2011 GREAT EAST JAPAN (TOHOKU) EARTHQUAKE & TSUNAMI

Earthquake Reconnaissance
OBSERVATIONS

STRUCTURAL ENGINEERS ASSOCIATION
SEA
WASHINGTON

JUNE 2011

Introduction

On Friday, March 11, 2011 at 2:46 PM (local time), the Northeast coast of Japan was struck by a magnitude 9.0 (M9.0) subduction earthquake as the boundary between the Pacific and the North American plates ruptured along an offshore section. The rupture extended about 200 miles along the Japan coast, resulting in approximately 100 feet of vertical slip and causing a devastating tsunami. A similar event along the Cascadia Subduction Zone would extend from Vancouver Island to Northern California.

The ground motion records indicate very strong ground shaking (>1.0g) with long duration (>3.0 minutes). The M9.0 earthquake and five aftershocks greater than M7.0 affected coastal areas as well as the Tokyo metropolitan area, and were felt across the Pacific Ocean. The earthquake and tsunami resulted in approximately 15,000 fatalities, approximately 12,000 missing, displaced 160,000, and caused an estimated $200- $300 (USD) billion in losses.

Recognizing the impacts an earthquake of similar magnitude would have on the Pacific Northwest, the Structural Engineers Association of Washington (SEAW) formed a reconnaissance team of engineers to observe and evaluate earthquake and tsunami damage in the affected areas. As shown in Figure 1, the team traveled to the metropolitan cities of Tokyo and Sendai, and along the Tohoku coast to observe the impacted areas. The team also met with Japanese earthquake research organizations, design/construction professionals, and public officials to learn more about the extent of the damage and seismic design practices in Japan. This report provides a brief summary of the team's observations.

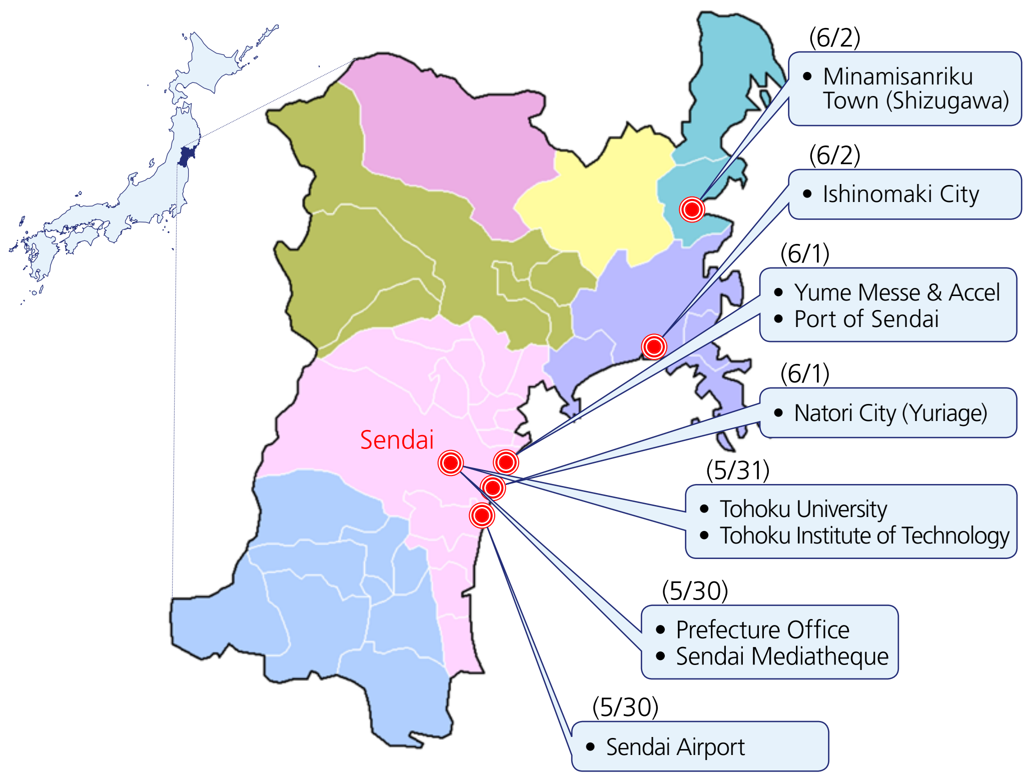


FIGURE 1 - Sites Visited by the SEAW Reconnaissance Team in Miyagi Prefecture (Sendai Area) following the March 2011 Earthquake and Tsunami. (visit dates shown in parentheses.)

FIGURE 2 - Tsunami Damage in Minami Sauriku, Japan (Swanson)

FIGURE 3 - Residential Building Collapse from large areal landslide beneath a residential neighborhood in Sendai City, Aoba Ward (Swanson)

General Observations & Lessons Learned

TABLE 1 - March 11, 2011
Great East Japan Earthquake & Tsunami Statistics as of Oct, 2011

Epicenter 80 miles from Sendai
50 ft tsunami height in Onagawa
12 mile max inland tsunami travel
200 mi^2 of land flooded
58,000 acres (91 mi^2) of farmland destroyed by saltwater inundation that can't be cultivated for 2 or more years
22,000 fishing boats destroyed
100,000 houses destroyed
400,000 evacuees
8,000,000 households with blackouts
24,000 perished or missing
15,217 confirmed dead, 90% by drowning, 60% were over age 60 *(Note: The 1995 Kobe earthquake resulted in 6,434 deaths, primarily caused by collapsing buildings)* *Source: Japan Times & Miyagi Prefectural Government*

- Japan is the most prepared country in the world for earthquakes and tsunamis. This earthquake exemplifies how earthquake planning and preparedness can save lives and property, preventing an even greater disaster.
- The 2011 Magnitude 9.0 Great East Japan Earthquake was the largest ever in Japan and the fourth largest ever recorded in the world. Table 1 summarizes its statistics.
- Seismic retrofit and protection technology works:
  - Japan has been quick to implement lessons learned from past earthquakes and use protection technologies. Seismic protection technologies (e.g., seismic base isolation and structural damping systems) are widely used in new construction and retrofits in Japan, not only in essential facilities but in single and multi-family housing, commercial buildings, and industrial facilities.
  - Most retrofitted buildings performed well during this earthquake for both life safety and damage control.
  - The Japanese public demands enhanced seismic performance and understands its value in protecting people, buildings, and infrastructure from frequent strong earthquakes.
- This large M9.0 earthquake serves as a reminder that the life safety performance of structures and infrastructure is not enough for earthquake-resilient communities. Higher earthquake performance levels are also required to permit continuously habitable communities and promote rapid economic recovery.
- Current U.S. building codes and standards for earthquake design of new structures are very good at addressing life safety.
  - U.S. codes and standards are comparable to state-of-the-art Japanese codes.
  - The Japanese government encourages private sector support of earthquake and tsunami research and development. This has resulted in widespread application of earthquake protection technologies in constructed projects.
- Earthquakes around the world provide a real-world laboratory that teaches engineers, architects, and public officials how infrastructure and communities will perform in earthquakes. We must heed the lessons learned from these disasters.
- Geologic studies along the Pacific Northwest Coast indicate that multiple earthquakes have occurred in the last 1,500 years, with the most recent occurring in 1700. An earthquake similar to the Great East Japan Earthquake will occur again along the Cascadia Subduction Zone, located just off the Pacific coastline. The impacts of this event on our communities and industry will depend on the actions we take now to prepare for it. The lessons learned from Japan can be applied in our own communities.

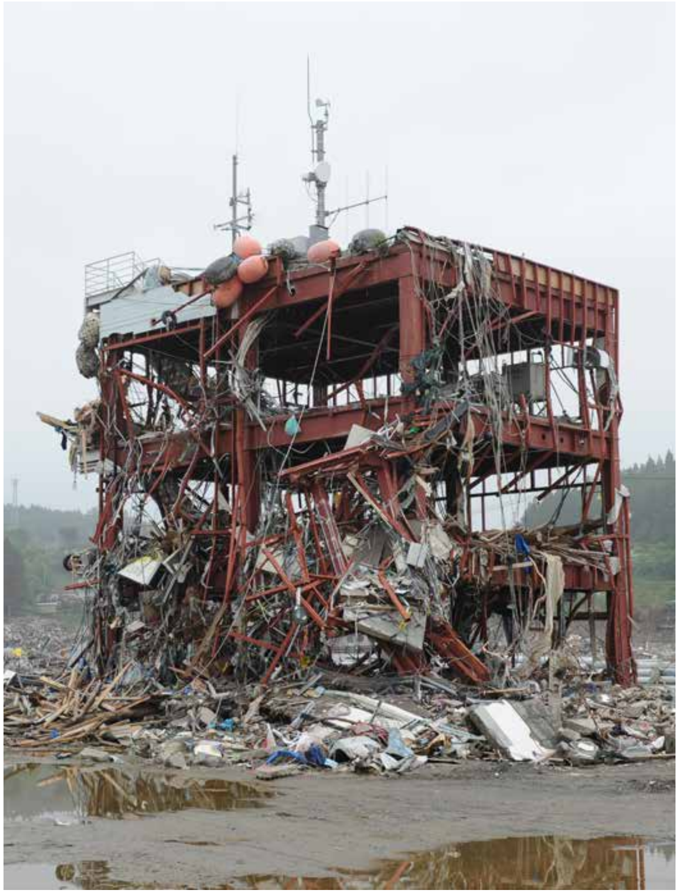


FIGURE 4 - Modern Disaster Prevention Center building in Minami Sauriku after the 14m high tsunami (Swanson)

FIGURE 5 - Bent Wood-framed Shear Wall Hold-Down Connection from Tsunami (Swanson)

FIGURE 6 - Tsunami Damaged Steel Moment Frame Building in Natori from 7m Tsunami Height (Swanson)

Specific Observations

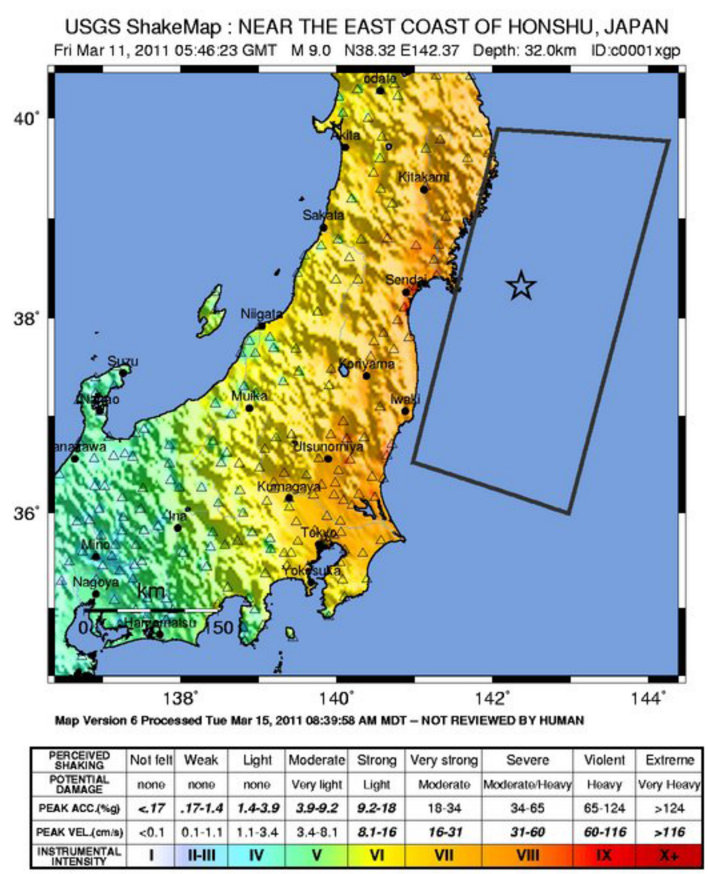
This section includes individual team members' observations, categorized by area of study.

SEISMOLOGY/GROUND MOTIONS/TOPOGRAPHIC EFFECTS (King Chin)

The Tohoku Earthquake had the following characteristics:

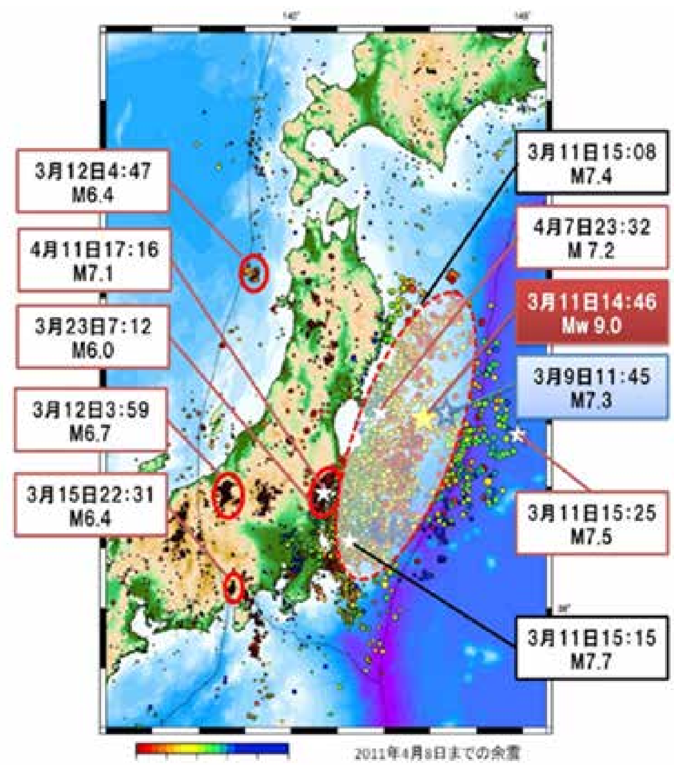
- Multiple ruptures occurred in two fault segments.
- Coastal subsidence (lowering of the earth's crust) of approximately 1 meter occurred.
- Near the earthquake's epicenter, the sea floor uplifted approximately 5.5 meters and caused the tsunami.
- Shaking had a long duration (up to 6 minutes).
- A large number of aftershocks occurred; nine were over magnitude 6.0.
- Ten recording sites documented a Peak Ground Acceleration (PGA) of over 1g.
- It had a relatively high predominant shaking frequency and compared to past earthquakes (e.g., the 1995 Kobe earthquake) was less destructive to buildings over ten stories high.
- Amplification of ground shaking occurred in high-ground regions.

Note: PGA is a measure of how hard the earth shakes (intensity) in a geographic area. "g" is acceleration due to Earth's gravity, equivalent to g-force. Over 0.50g is considered very high, with shaking perceived to be violent and potential for heavy damage.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: USGS



Source: University of Tokyo

FIGURE 7 - Ground Shaking Intensity Map and Aftershocks over 6.0 Magnitude (images courtesy USGS & University of Tokyo)

GEOTECHNICAL EFFECTS (Doug Lindquist)

This earthquake's damage related to geotechnical effects generally occurred in known geologic hazard areas, such as:

- Landslides and rockfalls that occurred in areas of past instability.
- Liquefaction that occurred in areas with loose to medium-dense, saturated sand and silt, especially reclaimed land (e.g., Urayasu City).

Liquefaction damage was extensive, even at sites over 150 km from the fault rupture.
Examples include:

- Damage to structures caused by ground movement and lateral spreading toward bodies of water.
- Ground and structure settlement.
- Ground and utility line settlement, causing breaks where utilities entered pile-supported structures.
- Damage to inadequately designed pile foundations.
- Sand boils at the ground surface, limiting recovery.
- Pipelines, manholes, and vaults floating out of the ground.

Observation Summary

- Ground improvement measures are effective in mitigating liquefaction-induced damage.
- Engineering methods exist that can provide a reasonable estimate of likelihood and effects of liquefaction.
- Newer structures designed for known geologic hazards performed well.

FIGURE 8 - Performance difference between adjacent buildings supported on piles versus shallow foundations in Urayasu City (Lindquist)

FIGURE 9 - Temporary utility connection following settlement caused by liquefaction in Urayasu City (Lindquist)

BUILDING CODE COMPARISON (Andy Taylor)

Japan's modern design codes consider seismic hazard levels that are similar to current U.S. codes. One exception is that in some cases Japan's codes required higher design forces for very flexible structures (e.g., some high-rise buildings).

In addition to life-safety, Japanese codes require considerations of building functionality following a moderate earthquake.

Observation Summary

- Buildings designed under recent Japanese design codes performed well during this earthquake, with limited structural damage. However, costly non-structural damage was common, largely due to the lack of proper seismic restraints for building contents and building systems.
- It is expected that the Japan national standard for non-structural elements will be significantly updated based on the lessons learned from this earthquake.

BUILDING EARTHQUAKE PERFORMANCE – GROUND SHAKING (Jon Siu)

Buildings designed to modern codes (post-1980) performed well in this earthquake, unless other factors (e.g., soils) were involved. The team observed no structural failures of modern buildings, but older/non-ductile buildings experienced damage. In many cases, structural irregularities in combination with soil or topographic conditions were major contributing factors to damage.

Seismically retrofitted buildings are common in Japan and performed well, demonstrating that seismic retrofitting is a very effective way to preserve older buildings in a high seismic zone. Buildings in the Pacific Northwest are expected to perform similarly to buildings in Japan: newer buildings should do well but older buildings (without seismic retrofits) are likely to be damaged.

Contents and equipment (non-structural elements) were heavily damaged in many buildings. Design beyond life safety (i.e., occupiable design) is needed for true seismic resilience.

FIGURE 10 - Non-ductile concrete frame-over shear wall building. First-story walls failed in out-of-plane direction, Second-story columns failed in shear. (image courtesy of Motosaka)

FIGURE 11 - Non-ductile shear wall boundary member detailing at a penthouse on top of a nine-story concrete building with a two-story podium. (Siu)

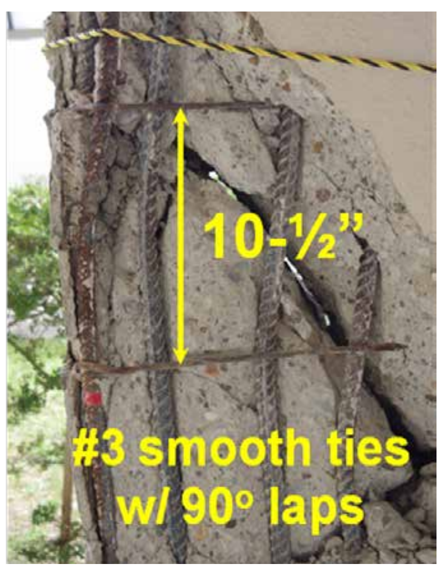


FIGURE 12 - Non-ductile concrete column detailing at the first story of a two-story building located in an area with potential topographic effects. (Siu)

FIGURE 13 - Retrofitted building in Sendai.

FIGURE 14 - Cladding damage at a school in Sendai. (Siu)

FIGURE 15 - Unbraced suspended ceiling collapse at the Sendai Mediatheque. (Siu)

HIGH-RISE BUILDINGS
(Andy Taylor)

No reports of structural damage to high-rise buildings in Miyagi Prefecture (Sendai) and Tokyo were made, but there were many reports of non-structural damage (building contents, interior finishes, equipment) and loss of building systems, water, sewer, gas and electricity.

The loss of building systems in residential structures over eight stories high led to "high-rise refugees". Without power for elevators, residents couldn't reach their apartments and condos. Pumps providing water to upper stories weren't operational and without gas, residents couldn't heat their units or cook. This displaced population had not been anticipated in earthquake planning scenarios, illustrating that life-safety seismic performance is not enough—buildings must be habitable after seismic events.

Buildings in Japan are commonly outfitted with seismic sensors and shutoffs on gas and water systems. Backup generators can provide emergency power to high-rise buildings, but after the first 24 hours, additional fuel supplies were difficult or impossible to obtain.

FIGURE 16 - High-rise building in Sendai. No structural damage was reported, but businesses and equipment on the top floors were damaged. (Taylor)

FIGURE 17 - High-rise buildings in Tokyo's Shinjuku district. Some buildings swayed for over ten minutes, but no structural damage was reported. (Taylor)

BUILDING PROTECTIVE SYSTEMS (Andy Taylor)

Since the 1990s, Japan has enthusiastically embraced special seismic protection systems for buildings. These include base isolation systems, where a building is placed on flexible or sliding supports, and damping systems, where damping devices are installed within the structural frame to absorb earthquake energy and reduce earthquake damage.

For comparison:

- Japan has over 2,600 commercial and residential buildings with seismic isolation systems. Washington State has eight such buildings, including the Washington State Emergency Operations Center at Camp Murray.
- Japan has over 3,800 single-family homes with seismic isolation systems. In Washington State there is one, currently under construction.
- Japan has over 1,000 buildings with earthquake damping systems. Washington State has only ten buildings with damping systems.

The Tohoku earthquake was a "living laboratory" for studying the performance of buildings with base isolation systems and damping systems. These systems performed as expected: in all cases studied by the team, the base isolation and damping systems provided effective damage control.

Observation Summary

This earthquake demonstrated that these systems worked well, and should be considered more often for important structures and facilities in the Pacific Northwest.

FIGURE 18 - Rubber seismic isolation bearing beneath a building in Tokyo. (Taylor)

FIGURE 19 - Sliding seismic isolation bearing beneath a building in Sendai. (Taylor)

FIGURE 20 - Tohoku Institute of Technology Building with damping system for earthquake protection. (Taylor)

FIGURE 21 - Hydraulic Fluid Viscous damper at Tohoku University. (Swanson)

TABLE 2 - Sample statistics for two coastal towns inundated by tsunamis as of May 14, 2011 (Source: Japan Times)

TOWN	Ishinomaki (50% of town flooded)	Minamisanriku Town
POPULATION	Approx. 160,000	Approx. 17,500
PERISHED	2,964 (2%)	514 (3%)
MISSING	2,770 (2%)	664 (4%)
EVACUEES	8,780 (5%)	4,870 (28%)

TSUNAMI DAMAGE IN COASTAL TOWNS
(Mark Pierepiekarz)

The Team visited several coastal towns along the Miyagi coast that experienced strong ground shaking followed by several tsunami inundation events. The region includes relatively flat coastline as well as hilly areas (north of Sendai). Table 2 summarizes tsunami impacts on the towns of Ishinomaki and Minamisanriku.

The Team's major observations follow:

- This event exceeded the anticipated maximum scenario.
- State-of-the-art early warning systems and aggressive mitigation actions prevented an even larger catastrophe.
- The region and local population experienced over 3 minutes of strong ground shaking followed by multiple tsunami inundations along the coast.
- Maximum wave heights ranged from 15 to 50 feet and overtopped coastal seawalls, as well as some multi-story structures designated as vertical evacuation shelters.
- A seismic retrofit program instituted after the 1978 earthquake proved effective. Retrofitted structures such as schools and hospitals survived the ground shaking and, in areas also inundated by tsunamis, provided reliable vertical evacuation shelters.
- Inundated wood-framed structures were mostly destroyed. Extensive debris impact on the surviving structures was evident.
- Erosion of building foundations and in-ground utilities was also very evident.
- Fire events followed tsunami events at a number of locations.
- Hybrid automobiles were reported to have shorted out battery systems. Hybrid vehicles were reported to have started several fires.

Comparison to Local Conditions:

The coastline of the Pacific Northwest and British Columbia exhibits similar features to the Japanese coast. Cascadia Subduction Zone earthquakes can generate strong ground shaking, tsunamis and coastal elevation changes. Lessons for our region follow:

- Planning and mitigation activities for large magnitude subduction zone events are required. Some planning has been done for the Washington coast, but progress on implementation is needed.
- Early warning systems (tsunami and ground shaking) save lives and are needed along the Pacific Northwest coastline.
- Reliable vertical evacuation shelters are required in potential tsunami inundation zones. These structures must be adequately tall, accessible for the elderly and disabled population, capable of surviving long-duration strong ground shaking, and resistant to multiple debris impacts.
- Coastal subsidence will affect local utilities and drainage patterns.
- Extensive multi-year cleanup and debris removal will be required.
- Continued application of best practices from Japan will improve the Pacific Northwest coast's resilience in the event of a subduction earthquake.

Useful Tsunami-Related Internet links and references:

FEMA

- FEMA 646 Vertical Evacuation Structures Guides
- FEMA 540 550 Post-Katrina Construction Guides

Washington State

- Project Safe Haven: Vertical Evacuation on Washington Coast
  – https://catalyst.uw.edu/workspace/iserjc/19587/116498
  – www.facebook.com/projectsafehaven

Oregon (Cannon Beach – City Hall)

- CREW and DOGAMI Workshop
  – http://www.crew.org/products-programs/tsunami-evacuation-buildings-forum

FIGURE 22 - A retrofitted school building in Arahama Ward (Sendai) provided vertical shelter to the devastated community, as shown in Figure 24. (Pierepiekarz)

FIGURE 23 - Retrofitted hospital in Minamisanriku Town survived the ground shaking and provided shelter from 15m tsunami. (Pierepiekarz)

FIGURE 24 - Destroyed wood-framed buildings in Arahama Ward (Sendai). (Pierepiekarz)

FIGURE 25 - Overturned steel-framed structure in Onagawa City. (Taylor)

ROAD AND BRIDGE PERFORMANCE

(Paul Brallier, HNTB)

The following observations were made related to road and bridge performance:

- Ground-shaking damage to bridges was limited, due to adoption of modern seismic design codes and an aggressive seismic retrofit program implemented after the 1995 Kobe earthquake.
- Tsunami damage to bridges was primarily due to crossings with deep-profile girders, spans lacking vertical hold-down anchorage at supports, and scour at approaches.
- Many shallow-depth, short-span bridges survived many meters of tsunami inundation with repairable damage to their railings.
- Roadways were damaged by the earthquake in thousands of locations due to embankment settlement or failure, bridge approach settlements, and lateral spreading. The extent of roadway damage impeded the disaster response and evacuations. After three months, most repairs were made with reduced speed limits necessary at many locations.
- The tsunami debris blocked most roadways in the inundation zones. This further impeded the disaster response. Roadway embankments overtopped by the tsunami were typically severely damaged. Many roadway embankments that were not overtopped acted as barriers to the tsunami.

FIGURE 26 - Functional Low-Profile Vehicle Bridge In Ishinomaki City. Note Damage from Tsunami to Leading Edge of Bridge Walkway and Guardrail on the left side of the photo. (Swanson)

FIGURE 27 - Waterfront Tsunami Scour Behind Seawall in Yuriage. Note Exposed Seawall Tiebacks. (Swanson)

PORT AND WATERFRONT STRUCTURE PERFORMANCE
(Paul Brallier)

Observed earthquake shake damage to port structures was primarily due to soil effects such as liquefaction, lateral spreading, and seismic-induced settlement. These effects were likely minimized at the Port of Sendai by use of engineered backfill at Quaywalls and bulkheads. Port of Sendai, the largest port area visited, had minimal shake damage to structures but considerable impact from the tsunami.

Tsunami damage to port and waterfront areas was extreme. Where provided, many coastal harbor defenses such as seawalls failed catastrophically. Japan is considering multi-event design for future tsunamis (performance level design) to ensure that harbor defense structures 'bend but don't break' under major tsunami's.

LIFELINES AND INDUSTRIAL FACILITIES PERFORMANCE
(Mark Pierepiekarz)

The team observed earthquake impacts on several industrial facilities as well as critical utilities and lifelines. The observations included are examples, rather than a comprehensive assessment of industry and utility damage. Significant regional industries in the affected Miyagi area include agriculture, beverage and food processing, forest products, high-technology, petrochemical, ports, fishing, manufacturing, assembly, and steel mills.

Earthquake impacts on these industries included shake damage to structures and equipment (contents), as well as tsunami inundation (flooding) followed by fires.

Many industrial facility structures provided life-safety earthquake performance as intended by building codes for new construction. The extensive impacts and losses to the region and nation indicate that "operational" or "functional" performance is often required to achieve a resilient (i.e., quickly recoverable) status following a major event.

As shown by this event, in subduction-type earthquakes, facilities (and lifelines) located over 400 km from the epicenter (Tokyo) can be impacted. For industrial facilities, achieving acceptable seismic performance depends on the following factors:

- Location (elevation, soils)
- Critical services (bracing, impact)
- Tanks and piping (anchorage, debris impact)
- Power supply (backup, fuel supply)
- Electrical equipment (elevation, redundancy)
- Fire-following-earthquake hazards (on/off-site ignition sources)
- Supplier damage (supply-chain dependency)
- Customer impacts (post-event sales)
- Extent of debris (impact and cleanup)
- Available post-event resources (pre-arranged)
- Redundancy of operations

Lifelines include the external critical utilities and systems that a facility needs in order to be functional. Examples of critical lifelines include water supply, sewer and wastewater treatment, power supply and distribution, communications, and transportation (highway, rail, airport, natural gas & fuel).

Although the team's mission did not include a comprehensive treatment of lifeline systems, the following observations and lessons can be applied to other regions prone to similar events:

- Electrical supply
  - Locate substations and electrical equipment above grade (inundation areas)
  - Power poles were wiped out by tsunamis (scour, debris impact)
  - Prolonged power shortages impeded repair and recovery actions
- Water and sewer
  - Soil liquefaction caused piping damage
  - Coastal subsidence altered drainage patterns
  - Coastal treatment facility locations required extensive debris damage/cleanup
- Communications
  - Mobile network may not be reliable for up to a week (congested network, back-up power, and fuel shortage issues)
  - Voice-over-internet-protocol (VOIP) and satellite systems are good alternatives

FIGURE 28 - Ishinomaki City – tsunami impacts to warehouses and infrastructure. (Pierepiekarz)

FIGURE 29 - Fire-following-earthquake impacts at Sendai Airport cargo area. (Pierepiekarz)

FIGURE 30 - Underground utility impacts (soil liquefaction) in Chiba (Tokyo metro) area. (Pierepiekarz)

FIGURE 31 - Sendai Airport – main utility room located below grade was flooded. (Pierepiekarz)

PREPARATION, RESPONSE, AND RECOVERY
(Jon Siu)

These observations are based on discussions with officials from particular jurisdictions (prefectures, towns, or cities) in Japan and may not reflect issues in the entire affected area.

Preparation:

- Japan invested in physical barriers to protect coastal communities from tsunamis. Most, but not all, of these barriers (e.g., seawalls, levees, and "tsunami forests") proved to be ineffective given the extreme heights of the tsunamis generated by this earthquake.
- Japan employs early-warning systems for ground shaking and tsunamis. These systems work to prevent injuries and save lives. The ground shaking warning system is readily available to everyone via mobile phones.
- Japan regularly conducts drills for earthquakes and tsunamis. A town official in Minamisanriku Town reported a high degree of participation in their annual tsunami drills. These drills saved lives in this event, since "everyone in Japan knows where to go" for tsunamis.
- Schools and hospitals are used for vertical evacuation and shelter, and their location and height must be carefully considered. Minamisanriku Town relocated their schools to higher ground after a 1960 tsunami, and they were safe in this event. However, many patients in the town hospital were not evacuated to a high enough floor to be safe, because the hospital's plan did not anticipate such large waves.
- The Pacific Northwest has a number of coastal communities without accessible vertical evacuation that are vulnerable to widespread casualties from a Cascadia Subduction Zone earthquake and tsunami. Although some planning has been done in the Pacific Northwest for tsunami preparation and a few communities have begun implementation of those plans, much work needs to be done.

FIGURE 32 - Early-warning system Smart Phone “app” for ground shaking (Siu)

FIGURE 33 - Reminder of 1960 tsunami event, Minamisanriku Town (Siu)

Response:

- Self- evacuations and rescue evacuations made it difficult for local authorities to get accurate counts of dead and missing people.
- Earthquake-damaged roads and tsunami inundation slowed response. One group in Ishinomaki City, stranded on the upper floors and roof of their evacuation center, waited two to three days for food, medical supplies, and rescue evacuation.
- With the loss of their hospital, Minamisanriku Town had to wait over two weeks for a temporary field hospital to be set up by military personnel from Israel. In the meantime, people needing medical care had to be taken to a distant town.
- Japan evaluates and posts building conditions using a red/yellow/green placard system very similar to the ATC-20 system used in the US. The City of Sendai had completed safety evaluations of over 85% of their 8,900 buildings within three and a half weeks after the earthquake. On April 7, a large aftershock (M7.2) required them to start over. Building evaluations were completed two months after the March 11 main shock. 17% of the buildings were red-tagged (unsafe to enter).
- Debris management was the highest priority at the time of the team reconnaissance. Mind-boggling quantities of building materials (mostly wood from residences), personal belongings, cars, and mud/sand had to be removed from sites and piled up so reconstruction and other aspects of recovery could begin. Government officials had not decided what the final disposition of all the debris would be at the time of the team’s visit.

Recovery:

- Sendai Airport was only able to operate at 20% capacity due to tsunami damage to the main terminal. Full service was not restored until July 25, over four months after the earthquake and tsunami.
- Restoration of utilities to coastal areas was a high priority but as late as three months after the event, electricity had not been restored to some areas.
- Urayasu City (Tokyo metropolitan area) was built on fill and suffered extensive damage to utilities from liquefaction and subsidence. Temporary systems were in place at the time of the team reconnaissance, but city officials estimated it would take five to six years for total permanent restoration.
- Japan has needed to adjust to the reduced electrical generating capacity resulting from failure of the Fukushima nuclear plant. The Tokyo Electrical Power Company produced graphs showing power consumption versus available capacity, to be shown in near-real time in public messaging outlets such as screens on trains.
- Although some people who lost their homes moved in with relatives or friends in other parts of the country, Japan is faced with the need to provide temporary housing to replace many of the 100,000 homes destroyed by the

FIGURE 34 - Temporary field hospital at Minamisanriku Town (courtesy of the Israel Foreign Ministry)

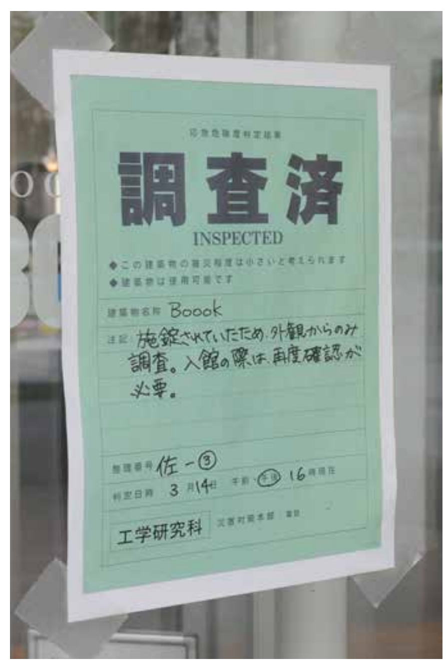


FIGURE 35 - Green placard, Tohoku University in Sendai (Swanson)

tsunamis. In Miyagi Prefecture alone, 23,000 housing units were needed. At the time of the team reconnaissance (ten weeks after the event) 15,000 units had been constructed, but only half had been turned over to occupants.

- Communities were making plans for rebuilding, but decisions on what and where to rebuild were still being made at the time of the team reconnaissance. Cash-strapped local governments needed help from an equally cash-strapped federal government to implement any rebuilding plans.
- As expected, the planning process is taking time. In Miyagi Prefecture, draft rebuilding plans are expected to be submitted to the Prefecture Assembly for review and approval by late August. One idea was to zone lowland tsunami inundation zones for commercial buildings (some of which could be built as vertical evacuation structures) and keep residential buildings in the hills above inundation areas. However, this would be challenging for communities without hills. Whatever is decided, prefecture officials expect it will take at least two years to rebuild once plans are approved.

General Observations

- Recovery efforts will need to focus on debris management and restoration of utilities.
- Quickly-available temporary housing will reduce the burden on social services and decrease the stress on victims of being in emergency shelters.
- As we make disaster response and recovery plans, we need to focus on what the recent earthquakes in Japan and New Zealand have shown: commercial and residential needs will have to be carefully balanced.

FIGURE 36 - Temporary housing, Miyagi Prefecture (Siu)

FIGURE 37 - One of three mountains of liquefaction sand in Urayasu City. Liquefaction ejecta totaled over 80,000 m^3. (Siu)

FIGURE 38 - A car graveyard with a general debris pile in the background, Miyagi Prefecture. (Siu)

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  - Mt. Tacoma Post

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