



KNOWLEDGE NOTE 6-5

**CLUSTER 6: The economics of disaster risk,
risk management, and risk financing**

Strategies for Managing Low-probability, High-impact Events



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Strategies for Managing Low-probability, High-impact Events

Every country should develop strategies for managing low-probability, high-impact extreme events—strategies that reflect their own as well as global experiences with megadisasters. These strategies should integrate structural and nonstructural measures tailored to local conditions. Forecasting and early warnings, land-use planning and regulation, hazard maps, education, and evacuation drills are all vital. Lessons from the Great East Japan Earthquake (GEJE) can help improve these nonstructural practices, which in Japan have been shaped by trial and error after experiences with many natural disasters. The international community should develop knowledge-sharing mechanisms to help countries prepare for low-probability, high-impact extreme events.

FINDINGS

NATIONAL STRATEGIES TO ADDRESS LOW-PROBABILITY, HIGH-IMPACT EXTREME EVENTS

The Great East Japan Earthquake (GEJE) was the first disaster in Japan’s modern history that exceeded all expectations and predictions. Its dimensions were almost “beyond imagination” (KN 5-1). Its enormous impact prompted the government to seek a paradigm shift in disaster risk management (DRM), moving from structure-focused prevention to a strategy of mitigation by integrating structural and nonstructural measures.

Excessive reliance on structural measures proved to be ineffective, and even detrimental, when the forces of nature exceeded the structures’ design limitations. In some towns, evacuation was delayed because people did not expect a tsunami to overtop an embankment as high as 10 meters or more. Some could not escape the tsunami in time because they had moved their homes to the lowlands along the coast to be closer to their source of income. They felt safe because high embankments had been built (KN 2-2-2).

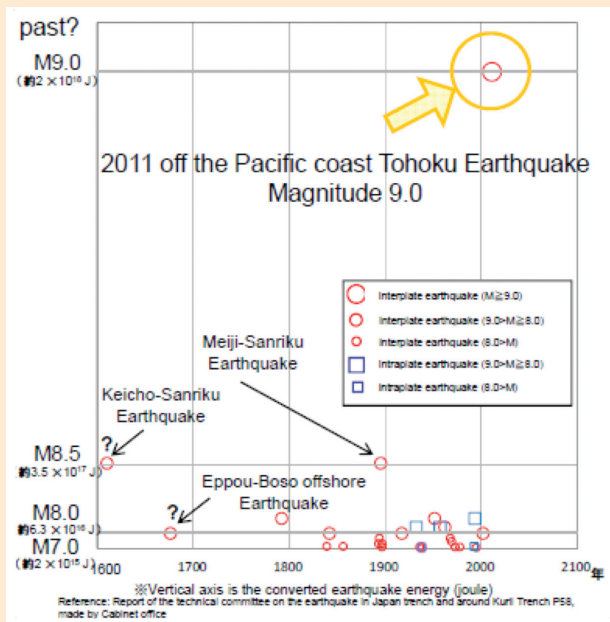
Addressing low-probability, high-impact extreme events requires an integrated DRM strategy, combining structural and nonstructural measures. Disasters should be catego-

alized into two levels: level 1 consists of disaster events that occur with relatively high frequency (with a return period of around 100 years or less) and level 2 consists of events that rarely happen (with a return period of around 1,000 years or more). The GEJE was a level 2 event as illustrated in figure 1. Level 1 events can be addressed mainly by disaster prevention structures, while level 2 events require an integrated DRM strategy.

Strategies for level 2 events should focus on saving lives. Measures to be used in an integrated manner to ensure immediate evacuation include installing disaster forecasting and early warning systems; land-use planning; designating and building of evacuation sites, shelters, and other facilities; and installing structures to delay and weaken the force of waves. Education, practice drills, and mutual help mechanisms are extremely important. Urban and land-use planners need to consider mechanisms for speedy emergency evacuation and for sustaining social and economic activities. People’s participation is the critical factor in the planning process.

During the GEJE, catastrophic damage was inflicted when structures were overtopped by the tsunami, reached their breaking point, and suddenly collapsed. Structures should be resilient enough to hold up, or succumb gradually, even when the natural forces exceed their structural design limitation. Nonstructural measures such as land-use planning, forecasting and warning systems, evacuation drills, and public awareness-raising, should be designed with enough redundancy and flexibility to address different disaster scenarios.

FIGURE 1: Magnitude of earthquakes in Japan



Source: Cabinet Office.

Strategies should take into account the unexpected. In the GEJE, many plans did not specify the actions to be taken in the face of an unexpected event, contributing to catastrophic damage to facilities, communities, and socioeconomic systems.

STRUCTURAL MEASURES

Structural measures will continue to play a key role in managing low-probability, high-impact extreme events. Although many disaster prevention structures, such as tsunami defense dikes and gates, collapsed and were washed away in the GEJE, some withstood the waves even after they were overtopped, reducing the force of the tsunami and delaying its penetration inland (KN 1-1-1). In a number of cases the dikes were not overtopped, and kept the hinterlands from being inundated. Postdisaster computer simulations for the Kamaishi Port indicated that the wave breakers around the port reduced the peak height of the tsunami by 40 percent: from 13.7 meters to 8 meters.

Damage by the tsunami of 10 meters or higher to structures and buildings was extensive and severe. Almost all buildings and structures made of wood were destroyed. Iron structures were left with only their skeletons. Most reinforced concrete buildings withstood the tsunami, although they suffered internal damage (KN 1-2).

After the Indian Ocean tsunami and Hurricane Katrina, design standards for defensive structures, such as dikes and water gates, have been reevaluated. The conclusion is that using only preventive structures to defend against low-probability extreme events is not an economically, environmentally, or socially viable option. For example, it is not realistic to try to protect hundreds or even thousands of kilometers of seacoast using embankments, even as high as 20 meters.

Tsunamis should be classified into two or more categories. Level 1 tsunamis may occur once in a 100 years; level 2 tsunamis are extreme events that may occur once in a 1,000 years or more. Disaster mitigation structures such as wave breakers and dikes should be designed to prevent inland penetration by level 1 tsunamis, saving lives and properties. Although these structures could be overtopped by a level 2 tsunami, they should be able to withstand complete collapse, thereby reducing the force of the tsunami and delaying its progress. In the case of level 2 tsunamis, the structure is not expected to achieve complete mechanical prevention, but rather to mitigate damage, in combination with other nonstructural measures.

Using infrastructure such as highways and trunk roads as defensive structures is also recommended. In the GEJE, coastal highways and trunk roads functioned not only as evacuation routes but also as temporary evacuation sites and even as dikes (KN 1-4).

People in Kamaishi city's Katakishi district fled to the Sanriku-Jukan Expressway which had opened on March 6, 2011, just six days before the earthquake. The expressway, which was on a hill, first served as an evacuation area and then as a main road for delivering relief goods and reconstruction materials. National routes running along the coast served as embankments preventing the tsunami from advancing inland.

NONSTRUCTURAL MEASURES

As Sanriku's coastal areas have been repeatedly hit by tsunamis, many towns and communities had developed both structural and nonstructural measures which mitigated the impact of the tsunami substantially.

In addition to information dissemination and evacuation measures, the following nonstructural approaches were found to be effective against extreme water disasters:

- Moving residential areas and public buildings to higher ground, while keeping commercial installations and activities based in the lowland coastal areas (KN 2-8).
- Securing evacuation routes (such as roads and stairways) that connect public facilities (such as schools) to higher ground (KN 1-4).
- Planting trees densely in coastal areas (KN 2-8).
- Using tall concrete buildings (four to five stories or higher) as evacuation places.
- Using highways and trunk roads as secondary protective embankments.

The government of Japan enacted a new law—the *Act on Tsunami Resilient Community*—to promote these nonstructural measures in the tsunami-affected municipalities (see KN 2-7). The act requires: restricting the construction of buildings in risk areas; introducing integrated tsunami mitigation plans comprising evacuation routes and facilities, hazard mapping, drills, and warning systems; relaxing the floor-space ratio of buildings to encourage the construction of taller buildings; reducing property taxes on designated evacuation sites; and relocating houses to higher ground.

EVACUATION

Evacuation is the highest priority in low-probability, extremely high-impact events (KN 2-6). A large number of casualties can be expected not only because of the scale of the event, but also because:

- The lead time is shorter because of the sudden or unexpected occurrence of the event.
- Information networks and tools tend to malfunction when sensors and communication lines are destroyed, constraining people to react without accurate information.
- Evacuation options tend to be limited as the means of evacuation become fewer, for example, roads become impassable, traffic jams occur, and so on.
- People base their actions on past experiences with less-severe disasters, leading them to underestimate the time they have to evacuate and the severity of the consequences.

Raising awareness, education, and practice drills are the keys to ensuring faster, more complete evacuation in extreme events.

In Kamaishi City, where 1,000 people died out of a population of 40,000, the casualty rate among school children was low. Only 5 out of the 2,900 primary and junior high school students lost their lives. A survival rate of 99.8 percent for these school children is most impressive in a city where 1 in 40 lost their lives: the rate for school children was 20 times higher than for the general public. According to one headmaster, “repetitive drills, school education, and hazard maps” were the reasons for the high survival rate (KN 2-3).

In Kamaishi city, “a touch of disaster” is built into various lessons. In mathematics, for example, students may be asked “If the speed of a tsunami is xx kilometers per hour when it hits land, how long will it take the tsunami to get from the coast to a house that is xxx kilometers inland?” In a field exercise, students produced a tsunami hazard map on their own by visiting hazard and evacuation areas within the school district.

The students were also trained in key concepts, such as:

- “Tsunami *tendenko*,” that is, “Everybody should immediately evacuate without caring for anything or anybody else at tsunami onslaught.”
- Do not believe in human assumptions of disasters, even one in a hazard map, as nature behaves differently from human assumptions.
- Do your maximum when encountering disasters. Always think and be prepared for the worst.
- Lead evacuation—you are saving others’ lives by showing that you are evacuating for life and death.
- Although more than 90 percent of students were out of school when the earthquake occurred on March 11 (whether they were walking home, playing outside, or in their homes), almost all of them headed for higher, safer areas on their own initiative and encouraged the others to run with them to safety. Having already discussed it in their homes, children and parents alike knew and trusted that they would all evacuate individually if a tsunami hit Kamaishi.

Keeping individual, community, and institutional memory alive between disasters is critical to successful evacuation. A number of monuments had been built in the coastal towns commemorating past events and citing lessons such as: “Run to a hill if you feel a strong shake or the sea suddenly withdraws.” An nongovernmental organization (NGO) has called for the planting of cherry trees to delineate where the tsunami reached on March 11, so that future generations would remember the extent of the flooding.

The elderly, the disabled, and foreigners or outsiders to the locality needed extra help in evacuating. Sixty-five percent of those who died in the GEJE were more than 60 years old, which raised the issue of how senior citizens can be safely evacuated.

HAZARD MAPS

Hazard maps are a useful tool for enhancing the preparedness of local governments, municipalities, and residents, but they can exacerbate the damage if not prepared or used properly. A number of cities and towns had produced and distributed hazard maps. In some of the towns they contributed to faster evacuation, but in others they actually provided misinformation since the tsunami was far larger than the hazard maps assumed. Casualties occurred because some of the designated evacuation sites and buildings where people had fled to were totally submerged. Many people who were living in nonflooding zones, according to the hazard map, had not evacuated when the tsunami hit (KN 5-1).

Both level 1 and 2 events should be accounted for in hazard maps so that people will have enough information to deal with either category. Hazard maps should indicate all evacuation options. Just distributing these maps to citizens is not enough—evacuation practices drills should be conducted using these maps. Preparing hazard maps with people’s participation will also help ensure effective evacuation.

FORECASTS AND WARNINGS

Accurate forecasting and early warning systems are vital for safe and quick evacuation and disaster response. In the GEJE, hundreds of thousands of people evacuated in response to the warning by the Japan Meteorological Agency (JMA) a few minutes after the earthquake. The Earthquake Early Warning System also enabled all the high-speed express trains, traveling at over 200 kilometers per hour, to come to a halt before the main tremor, which saved thousands of passengers. The emergency warning system announced the arrival of the main tremor nationwide on TV and other broadcasting systems, providing the public with a little lead time (a few to 10 seconds) to react (KN 2-2-1).

Although the earthquake and tsunami warning system helped save many lives, there was room for improvement and some key lessons emerged. Because of the unprecedented size and complexity of the event, the JMA’s first announcement underestimated the maximum tsunami height at 6 meters, while the actual height was more than 10 meters. Although the forecast was corrected 10 to 20 minutes later, the original estimate may have caused people to delay their evacuation, possibly leading to increased casualties. This occurred even though Japan is equipped with one of the most advanced forecasting and warning systems. The international community should invest not only in the installation of existing disaster forecasting and warning systems, but also in the development of new systems in combination with repetitive drills/practices. Advanced off-the-coast water pressure gauges and global positioning system (GPS)-based wave sensors have been effective in monitoring tsunami heights.

ADDRESSING “CHAIN OF EVENTS” EFFECTS

The disaster unleashed a chain of events that affected people and organizations beyond Tohoku, including national, regional, and global economies. Following are a few examples of the chain of events observed in Japan:

- Earthquake and tsunami → nuclear accident → power shortage → economic stagnation → social unrest.
- Earthquake and tsunami → dramatic increase in telecommunication activity → telecommunication system failures → interruption of social and economic activities (KN 3-2).
- Earthquake and tsunami → damage to specific industries → interruption of parts supply → global slowdown of industrial activities (KN 6-3).

Although it is impossible to foresee every eventuality, DRM strategies should include contingency measures for preventing the knock-on effects of low-probability, high-impact events (KN 1-5). Providing for sufficient redundancy in various systems is one way of breaking the chain; business continuity planning is another (see KN 2-1-4). Analyzing past examples of “chain of events” effects, and sharing them with the public, the business sector, and governments can help prevent them from recurring.

LESSONS

OVERALL STRATEGY

- Use integrated disaster mitigation strategies, rather than structure-focused disaster prevention measures, to address low-probability, high-impact extreme events.
- Categorize tsunamis into level 1 events (fairly frequent disasters) and level 2 events (low-probability, high-impact extreme disasters). Level 1 can be addressed by preventive structures; level 2 requires integrated measures.
- For level 2, prepare strategies that focus on saving lives.
- Use resilient disaster mitigation systems, structural and nonstructural, in strategies to address level 2 events.
- Consider and discuss what should happen if an event exceeds expectations. This is critical in establishing effective, functional strategies.

STRUCTURAL MEASURES

- Structural measures can mitigate low-probability, high-impact extreme events if they are resilient and resistant to natural forces.
- Structural measures should be included in an integrated disaster mitigation strategy.
- Highways and trunk roads along the coast should be used as secondary protective embankments against tsunamis.

NONSTRUCTURAL MEASURES

In addition to information dissemination and evacuation, the following nonstructural measures have been effective against water-related megadisasters:

- Moving entire residential areas and public buildings to higher ground while keeping commercial enterprises and activities in the coastal areas.
- Securing the evacuation routes (such as roads and stairways) that connect public facilities (such as schools) to higher ground.
- Planting trees in coastal areas.
- Using tall concrete buildings (of four to five stories or higher) as places for evacuation.

EVACUATION

- Drills, education, and awareness-raising are the keys to ensuring effective, more complete evacuation.
- “Tsunami *tendenko*,” that is, everybody should evacuate immediately without waiting for anything or anyone else when the tsunami is assumed/feared to approach.
- Prior discussion at home and in communities about evacuation helps ensure its success.
- Blind assumptions should not be made about any disaster, even those reflected in hazard maps, as nature behaves differently from human assumptions.
- Individual and institutional memory about past disasters should be kept alive to facilitate successful evacuation.

HAZARD MAPS

- Hazard maps are a useful tool for enhancing the preparedness of local governments, municipalities, and individuals.
- Hazard maps should address both level 1 and 2 events.
- A hazard map functions well only in combination with awareness-raising, community education, and evacuation drills.

FORECASTING AND WARNING

- Forecasting and warning systems pay off.
- Tsunami and disaster warning networks should be built and used globally.
- The international community should promote and invest in the use and development of new technologies to improve the accuracy and timing of forecasts and warnings.

ADDRESSING THE “CHAIN-OF-EVENTS” EFFECT

- The indirect effects of extreme events travel far beyond the disaster-stricken areas, hence, building redundancy into systems helps break these chains of events.
- Probable chain-of-events effects should be considered in business continuity planning.
- Experiences of these effects should be evaluated and shared to help prepare for future events.

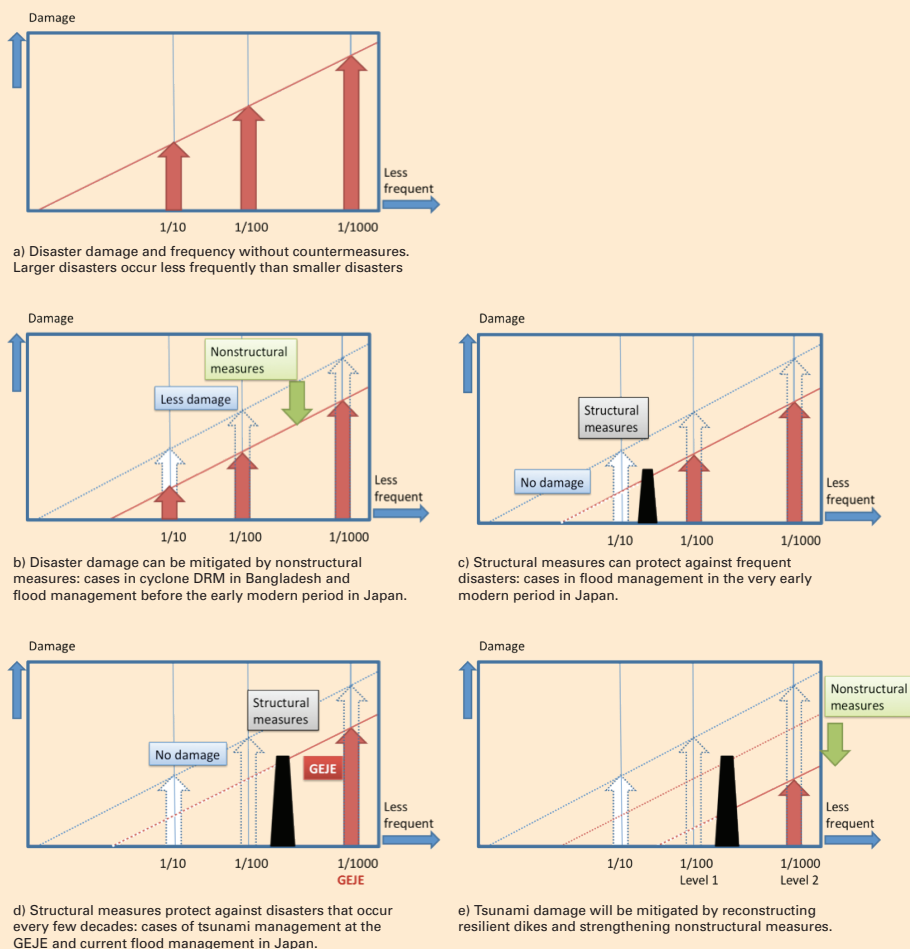
RECOMMENDATIONS FOR DEVELOPING COUNTRIES

Every country needs a national integrated DRM strategy. Many of the lessons from the GEJE are relevant for developing countries. Different combinations of structural and nonstructural measures may be used depending on a range of factors, such as socioeconomic conditions, budgetary constraints, geography, and the scale of the disasters. In the GEJE, DRM systems relied heavily on structural measures and could not prevent damages from the tsunami (figure 2 [d]). The Japanese government is revising its tsunami DRM policies to better integrate structural and nonstructural measures (figure 2 [e]). Level 1 tsunamis will be prevented by structural measures and level 2 tsunamis will be mitigated by both structural and nonstructural measures.

It is advisable to develop integrated measures for both level 1 and 2 events. For developing countries, greater reliance on nonstructural measures may be the most realistic approach even for level 1 events. But it is important to build structural measures to prevent loss of human lives and properties from frequent disasters. Disasters, especially high-impact events, tend to discourage people from investing for the future. Governments and communities should keep repeating the message that “prevention pays off,” to avoid creating a vicious cycle between poverty and disasters.

Forecasting and early warning is fundamental. Developing countries can and should develop local networks for forecasting and warning about disasters. Countries can also join forces in building regional and international systems. For example, Sentinel Asia is a regional network for sharing satellite imagery and other observation data free upon requests by member countries.

FIGURE 2: DRM using structural and non-structural measures



Hazard maps are useful tools to help people save their own lives. Developing countries should take legislative, administrative, and financial measures to ensure that hazard maps are provided to all the disaster-prone localities. The international community should help countries to develop hazard maps that reflect the lessons described in this note. It would also be useful to create regional and global mechanisms to share good practices and examples of hazard maps.

Archiving disaster records and experiences in disaster databases is essential for designing viable DRM strategies. The government should stress the importance of these

less visible but critical activities and the people who are engage in them tirelessly. Regional data sharing would also benefit neighboring countries. Countries should put agreements in place to share hydrological, meteorological, geological, and other information.

Education, drills, and awareness-raising are indispensable to avoid high death tolls in low-probability, high-impact extreme events, particularly in countries where physical defenses may be insufficient. The Japanese approaches to education, drills, and awareness-raising have been developed over time through trial and error. But simply copying them exactly may not be advisable in other, often more challenging, circumstances. The first step is to evaluate, simulate, and test whether the Japanese measures are congruent with local social and cultural practices and behaviors.

Countries must learn from one another by sharing information and experience, since low-probability, high- impact extreme events happen infrequently in any given country. The international community could facilitate regular dialogues and information-sharing mechanisms, for example, through the United Nations. Regional cooperation mechanisms would serve not only to help disaster-affected countries but also to mitigate the negative inter-regional and international effects of megadisasters.