Earthquake

New Codes Provide Tools, But We Need to Ensure Compliance

By James A. Carlson, P.E.; Robert E. Simmons, P.E., Member ASHRAE

Devastating earthquakes have occurred all over the world in the last year. On Jan. 12, 2010, a 7.0 earthquake hit Haiti, leveling much of Port-au-Prince. An 8.8 in Chile toppled entire buildings on Feb. 27, 2010. The city of Christchurch, New Zealand, was rocked by a 7.0 on Sept. 4, 2010, followed by a strong targeted 6.3 on Feb. 22, 2011. The one–two punch destroyed hundreds of buildings.

And, most recently, a 9.0 earthquake with tsunami shocked Japan on March 11. Japan’s northern shore experienced total devastation and caused a state of emergency for four nuclear reactors. In the wake of recent tragedies, it is natural to wonder just how vulnerable we are here at home. We will take a thoughtful look at the state of preparedness of our buildings in the U.S. today.

Fukushima Daiichi Nuclear Complex

The ongoing issues at the Fukushima Daiichi Nuclear Complex started with a 9.0 earthquake 81 miles offshore. There were three of six nuclear cores operating and three cores empty for refueling. In a refueling mode, the nuclear fuel bundles are temporarily moved to a spent fuel pool. Japanese nuclear power plants automatically shut down when there is an earthquake. And as planned, the three operating nuclear cores shut down on March 11, and they started shut-down cooling. The offsite power did not fail until the tsunami hit approximately one hour after the earthquake. Generators may have started during the tsunami, but shut down relatively quickly because the tsunami wiped out the emergency generator’s aboveground fuel tanks.

This condition of no power is considered a “blackout.” Nuclear power plants typically have four to eight hours of battery life to operate controls (not pumps). Steam-driven feed water pumps use

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steam to pump water and cool the nuclear cores with an automatic start feature. Japanese plants rely heavily on motor operated valves (MOVs) that take power to operate and allow the steam-driven pump lineup to pump water. However, the tsunami damaged other equipment that cools the reactor cores.

The situation is dire. No generator, no power, no phones, no cell phones, no cooling capability, and you need to cool the core. The infrastructure that backs up the operators is gone. It is assumed that Unit 2 had issues with getting an emergency steam-driven pump running. At this point, it will take about 15 minutes to uncover the core and start melting the fuel. Unit 1 and Unit 3 must have successfully started their steam-driven pumps, which delayed this problem for one or two days. A core meltdown was inevitable in Units 1 and 3 because the steam-driven pumps provided flow, but there was no cooling capability due to the tsunami, and the steam-driven pumps will lose their suction over time.

Operators determined that the diesel-driven fire water pumps were operable. These pumps were staged to pump water into the core. But the pressure in the core starts around 2,000 psi and goes up as the coolant inventory turns to steam. This steam must be vented to below 250 to 500 psi before the fire pumps can put seawater into the core. Steam is vented as fast as possible to lower the pressure. With the steam, hydrogen is created from the fuel as it is uncovered, where fuel cladding oxidizes rapidly absorbing oxygen from the water and releases hydrogen. Hydrogen concentration grows in the secondary containment and explodes. This is still necessary to reduce the pressure in the core as fast as possible to get the fire pumps running and cool the reactor cores, thus limiting the radiological issues.

Fuel in the spent fuel pool requires constant cooling. The heat up rate is approximately 4 degrees per hour. So it takes about two to four days to start boiling and uncover the fuel bundles in the spent fuel pool. This is about right as in the case of Unit 4. The fire in Unit 4’s spent fuel pool area was not fuel from the reactor core. Speculation of a leak is possible, but not likely. It is not clear if the diesel fire pumps can be lined up to provide water to the spent fuel pools or if the damage from the hydrogen explosions or fire restricted cooling the spent fuel pool. With no shielding, the radiation dose in these areas is extremely high. There has been a lot of speculation and misinformation about the events. It is clear that the workers have been doing everything possible given the conditions of the plant after the tsunami.

**U.S Nuclear Facilities**

U.S. nuclear power plants follow the Code of Federal Regulations (CFRs). CFRs are law and must be followed. Failure to comply with a CFR can result in a finding, violation, fine, or criminal prosecution. This law also applies to an “Appendix B Supplier” that provides equipment to the nuclear power industry. The CFRs associated with earthquake protection of a nuclear power plant are 10CFR50 Appendix A, Criterion 2 and 10CFR100 Appendix A.

- 10CFR50 Appendix A, Criterion 2: Design bases for protection against natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions.
- 10CFR100, Appendix A: (2) Determination of Operating Basis Earthquake. The Operating Basis Earthquake shall be specified by the applicant after considering the seismology and geology of the region surrounding the site. If vibratory ground motion exceeding that of the Operating Basis Earthquake occurs, shutdown of the nuclear power plant will be required. Prior to resuming operations, the licensee will be required to demonstrate to the Commission that no functional damage has occurred to those features necessary for continued operation without undue risk to the health and safety of the public.

Other requirements were issued by the NRC for earthquake safety of the nuclear fleet.

- NUREG-1030, Seismic Qualification of Equipment in Operating Nuclear Power Plants.
U.S. Building Code Development

There are new lessons learned with each earthquake. In 1989, during a World Series Baseball telecast, the 6.9 Loma Prieta earthquake struck 60 miles south of San Francisco, resulting in about $10 billion in damage. In 1994, the 6.6 Northridge earthquake struck about 20 miles outside Los Angeles, resulting in more than $80 billion in damages. Three important lessons learned from these two earthquakes were: 1) attention to details of construction and code compliance was important; 2) equipment did not perform well; and 3) disaster planning must include life safety and economic mitigation.

In an effort to reduce the impact of future earthquakes, the federal government looked to the National Earthquake Hazard Reduction Program (NEHRP), which consisted of:

- Federal Emergency Management Agency (FEMA);
- National Institute of Standards & Technology (NIST);
- National Science Foundation (NSF); and
- United States Geological Survey (USGS).

NEHRP developed new prescriptive code provisions to reduce potential damage caused by an earthquake. These new provisions were the bases for the then new International Building Code (IBC), IBC 2000. FEMA implemented a new public assistance policy in 2000. The Response and Recovery Directorate: 9527.1 required all construction of new buildings to include life safety and economic mitigation. The IBC specifically addresses these inspections.

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- Design for earthquakes is no longer just in California. Figure 1 (Page 45) is a map of Maximum Credible Earthquake acceleration for the United States based on the IBC maps. Projects located in a colored region must consider earthquake loads.

- More sophisticated formulas were developed to calculate the anticipated loads on the structure and components.

- Requirements for seismic special inspection of nonstructural equipment at the job site and equipment certification were introduced.

**Design Requirements for Commercial/Industrial Buildings**

The requirements for design are comprehensively described in the International Building Code (IBC) and Minimum Design Loads for Buildings and Other Structures (ASCE 7). This activity is well understood. ASHRAE has a chapter in ASHRAE Handbook—HVAC Applications that addresses seismic design and has published a seismic design guide.

- NUREG-1211, Regulatory Analysis for Resolution in Operating Nuclear Power Plants.
- Generic Letter No. 87-03: Verification of Seismic Adequacy.
- Unresolved Safety Issue (USIA-46) addresses the seismic equipment qualification in nuclear facilities. Issued by the NRC in 1980.

**IVB Special Inspections for Commercial/Industrial Buildings**

IVB special inspection programs are being implemented for nonstructural components in active construction projects. These inspection programs are accredited and should be comprehensive. Inspections should be conducted for seismic restraint devices (force-resisting systems), anchorage to the building structure, and certification validation with conformance of certification restrictions available in public reports. The IBC specifically addresses these inspections.

- The IBC Section 1704 describes requirements for special inspectors that include demonstration of competence, records, reporting, and resolution of discrepancies.

- IBC Section 1705.1 and 1707.7 itemizes the components and systems that require special inspections that include seismic-force-resisting systems and designated seismic systems. Itemized systems include piping and ductwork containing flammable, hazardous, or toxic materials. Other systems include electrical equipment and vibration-isolated equipment requirements.

**Certification of Equipment**

The IBC has extensive requirements for certification of equipment that was introduced in the IBC 2000 and further refined in subsequent revisions.

- IBC Section 1703.5 identifies requirements for certification by an approved agency with in-plant inspections and labeling.

Note: Some listing services for seismically qualified equipment are not complying with the in-plant inspections by an inspector knowledgeable to recognize the critical characteristics for seismic applications.

- IBC Section 1708.1 and 1708.4 define the testing and qualification of force-resisting systems, designed seismic systems subject to provisions in ASCE 7 Section 13.2.2, and certification of compliance for components defined in ASCE 7 Section 13.2.1 based on analysis, testing or experience data.

Note: Certification is required for all equipment in seismic areas identified by ASCE 7. Equipment and force-resisting systems require certification per 13.2.1. Certification criterion is more stringent for those components that need to operate after a seismic event per 13.2.2. Some components require testing. Experienced qualification agencies should be consulted.

- 1708.4 further requires a submission of a certificate of compliance for review and acceptance by the registered design professional responsible and for approval by the building official.

Certification is simply a statement by a manufacturer that its equipment meets the requirements of an industry adopted standard or compliance to a building code section. While any manufacturer can create a certificate, it is the basis of the certification that defines its credibility. Table 1 provides an
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explanation of the hierarchy of certification supporting documentation and applies a level of credibility to the equipment qualification/certification process.

How Are We Doing?

The 1971 San Fernando earthquake and previous earthquakes revealed inadequacies that resulted in advancement of earthquake engineering and code changes. This era of building construction fared better in subsequent earthquakes. Although the emphasis is on saving lives and not necessarily on lowering levels of economic loss, the earthquake showed that investments in building codes and good engineering practice did prove effective.

Even with improved building codes since 1971, there has been huge economic loss and building damage from more recent earthquakes. The 1994 Northridge Earthquake was the most damaging earthquake and produced the largest earthquake insurance loss to date. Investigations on the performance of buildings spawned new knowledge on vulnerability based on empirical studies of damage and loss. There was widespread welding failures at the beam-column connections of steel movement resisting frame structures and the widespread failure of non-structural components (MEP equipment). Some reports estimated 40% to 80% of earthquake damages were associated with the failures of non-structural components.

Lessons learned from past earthquakes were captured in the newer building codes. Ground motion data (earthquake maps) were increased and new detailing requirements, special inspection, quality procedures, and equipment seismic certification were added to the IBC. Enforcement and implementation of these new requirements has lagged, but have recently increased in compulsory.

The U.S. Embassy in Haiti was built to new building codes and performed well during the 2010 earthquake. The two-year-old embassy in Port-au-Prince sustained very little damage, including its mechanical spaces. The facilities manager attributed success to the attention to details. This facility demonstrates how effective site inspection to ensure code compliance results in successful earthquake resistance. Attention to detail is essential.

Special inspections and certification of product seismic compliance are perhaps the most overlooked tools of the code that help reduce the vulnerability of our buildings. To ensure compliance, many building officials are now beginning to require accredited seismic inspectors for jobs.

Are We Ready?

We are more prepared now than ever before. Earthquake engineering has advanced considerably in the last decade. There has been a tremendous effort to improve the IBC with better code language, clarification of confusing text, more comprehensive requirements, and development of commentary. New construction in full compliance with the IBC will reduce the risk for future earthquakes. The infrastructure for designing new construction, performing special inspections, and certifying equipment is now available by competent services. The local building officials are growing in their understanding of the IBC seismic requirements. Local, state, and federal response are continually improving with large scale exercises.

Past construction is a major risk for future earthquakes. In many areas, the maximum credible earthquake maps were ignored. Building codes were predominantly addressed in the building structure but ignored for nonstructural components, specifically the HVAC and electrical systems. Areas for improvement in the future include focus on comprehensive special inspection programs, certification of equipment using the highest level of credibility, and revisiting older facilities.

<table>
<thead>
<tr>
<th>Qualification/Certification Level</th>
<th>Basis of Evaluation</th>
<th>Explanation of Basis</th>
<th>Credibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Self Certification</td>
<td>Manufacturer Provides Certificate of Compliance Without Independent Verification</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>2 Testing or Analysis</td>
<td>Manufacturer Qualifies Products by Nonaccredited Agency Or by Other Means Such as Analysis</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>3 Testing at Accredited Laboratory</td>
<td>Testing is Performed Under a Test Program that Meets ISO 17025 and the Agency is Accredited</td>
<td></td>
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<tr>
<td>4 Certified Qualification Agency</td>
<td>Independent Agency Ensure Product is Qualified to Industry Standards and Has Quality Program</td>
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<td></td>
</tr>
<tr>
<td>5 QA Record Verification</td>
<td>Independent Agency Reviews Qualification and Performs an In-Plant Inspection by an Accredited Inspection Body (IB) to Minimum Quality Criteria</td>
<td></td>
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</tr>
<tr>
<td>6 Factory Inspection by Accredited Inspection Body (IB)</td>
<td>Listing Service Verifies Qualification to Industry Adopted Standards and Performs Accredited IB In-Plant Inspection For an ISO 9001 Quality Program</td>
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Table 1: Qualification/certification level and resulting credibility based on quality elements.

- **Qualified By Test or Analysis**
- **Certified**
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