KNOWLEDGE NOTE 1-5

CLUSTER 1: Structural Measures

Protecting Significant and Sensitive Facilities

GFDRR
Global Facility for Disaster Reduction and Recovery

THE WORLD BANK

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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.

FIGURE 1: **Relocation of municipal buildings after the GEJE**

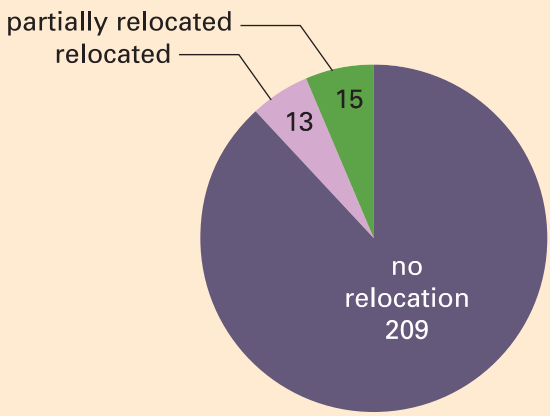


FIGURE 2: **Otsuchi city hall**

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

BOX 1: **An angel's voice**

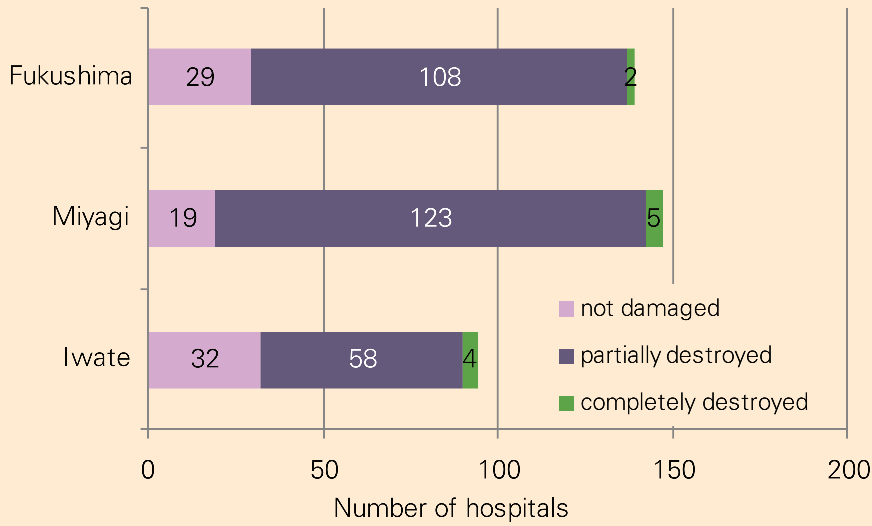
A woman on the municipal staff in Minami-Sanriku City was urging residents over the radio to evacuate to higher ground. Although tinged with fear and apprehension, her voice gave people courage and helped save countless lives. She continued broadcasting to the very end before being engulfed by the tsunami. 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**

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.

FIGURE 4: **Evacuation stairway at the Omoto Elementary School**



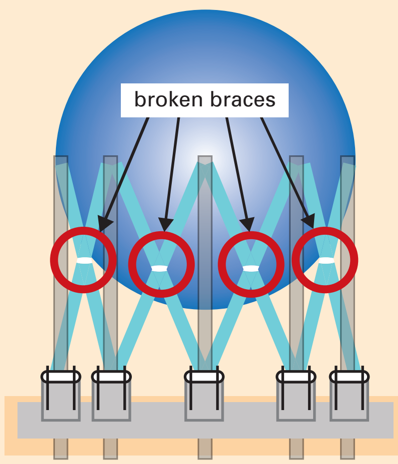
Health and social welfare facilities. Hospitals and social welfare facilities also need to be protected, because without medical response capabilities the number of casualties will increase and health hazards will spread. According to the Ministry of Health, Labor, and Welfare, almost 80 percent of hospitals 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).

FIGURE 5: **Leaked LPG catches fire at a refinery**

FIGURE 6: **Broken braces led to collapse of LPG tank**



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: **Retrofitting 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.

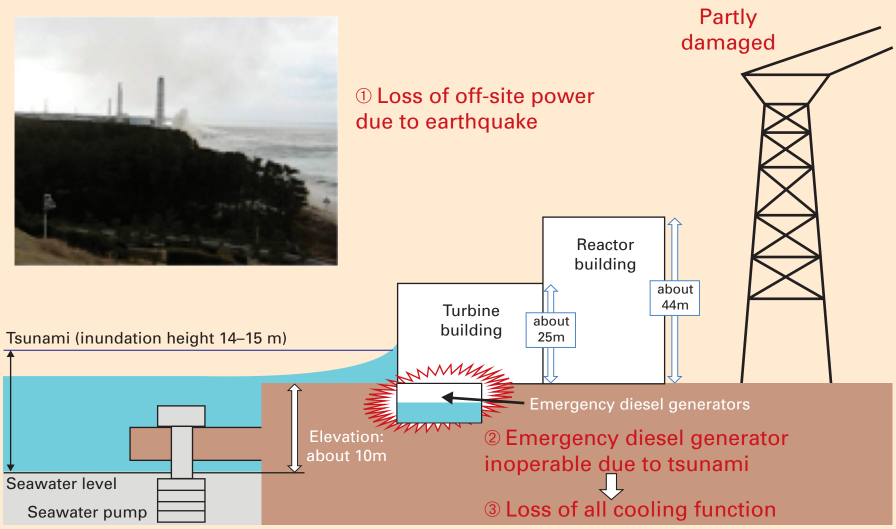
Some agricultural products were found to contain high levels of radiation, resulting in local products being stigmatized as unsafe. There was also an incident in which where radioactive gravel from Fukushima was mixed into the concrete used for construction of a new apartment building, exposing the residents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

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

		auto shutdown	cold shutdown
Onagawa			
Unit 1	524 MW, 1984–	✔	✔
Unit 2	825 MW, 1995–	✔	✔
Unit 3	825 MW, 2002–	✔	✔
Fukushima Dai-ichi			
Unit 1	460 MW, 1971–	✔	
Unit 2	784 MW, 1974–	✔	
Unit 3	784 MW, 1976–	✔	
Unit 4	784 MW, 1978–	Periodic inspection	
Unit 5	784 MW, 1978–		✔
Unit 6	1,100 MW, 1979–		✔
Fukushima Dai-ni			
Unit 1	1,100 MW, 1982–	✔	✔
Unit 2	1,100 MW, 1984–	✔	✔
Unit 3	1,100 MW, 1985–	✔	✔
Unit 4	1,100 MW, 1987–	✔	✔
Tokai Dai-ni			
Unit 1	1,100 MW, 1978–	✔	✔

Source: Office of the Prime Minister.

FIGURE 9: **Cause of the accident at the Fukushima Dai-ichi nuclear power station**



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.

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.

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.

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

Central Disaster Management Council. 2011. *Report of the Committee for Technical Investigation on Countermeasures for Earthquakes and Tsunamis Based on the Lessons Learned from the 2011 off the Pacific Coast of Tohoku Earthquake.*

Agency for Cultural Affairs. 2011. *Damages to Cultural Properties in the Great East Japan Earthquake.* http://www.bunka.go.jp/english/pdf/2011_Tohoku_ver14.pdf

Investigation Committee on the Accident at the Fukushima Nuclear Power Stations. 2011. *Interim Report.*

Nuclear Emergency Response Headquarters. 2011. *Report of Japanese Government to IAEA Ministerial Conference on Nuclear Safety--Accident at TEPCO's Fukushima Nuclear Power Stations.* http://www.kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html

Matsuo, A. 2012. Civil engineering technologies that support nuclear safety based on a site survey of Onagawa nuclear power station of Tohoku Electric Power Co., Inc. (*Genshiryoku anzenwo sasaeru dobokugijutsunituite*) (in Japanese). Journal of Japan Society of Civil Engineers 97(4): 95–97.

Tohoku Electric Power Co., Ltd. 2011. Tsunami assessment and measures at Onagawa Nuclear Power Station (*Ongawa genshiryoku hatsudensho ni okeru tsunami hyoka taisaku no keii nitsuite*) (in Japanese). http://www.nsc.go.jp/senmon/shidai/jishin/jishin4/siryo4-2.pdf