Understanding the requirements for IBC seismic-compliant power systems

By Allan Bliemeister and Michael Little

It is important for standby power systems to function after a catastrophic event, such as a hurricane, tornado, earthquake, or even a terrorist attack. In particular, critical-needs facilities—such as hospitals, police and fire stations, emergency shelters, power plants, airports, government facilities, and communications and operations centers—require standby power systems that have been specifically engineered to withstand physical shocks and multi-axis accelerations typical of these disruptive occurrences.

Building standards have evolved for decades in the United States, along with codes for electrical and mechanical systems. The latest edition of building standards is embodied in the International Building Code (IBC 2000, 2003 and 2006), which sets requirements for structures and ancillary systems, including standby power systems. The purpose of this paper is to familiarize building owners and power system specifiers with the seismic compliance provisions of the IBC and how they apply to the design and installation of standby power systems in critical-needs facilities.

International Building Code

In 2000, the International Code Council (ICC) issued its first version of the IBC. While most of the IBC deals with life-safety and fire protection of buildings and structures, it also addresses seismic design requirements for both buildings and systems attached to buildings—such as electrical equipment. The IBC has been updated every three years, and the 2006 edition references standards from a variety of sources, such as the design requirements originally promulgated by the American Society of Civil Engineers (ASCE 7-05) in its *Minimum Design Loads for Buildings and Other Structures.*

While the IBC has an “international” label, currently it only refers to building standards in the United States. All state and many local authorities have adopted one version of the IBC, either the 2000, 2003, or 2006 edition. Most states have adopted the code at the

state level, while other states have adopted versions of the code at the county level. While the IBC is not a government mandate, its adoption has been encouraged—and in some cases required—to ensure funding coverage by the Federal Emergency Management Agency (FEMA). California was the last state to adopt the code and has adopted the 2006 version. There is no requirement for a state to adopt the latest version of the code, though at this time 25 states have adopted the 2006 version.

Generally speaking, the requirements for emergency power systems are the same regardless of which version of the code a state has adopted. In all versions of the code, critical equipment—including emergency power systems—must be certified to comply with the same seismic standards as the building in which they are located. In general, any critical-needs facility must be certified to the seismic requirements of its location in accordance with the U.S. Geologic Survey (USGS) data for ground accelerations. Figure 1 illustrates the areas in the U.S. with the greatest risk of earthquakes.

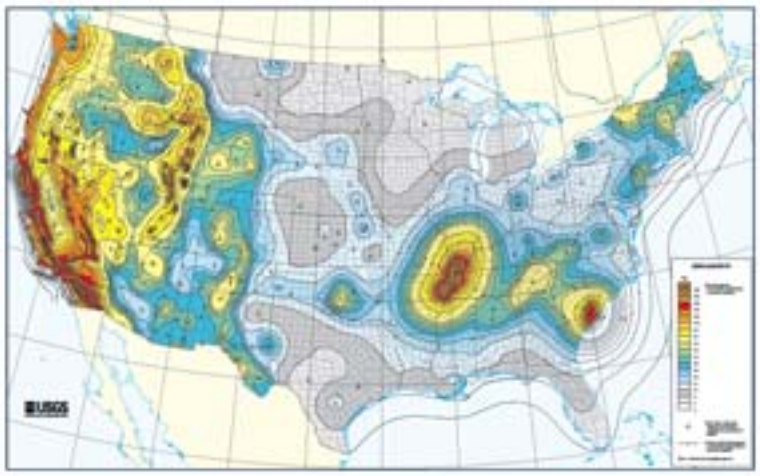

Figure 1: Seismic hazard map for the conterminous United States.

While seismic forces are usually associated with earthquakes, the same types of multi-axis accelerations and forces can occur during tornadoes, hurricanes, and explosions. The IBC, and its references to ASCE 7, establishes design standards for power systems to survive a seismic event. When certifying equipment by shake-table testing, the procedures are clarified by the ICC through ICC-ES 156 (*Acceptance Criteria for Seismic*

Qualification by Shake-Table Testing of Nonstructural Components and Systems). In addition to shake-table testing, manufacturers can qualify systems through mathematical modeling using computer programs and accepted engineering standards that are outlined in ASCE 7.

Force fundamentals

A typical emergency power system consists of a base, engine, alternator, fuel tank, transfer switch, controls, and associated engine cooling and ventilating systems. While the genset is itself a rugged piece of equipment, the more vulnerable and often overlooked parts of the system include the generator base connections, the fuel tank, and other connections, such as exhaust and wiring.

During a seismic or similar event, the Earth and man-made structures not only move, but oscillate, often in multiple axes. This movement is often violent and subjects structures and other systems to rapid acceleration and deceleration at oscillation frequencies predominantly less than 5 Hz (cycles per second). Every structure or object that is free to move in space has a natural frequency at which the object will continue to oscillate once it is set into motion, unless there are forces to damp its movement. For example, consider the simple spring and weight in Figure 2. Once it is set in motion, it will continue to oscillate at its natural frequency until friction forces damp its movement and use up the energy. For structures, movement is damped by sliding friction in structural joints, hysteresis losses, or by the type of soil on which the structure is built.

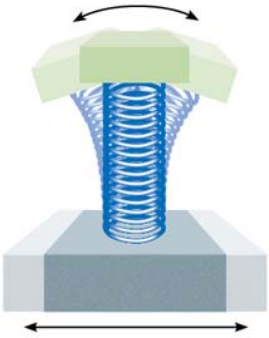

Figure 2: A model of a simple resonant system.

What's more, if the natural frequency of a structure is equal to or close to the frequency of the seismic input, and there is not sufficient damping, forces on the structure will tend to multiply, often with disastrous results. This is called transmissibility (see Figure 3). However, when the natural frequency of the structure or system is significantly below the input frequency of seismic force, little energy is transferred to the structure/system and minimal or no damage occurs. Similarly, when the natural frequency of the structure is significantly above the input frequency of the seismic force, the dynamics of the system result in the structure merely following the input force oscillation frequency without amplifying the seismic forces.

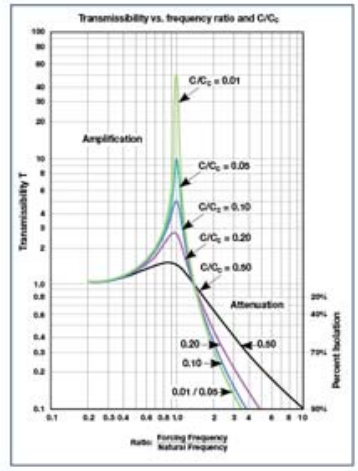

Figure 3: Transmissibility and multiples of resonant frequency

Seismic certification for power systems

The IBC has established design standards for structures and systems to withstand a seismic event. The likelihood and severity of a seismic event anywhere in the United States is shown in Figure 1; however, Figure 4 shows where electrical generating systems must certify that they will remain online and functional after a seismic event. In general, those areas in green represent areas of the country where critical facilities require certification. Those in blue or purple may require certification in *all* building types. Within these regions, specific site conditions such as soil type or the vertical location within a building can have a large effect on the seismic response of a structure and its

contents.

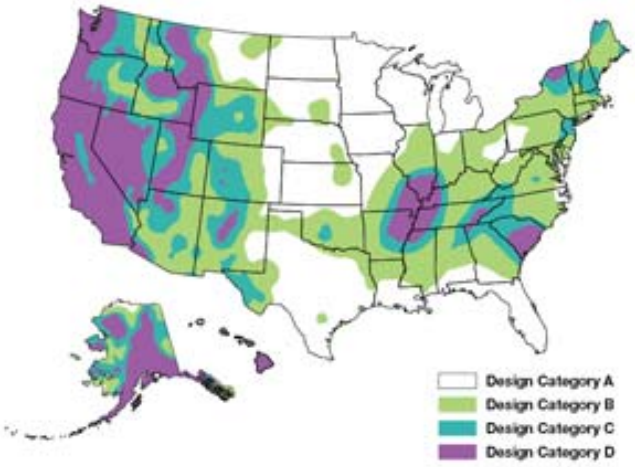

Figure 4: Map of areas that require seismically certified power systems.

Compliance with the seismic provisions of IBC requires either shake-table testing in three orthogonal directions or mathematical modeling incorporating techniques, such as finite element analysis, to establish whether the product can withstand the required amount of seismic activity. In practice, power system manufacturers use a combination of shake-table testing and finite element analysis to qualify their products. Tests are performed at a nationally recognized test facility while analysis is certified by an independent approval agency.

Numerous facilities perform shake-table testing. These tests can verify the integrity of a power system design, and the results of both successful tests and failures can be used to improve design. It is not always necessary to test every individual component. For example, several transfer switch models of similar construction can be grouped together, with only the worst-case configuration (mass, size, center of gravity) undergoing shake testing.

While it is possible to shake-table test gensets larger than 300kW, this is typically not done because of extremely high costs and a lengthy wait to access the few test facilities with sufficient capacity. While diesel engines and alternators are robust machines that

are normally immune to most seismic forces, mounting feet, skids, radiator supports, fuel tanks, ATS enclosures, and the like require engineering analysis to determine compliance to the IBC. Additionally, it is generally agreed upon that components of a genset, such as electronic controls and junction boxes, cannot be mathematically modeled to prove they can withstand the forces of an earthquake. These components need to be evaluated separately from the rest of the genset through shake-table testing. During that testing, the fixture design of the table needs to replicate the way those components are attached to the genset skid.

Rating parameters determine seismic survivability

Five critical parameters are used to certify and establish the seismic rating level of equipment. These are typically listed in the certified equipment's specification sheet so that specifying engineers can use the data to verify that the equipment is rated for a particular site. Ratings apply to gensets, sound-attenuated enclosures, fuel tanks, and transfer switches.

S_{DS} – IBC specifies a "design spectral response acceleration" factor (S_{DS}) that represents the base, unmodified acceleration forces used to design the system for the specific installation site. Thus, S_{DS} is a key parameter in designing a power system to resist seismic forces at a given site. S_{DS} ranges from 0 to 2.46. Below an S_{DS} of 0.167, seismic certification is not required.

I_p – The IBC incorporates an "importance" factor used to specify whether the power system is in a critical or noncritical application. A rating of 1.5 designates a critical system and 1.0 designates noncritical. The component importance factor (I_p) is determined to be 1.5 if any of the following conditions apply:

1. The component is required to function for life-safety purposes after an earthquake, including fire protection sprinkler systems.

2. The component contains hazardous materials.

3. The component is in or attached to an Occupancy Category IV structure, and it is needed for continued operation of the facility or its failure could impair the continued operation of the facility. All other components shall be assigned a component importance factor with I_p equal to 1.0.

a_p – The "component amplification" factor ranges from 1.0 to 2.5 depending on the specific component in consideration. Values are defined in the IBC and are dependent on the components' relative stiffness.

R_p – The "component response" factor ranges from 1.0 to 12.0, depending on the specific component in consideration. Values are defined in the IBC and are dependent on the components' relative damping.

z/h – Because equipment mounted on an upper floor of a building will experience greater forces than equipment mounted at ground level, the location of a power system within a building must be taken into consideration. This factor is expressed as a ratio of the power system installation height in the building (z) to the height of the building (h). Its value ranges from 0 at ground level to 1 for rooftop installations.

Installation and mounting considerations

Of equal importance to the design of the power system are installation and mounting to ensure that the components remain connected to the structure and to their foundations throughout a seismic event.

Specific site parameters need to be addressed to ensure that a power system complies with IBC. Geographic location, soil profiles, and installations below-ground, at ground-level, or on rooftops all play a role in determining a system's mounting requirements and IBC compliance.

Power system manufacturers supply installers with critical information about bases, anchor requirements and mounting considerations for seismic installations, but the installing contractor is responsible for proper installation of all anchors and mounting hardware. For example, anchor locations, size, and type are specified on the installation drawing. Mounting requirements, such as anchor brand, type, embedment depth, edge spacing, anchor spacing, concrete strength, and wall bracing, must be approved by the structural engineer of record, who is responsible for confirming that the system will withstand the specified seismic loads.

Structural walls, structural floors, and pads also must be seismically designed and approved by the structural engineer of record. The installing contractor is responsible for proper installation of all electrical wiring, piping, ducts, and other connections to the equipment. It is necessary that these components remain intact and functional and do not inhibit the functionality of the genset after a seismic event.

Mounting and misnomers

Mounting can be either direct or through anti-vibration isolators. In direct mounting, the product is fastened directly to a concrete pad. All sets with integral rubber anti-vibration mounts also should be direct-mounted. There is no need for additional isolators unless acousticians for the project require a lower vibration transmissibility into the structure. Figure 5 shows direct mounting. Be aware that the use of so-called “seismic isolators” between the tank or skid and concrete *will not* protect the product during a seismic event. In fact, the use of additional isolators allows the product to move more and is actually counterproductive during a seismic event.

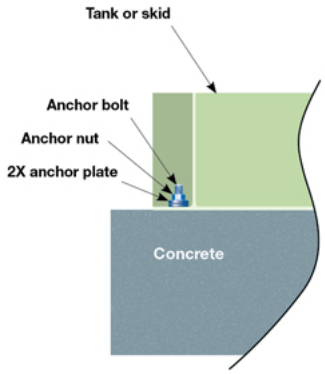

Figure 5: Example of direct mounting to a foundation

In the second mounting method, the product is mounted on seismically designed isolators, but the purpose of the seismic isolators is only effective in damping vibrations that might be transmitted from the genset to the foundation during normal operation. They are only called “seismic isolators” because they carry ratings for seismic applications and are designed to survive a seismic event. Additionally, they typically incorporate internal snubbing to reduce excessive motion of the equipment. However, they should always be mounted as the prints specify.

Conclusion

When standby or emergency power system must survive a seismic event or other disaster, seismically rated power systems are available for earthquake-prone areas of the United States. These have been designed in accordance with well-understood engineering principles and have undergone finite element analysis and/or shake-table testing by independent testing organizations. Power system specifiers can be assured that seismically certified systems will survive seismic events, as long as the systems have been installed according to the manufacturer’s specifications.

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Kohler Power Systems is a division of Kohler Co., and is a worldwide supplier of complete power systems, including generators (residential, industrial, mobile, and marine), automatic transfer switches, switchgear, monitoring controls, and accessories for emergency, prime power, and energy-management applications. Founded in 1873

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