Photo: Joseph R. Maffei

Preview of PCI's Japan Earthquake Reconnaissance Team Report

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The authors formed the PCI reconnaissance team that visited selected locations (**Fig. 1**) in Japan from June 27–30, 2011, following the Tohoku earthquake of March 11, 2011.

Tohoku earthquake

At 2:46 p.m. on March 11, 2011, a magnitude 9.0 earthquake occurred near the east coast of Honshu, the main island of Japan.[1] This earthquake, known as the 2011 Tohoku earthquake, caused strong ground shaking throughout much of eastern Honshu and triggered tsunami waves that caused widespread damage at many locations along the northeast coast of Japan.

The epicenter of the earthquake was located at 38.297° N, 142.372° E,[1] about 70 km (44 mi) off the coast. Strong ground shaking occurred in Sendai, the major city (130 km [80 mi]) nearest the epicenter. Peak ground accelerations exceeding 2*g* were recorded at locations near the east coast of Honshu.[1] Some ground shaking–induced damage was observed even in the Tokyo metropolitan region, more than 350 km (210 mi) southwest of the epicenter;[1] however, widespread structural damage was not observed across eastern Honshu.[2]

The tsunami inundated many locations along the northeast coast of Honshu. Depending on offshore topography and distance from the epicenter, the depth of water above grade on shore varied from 1 m (3.3 ft) to 8 m (26 ft) in the coastal plain region of Natori to more than 18 m (59 ft) in the Ria coastal town of Onagawa.[3] A tsunami wave typically crests before reaching the shore, creating a bore, which can move rapidly and produce impulsive forces on structures in its path. The subsequent inundation produces high-velocity water flow around and through structures. The effects of these forces on structures were widespread in the tsunami-affected coastal regions.

Earthquake-resistant building design in Japan

The lack of widespread significant structural damage to buildings from ground motions associated with the 2011 Tohoku earthquake has been noted by other observers.[2] This result has been attributed to important revisions over the past 40 years to the Japanese national building code and related national standards. The Japanese national code, the *Building Standard Law of Japan* (BSLJ), which includes the *Building Standard Law*, the *Enforcement*

Figure 1. Locations in Japan visited by PCI's reconnaissance team.

Order of the Building Standard Law, and the *Enforcement Regulations of the Building Standard Law*,[4–6] specifies design loads, allowable stresses, and other requirements. The details of structural design are specified in standards issued by the Architectural Institute of Japan (AIJ). These AIJ standards, prepared separately for each structural material, are supplements to the BSLJ.

The 1968 Tokachi-oki earthquake caused significant damage to buildings, and a revision to the BSLJ[5] reduced the spacing of steel ties in reinforced concrete columns to 100 mm (4 in.). In 1971, a major revision of the AIJ standard for reinforced concrete[7] incorporated ultimate-strength design for shear of beams and columns, including more stringent shear reinforcement requirements. These changes are comparable to important code changes in the United States following the 1971 San Fernando earthquake in California. Post-1971 reinforced concrete structures performed much better in the 1995 Kobe earthquake than their pre-1971 counterparts, primarily because of the improved shear design of columns.[8]

The 1978 Miyagiken-oki earthquake caused significant damage to buildings and led to a 1981 revision of the BSLJ,[6] which introduced two-phase earthquake-resistant design. The first-phase design (essentially the allowable stress design from the previous BSLJ) is intended to protect a building against loss of function in ground motions expected to occur several times during its lifetime, with peak ground accelerations in the range of 0.08*g* to 0.10*g*. The second-phase design is intended to ensure safety under a ground motion expected to occur once in the lifetime of a building, with peak ground accelerations in the range of 0.3*g* to 0.4*g*. Post-1981 structures designed by the two-phase procedure performed well in the 1995 Kobe earthquake.

Current earthquake-resistant design of reinforced concrete buildings in Japan is consistent with the 1981 BSLJ[6] and the 1971 AIJ standard for reinforced concrete.[7]

Figure 2. Tension-tie precast concrete frame retrofit of Shiogama Municipal No. 2 Junior High School.

Performance of precast concrete structures

The authors noted a lack of widespread earthquake damage to buildings in the affected areas, including Sendai, where the recorded peak ground acceleration on rock exceeded 0.34*g*. The authors observed some damage to conventional reinforced concrete buildings at the Aobayama Campus of Tohoku University, which is located in a hill zone above the city of Sendai.

The authors observed the exteriors of several precast concrete structures, all of which performed well during the earthquake with no indication of significant damage. Several of these structures are discussed in the following paragraphs.

The Shiogama Municipal No. 2 Junior High School (**Fig. 2**) was retrofitted in 2010 using an external precast concrete frame braced with tension ties. The existing cast-in-place concrete building was deficient in torsional resistance to earthquake loading. The north facade had stiff shear walls, while the south facade had moment frames, creating a torsional stiffness irregularity. The tension-tie-braced precast concrete frame increased the lateral stiffness along the south facade. The pieces included precast concrete columns anchored to the foundation using type II mechanical splices, architectural medallions on top of the columns, and drop beams between the medallions post-tensioned together on-site. To enhance the rigidity of the precast concrete frame, X-bracing with steel rods covered with plastic sleeves was used in the openings. Cast-in-place concrete diaphragms (**Fig. 3**) between the existing structure and precast concrete frame were used to transfer lateral shear forces to the external precast concrete frame. No damage to this structure was observed.

Figure 3. Cast-in-place concrete diaphragm of retrofit of Shiogama Municipal No. 2 Junior High School.

Figure 4. Total–precast concrete Namagachi Lions Tower in Sendai.

Figure 5. Minor spalling at the base of the columns of Namagachi Lions Tower.

The Namagachi Lions Tower (**Fig. 4**) in Sendai is a 29-story total–precast concrete tower on a two-story, cast-in-place concrete podium. The structure was completed in 1999, and the lateral-force-resisting system consists of precast concrete moment-resisting frames. There was minor spalling near the base of three columns on the front of the building (**Fig. 5**). The only other visible damage was spalling of the underside of the slab (**Fig. 6**) at two opposite corners of the building, where two orthogonal beams that appeared to be unconnected came together. This damage did not appear to be significant, and the building appeared to have performed well.

The four-story total–precast concrete residential apartment building shown in **Fig. 7** was constructed in Natori City in 2006. The building has shear walls to provide earthquake resistance. Viewed from the exterior, the building appeared to have no structural damage or distress. Similar apartment buildings in the Kobe and Osaka area performed well in the 1995 Kobe earthquake.[8]

The final report

A full report covering all of the observations made by PCI's Japan earthquake reconnaissance team will be published in a future issue of the *PCI Journal.*

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Figure 6. Spalling of slabs at corners of Namagachi Lions Tower.

Figure 7. Three-story total–precast concrete apartment building at Natori City.

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Abstract

This preview highlights observations made by PCI's Japan earthquake reconnaissance team, which visited selected locations in Japan June 27–30, 2011, following the Tohoku earthquake of March 11, 2011. A full report covering all of the team's observations will be published in a future issue of the *PCI Journal*.

Keywords

Code, earthquake, Japan, preview, seismic, tsunami.

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