJE are that seismic-resistant building design prevent collapse of buildings and protects human lives, that retrofitting vulnerable buildings is essential to reduce damage, that seismic isolation functioned well, and that nonstructural building components can cause serious damage. When applying these lessons to developing countries, local technical and socioeconomic conditions should be taken into account.

FINDINGS

HISTORY OF BUILDING CODES IN JAPAN

The world's first national seismic design code. Due to its location and tectonic settings, Japan is prone to large earthquakes. The Great Kanto Earthquake in 1923 caused some of the most serious damage in Japanese history, as fires consumed a large part of Tokyo, killing more than 100,000 people (table 1). Based on the lessons learned from the disaster, a seismic design code was introduced in the building code of 1924, the first national seismic design code applied anywhere in the world.

Building code updates following major earthquakes. After every major earthquake, Japan's national government and academic community carry out detailed surveys of building damage, and the building code is revised accordingly. Technical recommendations are based on the most recent lessons. The Tokachi-oki earthquake in 1968 caused serious damage to reinforced concrete (RC) buildings and inspired a major revision of the building code in 1981. Until 1981, the building code required buildings to withstand a lateral force of 20 percent of the total weight of the building without damage in structural members. The revised code, part of which is still in use, requires that buildings be strong enough to with-
stand a lateral force equal to 100 percent of the building’s weight. Damage to the building is permissible as long as human lives are not threatened.

**Current building code (1981) in Japan.** The main aspects in the current building code of 1981 are as follows:

- Buildings should be able to withstand within their lifetime several large earthquakes without structural damage.
- Building should be able to endure, without collapse or other serious damage, an extremely large earthquake with a return period of 500 years.

Technical guidelines for assessing and retrofitting existing RC buildings constructed under building codes in effect prior to 1981 were produced.

**Initiative to retrofit buildings following the Great Hanshin-Awaji Earthquake (Kobe earthquake) in 1995.** The 1995 Kobe earthquake caused heavy damage, 6,437 casualties,
and economic losses estimated at more than $120 billion. Of the buildings that collapsed in the Kobe quake, 97 percent were built before 1981 (figure 1). Based on this finding, the government implemented a new law in 1995 to promote retrofitting of old buildings.

Under the Act for Promoting Seismic Retrofitting of Existing Buildings (1995), the national and local governments offer incentives to private homeowners, such as:

- Subsidies for assessments of structural soundness
- Subsidies for the cost of retrofitting
- Reductions in income tax and property tax
- Low-interest loans to cover the cost of retrofitting.

Some 80 percent of local governments have established subsidy programs to encourage owners to assess the structural integrity of their homes, and, as of April 2011, some 64 percent of the local governments had programs that subsidized retrofitting work. The government’s target is to increase the ratio of earthquake-resistant houses to 95 percent before 2020. In 2008, the ratio was 79 percent, with some 10.5 million houses still requiring retrofitting. In spite of efforts to promote retrofitting, only 300,000 houses were retrofitted between 2003 and 2008. These numbers show that it is difficult to motivate homeowners to retrofit.

**DAMAGE TO BUILDINGS BY THE GEJE**

**Minimal damage by large shaking.** Table 2 shows the summary of the damage caused to the buildings following GEJE. Most of the collapsed residential buildings were washed
TABLE 2: Damage to buildings following the GEJE

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential buildings</td>
<td></td>
</tr>
<tr>
<td>Total collapse</td>
<td>107,779</td>
</tr>
<tr>
<td>Partial collapse</td>
<td>117,019</td>
</tr>
<tr>
<td>Burned</td>
<td>263</td>
</tr>
<tr>
<td>Partial damage</td>
<td>434,327</td>
</tr>
<tr>
<td>Nonresidential buildings</td>
<td>32,445</td>
</tr>
</tbody>
</table>

Sources: NILIM and BRI (2012).

FIGURE 2: Houses and cars were washed away by the tsunami

Source: Yamada-machi.
away or destroyed by the tsunami rather than the earthquake. The death toll from earthquake ground shaking is estimated to be less than 200.

The earthquake produced violent shaking over a very wide area. The strongest peak acceleration of 2,933 gal was recorded in Tsukidate, Miyagi Prefecture, but 18 observation stations in six prefectures observed acceleration greater than 1,000 gal. In spite of the strong acceleration, damage from shaking was minimal, owing partly to the characteristics of the ground motion (the dominant frequency was relatively high). Damage to buildings constructed under the 1981 and later building codes was limited and within the range anticipated by the design code.

**Serious damage by the tsunami.** The cause of most of the damage to houses was the tsunami that followed the main shaking. Most wooden houses in deeply inundated
FIGURE 5 (top): Reinforced concrete building damaged by scouring
FIGURE 6 (middle): Reinforced concrete building damaged by liquefaction
FIGURE 7 (bottom): Overturned building of reinforced concrete with pile foundation

Sources: BRI and NILIM.
areas were washed away or totally destroyed (figure 2). Many steel structures were also severely damaged (figure 3). By contrast, buildings of reinforced concrete performed well against the tsunami. Although many were completely submerged, they did not suffer structural damage (figure 4). Those reinforced concrete buildings that were damaged tended to be small and without a pile foundation (figures 5 and 6). Figure 7 shows a damaged building where the probable causes of the damage were a combination of weak connections between piles and footings, strong water pressure from the tsunami current, and liquefaction.*

**EFFECTIVENESS OF SEISMIC COUNTERMEASURES ON BUILDINGS**

**Good performance of seismic base isolation system.** Japan’s Building Research Institute (BRI) reported that the seismic base isolation systems† in all 16 buildings in Miyagi Prefecture performed well, reducing lateral motion by 40–60 percent. No damage was observed to the structures or to mechanical and electrical facilities inside the buildings. No fittings or furnishings fell. The dampers and the cover over the slits between the isolated and nonisolated parts were damaged as expected.

**Enhanced seismic design and retrofitting of transportation infrastructure facilities.** A major campaign to reinforce key infrastructure such as bridges following the Kobe earthquake in 1995 was undertaken by highway and railway companies and governmental agencies. As a result, serious structural collapses of infrastructure were avoided following the GEJE. The East Japan Railway Company had reinforced more than 17,000 bridge piers under the Shinkansen (bullet train) lines, and the central government had retrofitted 490 bridges in the Tohoku Region. Because of these works, some 1,500 bridges on national routes in the region were spared serious damage. Five bridges collapsed under the force of the tsunami. Because damage was generally limited, it was possible to repair the main highways and roads to the affected areas within one week of the event. However, serious damage in the coastal areas affected by the tsunami took longer to repair. Shinkansen service to the Tohoku region resumed after 49 days (KN 4-1), a huge improvement over the situation after the Kobe earthquake, when reconstruction of the roads required more than 18 months and repair of the Shinkansen line took 82 days.

**AREAS FOR IMPROVEMENT**

**Damage to nonstructural building components.** Much of the damage observed in buildings following the GEJE involved nonstructural components attached to structures, such as ceiling panels, nonstructural walls and finishing materials (figure 8). To date, no guidelines or codes cover the wide variety of materials and designs used on nonstructural components. In Japan, few engineers have devoted attention to the matter.

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* In an earthquake, soil behaves like a liquid, losing its strength and bearing capacity.

† Isolated structures damp the effects of earthquake ground motion through decoupling of horizontal components. Isolation systems may be laminated steel with high-quality rubber pads, or other energy-absorbing materials.
Liquefaction. Liquefaction occurred on reclaimed lands and river banks over a wide area. Small buildings without pile foundations built on plots that had not been treated for liquefaction were affected (figure 9). Existing building codes cover countermeasures against liquefaction for reinforced concrete and other buildings, but not for the detached wooden houses owned by most ordinary people. The Ministry of Land, Infrastructure, Transport and Tourism has now produced technical guidelines to fill these gaps. Some local governments have provided liquefaction risk maps to encourage building owners to take countermeasures.

Damage from failure of retaining walls. In Sendai City, more than 4,000 houses were damaged by landslides caused by the strong ground shaking (figure 10). Since 1961, to prevent landslide disasters the city government has regulated housing in hilly areas under the Act on the Regulation of Housing Land Development. Most locations that experienced
landslides following the GEJE were developed before the act came into effect. In 2009, in response to landslides caused by earthquakes since 2000, the central government established a subsidy mechanism whereby local governments were tasked to carry out geotechnical work to stabilize the ground for large-scale housing projects in high-risk areas. However, stabilization work had not started by the time the March 2011 disaster struck.

**Effect of ground motion of long periods on skyscrapers.** The potentially devastating effect of ground motion of long periods on skyscrapers and seismically isolated buildings has been recognized in the recent years. Recently skyscraper designs take into account the effects of ground motion of long periods. Some skyscrapers had been retrofitted by installing devices to control deformation or absorb energy. On March 11 strong and sustained ground motion of long periods reached Tokyo (approximately 400 km from the epicenter) and even Osaka (800 km), affecting the skyscrapers in both of these metropolitan areas. Recognizing the importance of countermeasures against the risks from sustained ground motion, the
Japanese government has now released a draft of a new technical guideline that revises structural design procedures, safety measures for furnishings and fittings, and a screening method to identify skyscrapers that need to be examined in detail.

**Technical guideline for tsunami evacuation shelters.** Japan’s first technical guideline for tsunami shelters was published in 2004. A revised guideline was released in November 2011, based on detailed surveys of the areas affected by the GEJE. Where the risks from tsunamis pressure are less serious, the tsunami load can be smaller under the revised guideline than under the previous guideline (figure 11).

**LESSONS**

**The importance of retrofitting older buildings.** The importance of retrofitting buildings is demonstrated by the fact that buildings designed under the 1981 building code and retrofitted buildings performed well in the GEJE, whereas most of the damaged buildings were constructed before 1981 and had not undergone any retrofitting. Further efforts to retrofitting are required, including more attractive incentives for those who cannot afford to invest in safety or are reluctant to do so (as are many elderly people). More affordable retrofitting methods should be developed. Partial retrofitting, safety shelters inside the home, and beds covered by safety frames are examples of affordable options.

**Safety of nonstructural building components.** The GEJE demonstrated the importance of considering nonstructural elements when thinking about earthquake safety. The materials, design, and construction of nonstructural components vary greatly. Technical guidelines are needed to ensure that such components are earthquake-resistant.
Structural safety and functional continuity of buildings. Even when structures withstood ground shaking and saved the lives of their inhabitants, inhabitants could not reoccupy their dwellings because of deformation of walls and doors. Substantial sheer cracks in nonstructural walls made the inhabitants feel that it was dangerous for them to stay. Besides structural safety is achieved, it is recommended that efforts to achieve functional continuity of the buildings—with minimum disruption to everyday lives—are made.

Liquefaction and landslides. Countermeasures against liquefaction and landslides need to be enhanced in Japan. Following the GEJE, the Japanese government has reviewed the method of assessing the risk of liquefaction. Developing more effective and affordable anti-liquefaction treatments is needed. The government is considering a requirement that home buyers be notified of the risk from liquefaction. The government is also providing subsidies for projects to stabilize slopes with landslide potential near houses.

Long-period ground motion. The GEJE demonstrated the possibility of a gigantic earthquake occurring as a result of three large earthquakes (Tokai, Tonankai, and Nankai) occurring in short succession. Such a series of earthquakes would be likely to produce strong ground motions of long periods. Structural and retrofitting measures should be performed according to the new guideline, lowering the risk from long period ground motion by preventing amplification of shaking motion through increasing buildings’ capacity to absorb energy, and reducing structural deformation.

Seismic isolation. Buildings with isolated bases performed well during the GEJE, enabling them to be used without interruption even immediately after the main shock of the earthquake.

RECOMMENDATIONS FOR DEVELOPING COUNTRIES

Seismic resilience of buildings is the most effective risk mitigation measure. One of the most basic and effective measure to mitigate risks from earthquakes is to build structures that are resilient to ground shaking. Many buildings in developing countries are extremely vulnerable to collapse (figure 12).

Use of technologies appropriate for developing countries. Various seismic design guidelines have been developed around the world. Direct application of such guidelines may not be appropriate in developing countries because of their costs, the limited knowledge and skills of builders, and limited tools and facilities on construction sites. What is needed are seismic design guidelines that are suited to local conditions and capable of enhancing the resilience of buildings.

Knowledge and lessons should be adapted and customized to local conditions. In Indonesia a simple technical guideline that is consistent with local technical capacities and other conditions was developed and is being disseminated with help from the Japan International Cooperation Agency (box 1). Knowledge based on detailed surveys of construction sites and motivation on the part of engineers, workers, government officials, and owners of buildings can improve safety. may be effective approach,
Implementation of building codes. Another important issue is how best to implement building codes and how to monitor their implementation. Legislation should include provisions related to the issuance of building permits, inspection of construction, and enforcement of building codes. Enforcement requires sufficient numbers of trained and equipped officials and inspectors with access to technical information.

Japan’s Building Standard Law mandates the implementation systems shown in figure 13. Local government officials (or “designated confirmation bodies”) conduct examination/inspections before, during, and after construction. If conformity with building standards is confirmed, the building official (or “designated confirmation body”) issues a “confirmation certificate.” An interim inspection is performed on buildings that have certain structural characteristics or purposes. Multifamily dwellings, multistoried buildings, and public buildings are generally subject to this type of inspection.

Retrofit historical buildings. In countries with many vulnerable historical buildings, retrofitting is a big issue. Retrofitting should be considered in the context of striking a balance between affordable and effective retrofitting methods, a balance that motivates both private owners and government officials and politicians.

Secure safety of nonstructural components. The issue of nonstructural building components is common in developing countries, although the critical elements may be different. Nonstructural walls, roofing materials, and ornamental attachments such as pediments and signs are examples observed in field surveys in affected areas. Complicating this issue are the large variety of materials and designs and the scarcity of engineers. Materials that provide shelter and the curtain walls of outside buildings must be regulated first, given the
BOX 1: Simple technical guideline and its dissemination through the building permit process throughout Indonesia

The Central Java Earthquake in 2006 caused heavy damage and killed some 6,000 people, mostly through collapse of their houses. During reconstruction, the provincial government developed a technical guideline for small, one-story houses. The guideline, simple enough to be illustrated in a poster, has been well accepted by the population. The central government decided to apply it across the country through the building permit system.

Source: Japan International Cooperation Agency (JICA).
BOX 2: Tsunami evacuation shelters applying the Japanese technical guideline

Banda Aceh was severely damaged by the Indian Ocean Tsunami of 2004. Despite the devastation wrought by the tsunami, local people are returning to the coastal areas because their livelihoods are tied to the sea. Because no suitable evacuation areas are found along the coast, evacuation shelters are being constructed. The Japan International Cooperation Agency is supporting the construction of vertical evacuation shelters that embody Japanese technical guidelines. The shelter shown below was used for emergency evacuation in 2012.

Source: JICA.
risks they pose to pedestrians. To resolve the issue of roofing materials, manufacturers and engineers should be involved in improving construction methods and materials. Also, construction workers should be trained to install such materials in safer ways.

**Prevent large deformation of structures.** Japanese experts are examining ways to minimize structural deformation. This could be useful to countries whose seismic design codes allow larger deformation than Japan’s.

**Prepare for tsunamis.** Japan’s experience and knowledge with tsunami evacuation shelters is useful to other countries exposed to tsunamis, such as Indonesia. The tsunami evacuation shelter in Banda Aceh is an example of Japanese technical cooperation (box 2).

**Promote seismic base isolation.** Buildings with seismic base isolation features suffered very little damage from the GEJE. More key public buildings, particularly those that will be used for emergency relief activities and emergency response—that is, evacuation shelters and fire stations—should be built using base isolation. Simple and affordable techniques for base isolation should be developed for use in developing countries.

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Hydro-meteorological Disasters Associated with Tsunamis and Earthquakes

CLOSEUP 1: Structural Measures

Hydro-meteorological Disasters Associated with Tsunamis and Earthquakes
Hydro-meteorological Disasters Associated with Tsunamis and Earthquakes

Earthquakes and tsunamis increase the risks of hydro-meteorological disasters. After the Great East Japan Earthquake (GEJE), disaster-prevention structures such as coastal and river dikes were quickly rehabilitated. A phased process of rehabilitation work made it possible to address urgent needs for protection against frequently occurring floods and storm surges, while at the same time meeting longer-term targets for protection against mega disasters. The deterioration of levels of protection against hydro-meteorological disasters was quickly assessed after the GEJE in order to identify priority areas for rehabilitation, revise standards for the issuance of warnings, and raise public awareness about the increased risks of hydro-meteorological disasters.

FINDINGS

THE GEJE AND TSUNAMI INCREASED THE RISKS OF HYDRO-METEOROLOGICAL DISASTERS

The Great East Japan Earthquake (GEJE) caused extensive damage to coastal and river infrastructure and diminished the level of protection they provided against floods and storm surges, thereby increasing the risk of hydro-meteorological disasters. Countermeasures against these risks have been successfully put in place (figure 1). According to the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), 426 coastal units (including coastal dikes and revetments extending along 190 kilometers) out of a total of 515 units with a total length of some 300 kilometers sustained damage in the Iwate, Miyagi, and Fukushima prefectures.

The MLIT began on the day of the earthquake to assess the safety of dams and structures in some 30 rivers. Slope failure and subsidence of dikes were observed at 2,115 sites in eight rivers managed by the MLIT, mainly in the Tohoku and Kanto regions (figure 2). Local governments reported damage to a total of 1,627 sites in the rivers they manage. Many river dikes were also damaged by liquefaction caused by earthquakes. The MLIT confirmed
**FIGURE 1: Countermeasures taken against hydro-meteorological disasters following the GEJE**

<table>
<thead>
<tr>
<th>Period</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding period</td>
<td>Snow melt flood</td>
<td>Rainy season</td>
<td>Typhoon season</td>
<td>Period when spring tide is relatively high</td>
<td></td>
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</tr>
</tbody>
</table>

**Assessment and announcement of secondary disaster risks**
- Overview assessment
- Assessment and announcement of risks
  - Subsidence on the Sendai Plain, Miyagi and Iwate coastal areas has already been announced

**Discharge of water from inundated areas**
- Emergency discharge
  - River, coastal, agriculture, and sewerage departments collaborate to implement emergency protection of coastal lowlands and continue necessary measures (water removal by discharge pump vehicles, etc.)

**Measures against storm surges**
- Restoration of coastal dikes, etc.
- Emergency measures
  - (stacking sandbags to high tide level) (reinforcement of fore side of sandbags, etc.)
- Temporary measures

<table>
<thead>
<tr>
<th>Prefecture</th>
<th>Snow melt flood</th>
<th>Rainy season</th>
<th>Typhoon season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miyagi</td>
<td>ca. 300</td>
<td>ca. 180</td>
<td>ca. 50</td>
</tr>
<tr>
<td>Iwate</td>
<td>ca. 19</td>
<td></td>
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<tr>
<td>Fukushima</td>
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</tr>
</tbody>
</table>

* Section where important public facilities exist

**Measures against heavy rains and floods**
- Warning/evacuation measures
- Lowering of standards for call-out of flood fighters, or announcement standards for river flood forecasting, warnings, communication to residents, etc.

<table>
<thead>
<tr>
<th>Area</th>
<th>Snow melt flood</th>
<th>Rainy season</th>
<th>Typhoon season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miyagi</td>
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<tr>
<td>Fukushima</td>
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</tr>
</tbody>
</table>

**Measures against sediment disasters**
- Warning/evacuation measures
- Detailed assessment
  - Inspection of sediment disaster areas
  - Strengthen warning level by lowering of announcement standards for sediment disaster warning information or installation of mudslide sensors

<table>
<thead>
<tr>
<th>Area</th>
<th>Snow melt flood</th>
<th>Rainy season</th>
<th>Typhoon season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miyagi</td>
<td>ca. 300</td>
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<td></td>
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<tr>
<td>Fukushima</td>
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</tr>
</tbody>
</table>

**Sediment management facilities**
- Stacking sandbags, etc.
- Construct sediment control dams as emergency measures in areas where failures occurred

<table>
<thead>
<tr>
<th>Area</th>
<th>Snow melt flood</th>
<th>Rainy season</th>
<th>Typhoon season</th>
</tr>
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<tbody>
<tr>
<td>Miyagi</td>
<td>ca. 300</td>
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<tr>
<td>Iwate</td>
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<td></td>
</tr>
<tr>
<td>Fukushima</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Source:** MLIT.
that none of the country’s dams suffered structural problems, except for minor leaks and cracks. One irrigation dam failed, killing seven leaving one person missing in Fukushima Prefecture.

**INCREASED INUNDATION RISKS FROM SUBSIDENCE**

The earthquake caused extensive subsidence in some areas. Rikuzentakata City in Iwate Prefecture, for example, saw subsidence of 84 centimeters, which led to flooding of coastal areas and roads at high tide, often hampering recovery and rehabilitation efforts.

The level of protection against storm surges and flooding was significantly diminished in the Sendai Plain. The area below mean sea level more than tripled (from 3 km² to 16 km²) after the earthquake (figure 3), as revealed in the MLIT’s laser profiling survey. The MLIT produced subsidence maps and revised downward the water levels at which it issues flood warnings. For management of spatial data and their use in mapping, see KN 5-2.
Landslides caused by the earthquake

The earthquake caused 141 landslides, as a result of which 19 people lost their lives (as of February 2012). Immediately after the earthquake, the MLIT began inspecting 1,952 sediment control facilities managed by the ministry, while the prefectural governments inspected 4,324 facilities. The MLIT conducted emergency inspections of about 32,000 sites with potential risks of sediment disasters such as debris flows and landslides in 220 municipalities where the Japan Meteorological Agency (JMA) had observed seismic intensity of 5+ or larger. Significant deformation was found at 66 locations; minor deformation at 1,077. The MLIT shared this information with municipalities so that they could take the necessary measures.

With the higher risk of sediment disaster since the earthquake, triggers for the issuance of sediment disaster warnings were temporarily lowered. Local meteorological observatories and prefectural governments jointly issue warning about such disasters. Prefectural governments and the JMA are reviewing the standards for the issuance of warnings by investigating the relationship between the amount of precipitation after an earthquake and the probability of a sediment disaster.
REHABILITATING COASTAL AND RIVER DIKES TO PREVENT SECONDARY DISASTERS

After the GEJE, emergency measures were implemented to restore coastal dikes to prevent coastal flooding from storm surges. Emergency rehabilitation was first implemented along about 50 of the 190 kilometers of damaged coastline. Those 50 kilometers were selected because of the important facilities and properties in the area, or because of the urgency of restoring livelihoods, industrial activities, transportation, and agricultural activities.

The emergency rehabilitation work was implemented in three phases determined by climatic conditions and the seasonal occurrence of natural disasters (figure 4). The first step was to reinforce and raise the height of the damaged dikes up to the high-tide protection level. This work was done before the June-July flood season. The second step was to raise the dike height to the high-wave protection level, which was completed by September, before the typhoon season.

FIGURE 4: Rehabilitation of coastal dikes

Source: MLIT.
Full-scale restoration, the third step, is scheduled to start in fiscal 2012 in accordance with reconstruction plans and other rehabilitation projects. The works will be carried out over about a five-year period so as not to disrupt community development and industrial activities. On the Iwanuma Coast and in other coastal areas with facilities that are critical to recovery and reconstruction, such as wastewater treatment plants, full restoration will be completed by the end of fiscal 2012, March 2013.

Rehabilitation of river dikes began directly after the earthquake as the first step in preparing for heavy rain and floods. One of the most urgent tasks was to reconstruct the dikes to their predisaster height before the rainy season began in June. Emergency rehabilitation work was conducted at the 53 heavily damaged sites: 29 in the Tohoku Region and 24 in the Kanto Region. These works were completed by July 11, 2011. The standard for flood warnings was lowered during the flood seasons. The MLIT and the prefectural governments measure rainfall and the water level in rivers, using automatic monitoring equipment and telemeter systems. The ministry and the governments then issue flood forecasts and warnings through the mass media, the Internet, and mobile phones.

Complete restoration of the river dikes to their predisaster condition began after the typhoon season and was completed by the time the 2012 rainy season began in June. Countermeasures against liquefaction also have also been implemented. The final step will be to improve dikes on the major rivers in the Tohoku region—the Abukumagawa, Narusegawa and Kitakamigawa—to protect against floods and tsunamis.

MEASURES TO MITIGATE INUNDATION RISKS IN THE DISASTER-AFFECTED AREAS

Inundation risks from heavy rain have increased in the disaster-affected lowlands of the Sendai Plain, where river dikes and drainage pump stations were damaged or destroyed and where extensive subsidence occurred. Temporary emergency measures were taken to reduce the risk of flood damage. Thirty-three drainage pump vehicles, provided by other regional bureaus of the MLIT around the country, were deployed in the disaster-affected area. A risk map showing inundation levels from daily precipitation of 100 millimeters and 200 millimeters provided information for local residents and municipalities. Inundation sensors were installed in areas with a high risk of flooding, and the information they collect is published to a Web page. Measures have been taken to send timely notifications automatically to relevant municipalities and local residents when there is a high risk of flooding.

LESSONS

Disaster prevention structures such as coastal and river dikes need to be rehabilitated quickly to prevent secondary disasters. Rehabilitation work should ideally be completed before the next rainy season and typhoon season.

In the aftermath of a disaster, it is important to identify the priority areas for rehabilitation and for protection against hydro-meteorological disaster. Priorities can be determined based on the existence of important facilities or commercial production centers and their significance for recovery and reconstruction on activities.
Rehabilitation work should take place in phases. This is an effective way of meeting the communities’ most urgent needs for protection against frequently occurring floods and storm surges, while at the same time meeting longer-term targets for protection from mega disasters.

Deterioration in levels of protection against hydro-meteorological disasters needs to be quickly assessed, and the relevant agencies, organizations, and the public should be informed. Damage information should be collected and disseminated as soon as possible (KN 5-2). Warning standards should be revised according to the assessment.

**RECOMMENDATIONS FOR DEVELOPING COUNTRIES**

Following any disaster, protective measures against collateral damage and secondary disasters is essential. The following actions are recommended:

**Conduct an assessment immediately following the disaster.** Damage to disaster prevention facilities and the risk of ensuing disasters should be assessed immediately after a disaster by quickly collecting relevant information. To make the most efficient use of resources, the areas to be rehabilitated should be dealt with in order of priority. Expert emergency teams should be formed during normal times by drawing on national networks (KN 3-1). Advance agreements can be made to allow the organizations concerned to mobilize private sector resources without going through the usual procurement processes (KN 4-1).

**Rehabilitate crucial structures before the next disaster.** A staged approach is appropriate, taking into account time constraints before the onset of the next season susceptible to hydrometeorological disaster. Rehabilitation works should be prioritized. Practical works, such as temporary structures made of sand bags or gabion boxes, need to be set up quickly.

**Consider financial mechanisms.** Financial arrangements, in particular the responsibilities of the central and local governments, should be made in advance during normal times (KN 4-1).

**Share risk information with the community.** “Post-disaster disaster risks” should be shared with local communities that may be affected. Nonstructural measures such as warnings should be strengthened in at-risk areas, since the effectiveness of countermeasures will have been diminished by the disaster.

**KEY REFERENCES**


KNOWLEDGE NOTE 1-4

CLUSTER 1: Structural Measures

Multifunctional Structures
Public facilities and infrastructure can be built in such a way as to reduce disaster risks and serve as disaster risk management facilities. Roads, expressways, and other public facilities helped reduce damage and loss in the Great East Japan Earthquake by providing protection against flooding, and by serving as evacuation routes and base stations for emergency operations. Organizations for disaster management and other public sector organizations should coordinate to ensure that their public works are multifunctional whenever possible; and cost-sharing mechanism should be developed to ensure that the financial burden is shared equitably.

**FINDINGS**

**EXPRESSWAYS SERVED AS DISASTER MANAGEMENT FACILITIES**

Expressways and roads mitigated damage resulting from the Great East Japan Earthquake (GEJE). The East Sendai Expressway, a 24.8-kilometer toll road running through the Sendai Plain, about 4 kilometers off the coast and at an elevation of 7 to 10 meters, acted as a secondary barrier or dike and prevented tsunamis from penetrating further inland (figure 1). It also prevented debris from flowing into the inland urban areas. The embankment served as an evacuation shelter for nearby residents, and about 230 people escaped the tsunami by running up to the expressway.

Many expressways were built on high ground, providing routes for evacuation as well as for rescue operations. Many coastal towns and communities were isolated immediately after the disaster because roads were flooded or covered with debris. Expressways built on higher ground served to connect otherwise isolated towns and communities (figure 2).

The Sanriku Expressway, a 224-kilometer expressway that runs along the Pacific coast through the Miyagi and Iwate prefectures, is still under construction. About 51 percent of the expressway was open for public use when the area was hit by the GEJE; it helped save many lives.
**FIGURE 1:** East Sendai Expressway

*Source: MLIT.*
Expressways constructed on higher ground were not damaged by the tsunami. In the aftermath of the GEJE, they provided an evacuation route for residents and enabled the self-defense forces and other emergency relief teams to get to the coastal municipalities that had been heavily affected. It also served as an important emergency route for transporting food, medical supplies, fuel, and other relief materials going to local disaster management bases and evacuation centers.

Miyako Road, a 4.8-kilometer section of the Sanriku Expressway, opened in March 2010. When the tsunami hit the area, about 60 residents managed to escape from the tsunami by climbing up the expressway embankment.

The Kamaishi–Yamada Road, a 23-kilometer section of the Sanriku Expressway that was opened only six days before the GEJE, served as a disaster management road. It was built to ease traffic congestion on Route 45, the main road connecting the coastal communities. Since Route 45 was prone to flooding from typhoons and tsunamis, the new road was expected to provide an alternative route if Route 45 were cut off in an emergency. In the Unosumai District of Kamaichi City, about 570 residents and school children escaped the tsunami. Because the road that led to the evacuation shelter had been destroyed, they climbed up to the Kamaishi-Yamada Road and managed to reach the evacuation shelter safely.

**SERVICE STATIONS AND PARKING AREAS ALONG HIGHWAYS SERVED AS DISASTER MANAGEMENT BASES**

Roadside service stations, service areas, and parking areas along highways also helped in the disaster management effort, providing bases of operation for rescue teams and evacuation shelters for local residents (table 1). The roadside service stations and rest areas along roads and highways, called Michi-no-eki (road stations), are equipped with toilets, restau-
TABLE 1: “Road stations” used in the aftermath of the GEJE

<table>
<thead>
<tr>
<th>Road stations</th>
<th>Location</th>
<th>Services during GEJE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanbongi</td>
<td>Osaki, Miyagi</td>
<td>Open for 24 hours with power. Supplied food to evacuees.</td>
</tr>
<tr>
<td>Tsuyama</td>
<td>Tome, Miyagi</td>
<td>Used as a base for self-defense forces and rescue teams and as an evacuation center.</td>
</tr>
<tr>
<td>Fukushima-Touwa</td>
<td>Nihonmatsu, Fukushima</td>
<td>Provided food, water, and toilets for evacuees. Used by 1,500 evacuees.</td>
</tr>
<tr>
<td>Kita-no-sato</td>
<td>Kitakata, Fukushima</td>
<td>Provided water and food. The hot-spring facility was made available to the affected residents.</td>
</tr>
<tr>
<td>Minamisouma</td>
<td>Minamisouma, Fukushima</td>
<td>Used as an evacuation center and emergency support base.</td>
</tr>
<tr>
<td>Hirata</td>
<td>Hirata, Fukushima</td>
<td>Provided power and water to evacuees and food to local hospitals and evacuation centers.</td>
</tr>
</tbody>
</table>

FIGURE 4: Self-defense force at a roadside station

Source: MLIT.

rants, and shops and are also intended to promote local tourism and business. These facilities are developed jointly by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) in cooperation with local municipalities. In April 2012, there were 987 such stations nationwide. During the GEJE road stations were turned into disaster management bases equipped with electric power. They were available to the public around the clock when the neighboring area experienced power failures (figure 4).
In Minami Sanriku City, sports facilities near a highway exit were used as a disaster management center, evacuation shelter, drop-off site for emergency supplies, and operating base for the local government, medical institutions, police, and volunteer workers. The local government even moved its office to the site, because its official building had been destroyed by the tsunami.

**EVACUATION STAIRS TO EXPRESSWAYS SAVED SCHOOL CHILDREN**

When Iwaizumi Town in the Iwate Prefecture was severely hit by the massive tsunami, an evacuation stairway constructed at the Omoto Elementary School two years before saved the lives of 88 children (figure 5). Because there was no escape route from the school, since it was surrounded by steep cliffs, some of the children, during a tsunami evacuation drill, suggested how improvements might be made. In response to their suggestions and those of local residents, a MLIT field office completed the approximately 30-meter evacuation stairway with 130 steps along Route 45, which runs right behind the school.

**LESSONS**

Embankment structures used to raise the elevation of highways and expressways can effectively prevent penetration of tsunami water and debris further inland. They can also be used as disaster management facilities (box 1).

Roads, highways, and expressways provided safe evacuation sites and escape routes because they were designed with earthquakes and tsunamis in mind. It pays to take disaster reduction into account when designing transport and other infrastructure.

Public facilities such as roadside stations and highway parking areas were used by various teams and organizations as base stations for rescue and emergency operations. They were
Recognizing that the embankment of the East Sendai Expressway had served as an effective evacuation site for local residents, evacuation stairs were temporarily installed at five locations along the embankment in May 2011. They are intended to facilitate evacuation in case of a tsunami.

Source: MLIT.

also used as evacuation centers because they were equipped with electricity, food, and water supplies.

**RECOMMENDATIONS FOR DEVELOPING COUNTRIES**

Infrastructure and public facilities such as roads, highways, and railways can be used as disaster management facilities in the event of floods, tsunamis, mudflows, and landslides. Facilities that are multifunctional are a particularly cost-effective approach to disaster management.

**Integrate various facilities into planning for disaster risk management.** DRM plans should include a range of public facilities. For example, playgrounds and parking areas can become rescue team bases or spaces for transition shelters. Expressway embankments can become evacuation sites in the event of cyclones, floods, and tsunamis.

**Develop cost-sharing mechanisms.** Cost-sharing mechanisms should be established between DRM organizations and public works organizations. The latter cannot be expected to bear all the DRM-related costs of a project, since those costs affect the project’s financial feasibility. In Japan the cost of adding height to an expressway is shared by the DRM organizations (KN 2-3-1).

**Coordinate with other sectors.** Coordination with other sectors, such as transportation, is required to develop multifunctional facilities. Platforms to coordinate planning, construction, and operation and maintenance should be established. In Japan prefectural governors designate the multifunctional facilities, allowing concerned organizations to initiate coordination under a new tsunami DRM law (KN 1-3).

**Consider negative effects.** High structures such as bridges and highways may have negative effects, such as water logging. They may isolate or separate communities and impose obstacles to the passage of people and animals. These effects should be assessed, and countermeasures or diversion channels and routes developed. In Japan, permission from DRM organizations is required before highways and bridges can be built.
KEY REFERENCES


Protecting Significant and Sensitive Facilities

The Great East Japan Earthquake was a multihazard event. A massive quake triggered a series of tsunamis of unprecedented dimension, as well as the subsequent nuclear accident. Sensitive facilities need to be protected against low-probability and complex events because damage to such facilities can have a cascading effect, multiplying the destruction and leading to irreversible human, social, economic, and environmental impacts.

FINDINGS

IMPORTANT FACILITIES WERE SERIOUSLY DAMAGED BY THE COMPLEX DISASTER

The Great East Japan Earthquake (GEJE) was a massive disaster triggered by the largest earthquake ever recorded in the history of Japan. But it was not only an earthquake disaster. The quake triggered a series of hazards and events including tsunamis of unprecedented dimensions, as well as a subsequent nuclear accident. Damages to critical disaster-response facilities, such as public buildings, hospitals and schools, hindered local capacities for response and recovery. Furthermore, destruction of sensitive facilities, such as a nuclear power station and industrial facilities, led to cascading damages and serious social, economic, and environmental impacts. The cascading effects of the GEJE revealed the weakness of Japanese disaster risk management (DRM) systems in the face of low-probability, high-impact events, and highlighted the importance of protecting sensitive facilities against disasters of any scale.

Government buildings. Local municipalities in Japan have the primary responsibility of saving and assisting people in the event of disasters. However, in the GEJE, many coastal towns and villages were devastated by the earthquakes and tsunamis, suffering great damage to their buildings, facilities, and personnel, and losing their capacity to take response measures promptly.
Based on a survey by Japan’s Cabinet Office, of the 237 municipalities that responded and that experienced seismic intensity of 6- or more, about 12 percent had to relocate their buildings either fully or partially (figure 1). In Otsuchi Town in Iwate Prefecture, a massive tsunami swallowed up the municipality building, destroying it and taking the lives of town officials including the mayor, who was at the time directing the disaster-response operations (figure 2). The town was without a mayor for five months.

Disaster management and evacuation facilities. Disaster management and evacuation facilities are critical to protecting people in times of disaster. Many of these facilities were devastated by tsunamis (box 1). In the 11 coastal municipalities of Iwate Prefecture, 48 out of 411 emergency evacuation shelters (designated shelters to which people are to
evacuate immediately after an earthquake, as distinct from evacuation centers) were inundated by tsunamis; and in Rikuzentakata City, one of the cities with the highest casualty rates, more than half the evacuation shelters were inundated. The city’s gymnasium was designated as a primary evacuation shelter, and more than 80 people were there when the tsunami hit (figure 3). Only a few survived.

BOX 1: An angel’s voice

A woman on the municipal staff in Minami-Sanriku City was urging residents over the radio to evacuate to higher ground. Although tinged with fear and apprehension, her voice gave people courage and helped save countless lives. She continued broadcasting to the very end before being engulfed by the tsunami. She never returned home. She had planned to be married in September 2011. In all, 39 staff members were declared dead or missing. The 12-meter-high building was located in a risk area that was submerged by 2.4 meters of water during the 1960 Chilean Tsunami.

Source: Prime Minister’s Office and Fire and Disaster Management Agency

FIGURE 3: The Rikuzentakata city gymnasium
Health and social welfare facilities. Hospitals and social welfare facilities also need to be protected, because without medical response capabilities the number of casualties will increase and health hazards will spread. According to the Ministry of Health, Labor, and Welfare, almost 80 percent of hospitals were either destroyed or severely damaged by the earthquakes and tsunamis (figure 4). Furthermore, more than 12 percent of social welfare facilities—such as homes for the elderly, children, people with disabilities, and other vulnerable groups—were damaged by the disaster.

Industrial facilities. Six out of nine oil refineries in the Tohoku and Kanto regions had to suspend operations; fire broke out at two of the nine facilities. At an oil refinery in Chiba, the structure holding one of the liquefied petroleum gas (LPG) tanks failed, and the tank collapsed, leading to LPG leakage. The leaked LPG caught fire and caused an explosion, spreading the fire from one tank to another (figure 5). Six people were injured and all 17 LPG tanks were damaged, along with pipelines and roads. The fire and debris from the explosions damaged the surrounding buildings and vehicles. Nearby residential areas also suffered as the blasts damaged windows, shutters, slate roofs, and more. The explosions at the oil refineries are believed to have been one of the factors that accounted for the fuel shortage immediately after the disaster, which disrupted people’s lives and hindered emergency recovery operations in the disaster-affected areas.

The collapsed tanks had met all the requirements for earthquake-proof structures; however, at the time of the earthquake the tank was temporarily filled with water, instead of the lighter weight LPG, in preparation for a regular inspection. The braces supporting the legs that held the tank up could not bear its weight during the earthquake, leading to its collapse (figure 6).
In light of this accident, a government committee that conducted a technical review of LPG facilities recommended:

- Revision of the technical guideline for the tank braces
- Confirmation of the facilities’ safety by private companies, and government monitoring of the confirmation
- Risk assessment and countermeasures against liquefaction to be undertaken by private companies
- Reassessment of earthquake risks following the government review.

**Cultural properties.** According to the Agency for Cultural Affairs, more than seven hundred nationally designated cultural properties (such as monuments and historic buildings and landscapes) were heavily damaged by the earthquake and tsunami. Many national treasures, important cultural properties, and special historic sites also have been affected. Fortunately, few cultural properties of national importance were damaged. However, several properties will take a long time to recover, and some have been lost forever.

Disasters that result in irreversible damage or losses of important cultural properties can have a severe negative effect on local businesses, such as those that depend on the tourism industry, and can also undermine people’s pride in their communities. A culture-sensitive approach to restoration, in which original or local materials are used, is required to maintain the cultural value of historical buildings (figure 7). Retrofitting work should not be carried out in a way that destroys the historic value of the monument or building. If retrofitting cannot be carried out without compromising the structure’s cultural value, the area should be closed to visitors rather than altered in a way that changes its character. Following the Great Hanshin-Awaji Earthquake in 1995, the Japanese government established guidelines for protecting cultural properties against earthquakes and began implementing seismic assessments and retrofitting structures associated with national treasures and important cultural properties.

**FIGURE 7:** Retrofiting Jokoji Temple

Source: Agency for Cultural Affairs.
THE CASCADING EFFECT OF THE ACCIDENT AT THE FUKUSHIMA DAIICHI NUCLEAR POWER STATION

Four nuclear power stations comprising 14 units were located close to the epicenter of the March 11 earthquake. The earthquake caused all operating units to shut down automatically. Large tsunamis hit all sites within an hour of the main shock, damaging several of them. The worst affected sites were Fukushima Daiichi and Fukushima Daini. Fukushima Daini lost some safety-related equipment, but off-site and on-site power remained available, although not at optimal levels. On the other hand, Fukushima Daiichi lost much of its safety-related equipment because of the tsunami and almost all off-site and on-site power. This led to a loss of cooling to the operating reactors, and the ensuing nuclear meltdowns and release of radioactive materials.

The failure of the Fukushima Daiichi nuclear power station has had severe social consequences. About 160,000 people in Fukushima were evacuated, of whom more than 60,000 were taken outside Fukushima Prefecture. Many were unable to return to their homes for a long time because of unsafe levels of radioactivity.

Some agricultural products were found to contain high levels of radiation, resulting in local products being stigmatized as unsafe. There was also an incident in which radioactive gravel from Fukushima was mixed into the concrete used for construction of a new apartment building, exposing the residents to radiation.

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**FIGURE 8: Nuclear power stations near the epicenter and their emergency shutdown modes**

<table>
<thead>
<tr>
<th>Power Station</th>
<th>Unit</th>
<th>Capacity</th>
<th>Start Year</th>
<th>Auto Shutdown</th>
<th>Cold Shutdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onagawa</td>
<td>Unit 1</td>
<td>524 MW</td>
<td>1984–</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td></td>
<td>Unit 2</td>
<td>825 MW</td>
<td>1995–</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td></td>
<td>Unit 3</td>
<td>825 MW</td>
<td>2002–</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Fukushima Dai-ichi</td>
<td>Unit 1</td>
<td>460 MW</td>
<td>1971–</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td></td>
<td>Unit 2</td>
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<td>✔️</td>
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</table>

*Source: Office of the Prime Minister.*
FIGURE 9: **Cause of the accident at the Fukushima Dai-ichi nuclear power station**

- **Loss of off-site power due to earthquake**
- **Emergency diesel generator inoperable due to tsunami**
- **Loss of all cooling function**

Source: TEPCO (Tokyo Electric Power Company).

FIGURE 10: **Fukushima Dai-ichi nuclear power station**

Source: TEPCO (Tokyo Electric Power Company).
The Japanese government has taken decisive steps to clean up contaminated areas around Fukushima and to minimize health risks. It has set aside about ¥1.15 trillion for decontamination and disposal of contaminated waste between fiscal years 2011 and 2013. The long-term environmental and health effects of the nuclear incident are unknown; and the Japanese government will be monitoring the health status of residents of Fukushima Prefecture over the next 30 years.

The Government Investigation Committee on the Accident at the Fukushima Nuclear Power Stations stressed that a paradigm shift is required in DRM for catastrophic events. The interim report of the committee pointed out:

“The following three factors contributed greatly to the occurrence and response of the accident:

- Lack of preparedness for serious accidents caused by tsunamis. Neither TEPCO, the operator of the nuclear stations, nor the regulatory authorities had prepared for accidents as serious as those caused by the enormous tsunamis that followed the GEJE. Countermeasures must be put in place to address high-impact events, even those with low-probability. All concerned organizations must recognize these risks.

- Lack of appreciation for the effects of complex disasters. Securing nuclear stations and ensuring the safety of people in the neighboring communities against unforeseen complex disasters is a serious issue. Existing countermeasures for dealing with complex disasters must be reviewed and revised.

- Lack of a holistic understanding of complex disaster scenarios. Existing countermeasures to address nuclear power accidents do not reflect a thorough understanding of the complexity of nuclear power station systems. The excuse that the event was “beyond assumption” is unacceptable. Serious problems existed in the disaster risk management system for nuclear accidents.”

LESSONS

Important facilities were in most cases well protected against large-scale earthquakes thanks to seismic reinforcement and other measures.

Crucial facilities or facilities sensitive to disasters should be designed to withstand extreme events. Although tsunami hazards were taken into account in the site evaluations and design of facilities, the hazard level had been underestimated.

Nuclear power stations and other disaster-sensitive facilities should be carefully evaluated against the risks of all natural hazards, and these assessments should be periodically revised based on the latest knowledge and technologies. The failure of a sensitive facility, such as the case of the Fukushima Daiichi nuclear power station, can cause not only short-term consequences but also long-term social, economic, and environmental problems.
RECOMMENDATIONS FOR DEVELOPING COUNTRIES

The cascading effects of the GEJE disaster highlight the importance of protecting sensitive facilities against disasters of any scale. The followings are recommended as important steps to lower risks for crucial facilities and to prevent high and irreversible impacts of complex disasters.

Identify critical facilities. Critical facilities need to be identified and well protected against extreme events. These include hospitals, government offices, evacuation shelters, schools, and other facilities to be used for rescue operations, evacuation, and other disaster management activities. Also, facilities, such as nuclear power stations and oil refineries that may cause cascading effects in various sectors should be identified. Disaster management plans should include information on the functions of these facilities and the risks they may pose.

Assess critical facilities. Facilities that are required to function as bases for disaster-response activities should be “stress tested” for disaster resistance. Even simple assessments, such as confirming a facility’s safety against recorded disasters, is useful in preparing for disaster. The risk of all natural hazards, including that of multihazard events, should be carefully evaluated. Risk assessment should incorporate not only statistics on recent hazards but also historical records of past disasters as well as future projections, if possible. Such assessments and assessment methodologies should be periodically updated.

BOX 2: Tsunami impact on the Onagawa nuclear power station

The Tohoku Electric Power Company’s Onagawa Nuclear Power Station is located about 120 km west of the epicenter of the March 11 earthquake. Although the tsunami was about 13 meters high at the Onagawa nuclear power station, the station’s structures and equipment were not severely damaged.

When the first unit was built in the 1970s, the site elevation of the station was set as 14.8 meters above sea level. A literature review and interview surveys revealed that the maximum tsunami height at the Onagawa site was estimated to be about 3 meters, but the 14.8 meter site elevation was considered appropriate.

Since then, the tsunami hazard assessment has been reviewed many times, using up-to-date findings and cutting-edge tsunami simulations and, every time, the safety of the facility against tsunamis has been confirmed. The most recent tsunami design standard was set as 13.6 meters. Even though the Onagawa site experienced a subsidence of 1 meter, the March 11 tsunami did not submerge the main facility.

At the second unit, however, the intake unit for the seawater pump station was built as a pit-structure, and the pump was situated below the rest of the facility. This caused the seawater to enter the pump room through the tide gauge, submerging an emergency generator and rendering it inoperable.

In the aftermath of the disaster, the main building of the nuclear power station was used as an evacuation center for about 400 local residents whose houses had been washed away. These people stayed at the power station for about three months.
Protect critical facilities. Critical facilities should be protected against the risks of all natural hazards. The possibility of multihazards should be considered in their design. Enforcement of building codes should be a high priority for buildings and other important structures.

Prepare for complex disasters. High-risk plants and facilities need to be included in disaster management plans. Plans for quick recovery and rehabilitation after a disaster of unexpected scale should be made. Evacuation drills should be conducted based on various disaster scenarios.

Establish enforcement mechanisms. Regular inspections of critical facilities by firefighters and other disaster management organizations should be established. Responsibility for safety guidelines, monitoring, and enforcement needs to be clearly established in land-use procedures, building codes, fire inspections, and so on. Effective enforcement requires appropriate legislation, organization, and human resources.

KEY REFERENCES


