Understanding the Requirements for

IBC SEISMIC-COMPLIANT POWER SYSTEMS

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INTRODUCTION

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 multiaxis 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 (IBS), 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 is updated every three years, and 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. 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 Administration (FEMA).

Generally speaking, the requirements for emergency power systems are the same regardless of which version of the code a state has adopted.

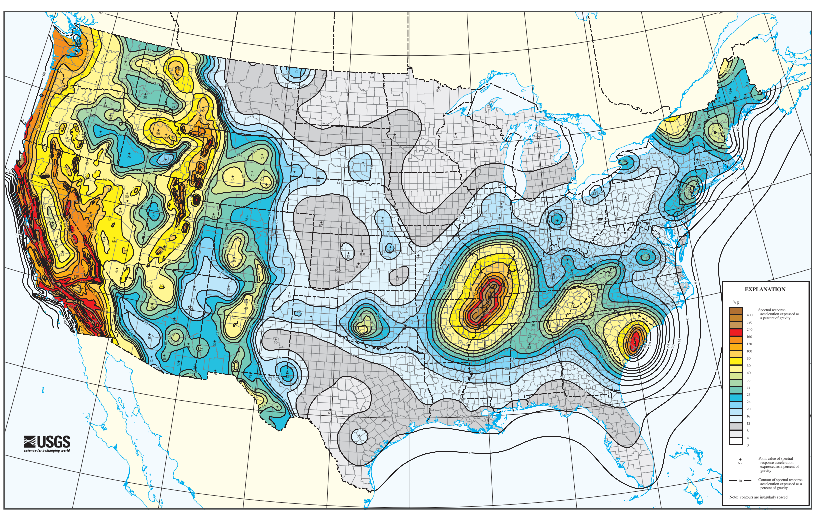

Figure 1: Seismic hazard map for the conterminous United States.

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.

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 generator 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 dampen its movement.

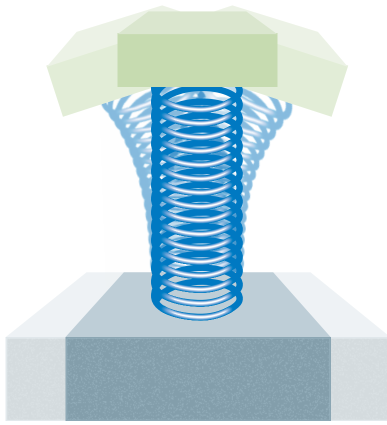

Figure 2: A Model of a Simple Resonant System.

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 dampen 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.

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.

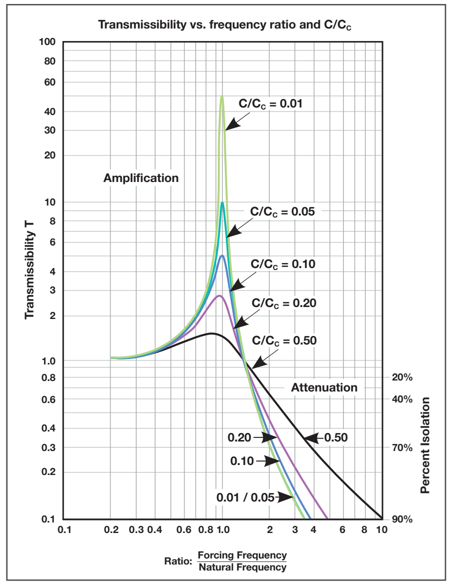

Figure 3: Transmissibility and Multiples of Resonant Frequency

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 U.S. is shown in (*Figure 1*); however, (*Figure 4*) shows where in the U.S. electrical generating systems require certification that they will remain online and functional after a seismic event. In general, those areas in dark blue/black (class D) represent areas of the country where critical facilities require certification. Those in blue or blue/black (class C and D) 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.

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.

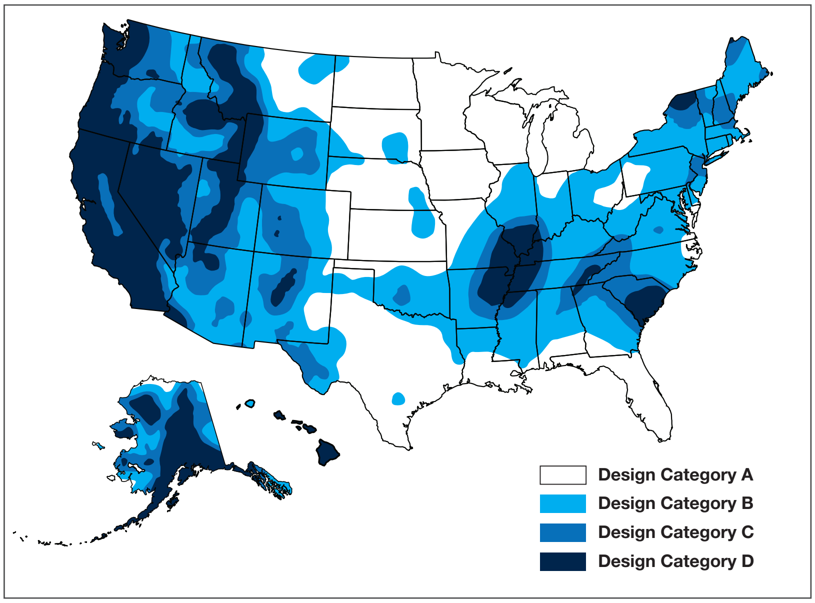

Figure 4: Map of Areas That Require Seismically Certified Power Systems.

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 generators larger than 300 kW, 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 generator, 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 generator through shake-table testing. During that testing, the fixture design of the table needs to replicate the way those components are attached to the generator 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 generator, sound-attenuated enclosures, fuel tanks and transfer switches.

SDS – IBC specifies a "design spectral response acceleration" factor, SDS, that represents the base, unmodified acceleration forces used to design the system for the specific installation site. Thus, SDS is a key parameter in designing a power system to resist seismic forces at a given site. SDS ranges from 0 to 2.46. Below an SDS 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, Ip, 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 Ip 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 – Since 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 must also 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 generator after a seismic event.

1708.5 of the IBC: Seismic qualification of the mechanical and electrical equipment

The registered design professional in responsible charge shall state the applicable seismic qualification requirements for designated seismic systems on the construction documents. Each manufacturer of designated seismic system components shall test or analyze the component and its mounting system or anchorage and submit a certificate of compliance for review and acceptance by the registered design professional in responsible charge for the design of the designated seismic system and for approval by the building official. Qualification shall be by an actual test on a shake table, by three-dimensional shock tests, by an analytical method using dynamic characteristics and forces, by the use of experience data (i.e., historical data demonstrating acceptable seismic performance) or by a more rigorous analysis providing for equivalent safety.

GENERAL SEISMIC INSTALLATION NOTES

- Anchors used for seismic installation must be designed and rated to resist seismic loading in accordance with ACI (American Concrete Institute) 355.2-04 and documented in a report by a reputable testing agency (i.e., The Evaluation Service Report issued by the International Code Council).
- Anchors must be installed as specified on the product ADV print.
- Anchors must be installed in minimum 4000 psi compressive-strength normal-weight concrete. Concrete aggregate must comply with ASTM (American Society for Testing and Materials) C33. Installation in structural lightweight concrete is not permitted unless otherwise approved by the structural engineer of record.
- Anchors must be installed to the required torque specified by the anchor manufacturer to obtain maximum loading.
- Anchors must be installed with spacing and edge distance required to obtain maximum load unless otherwise approved by the structural engineer of record.
- Wide washers must be installed at each anchor location between the anchor head and equipment for tension load distribution. See the applicable installation or dimension drawing for specific anchor information and washer dimensions.
- Equipment installed on a housekeeping pad requires the housekeeping pad thickness to be at least 1.5 times the anchor embedment depth.
- All housekeeping pads must be seismically designed and dowelled or cast into the building structure as approved by the structural engineer of record. Rebar reinforcing in the housekeeping pad is required for all installations.
- Rebar reinforcement in concrete must be designed in accordance with ACI 318-05.
- Wall-mounted equipment must be installed to a rebar-reinforced structural concrete wall that is seismically designed and approved by the engineer of record to resist the added seismic loads from components being anchored to the wall. When installing, rebar interference must be considered.
- Floor-mounted equipment (with or without a housekeeping pad) must be installed to a rebar-reinforced structural concrete floor that is seismically designed and approved by the engineer of record to resist the added seismic loads from components being anchored to the floor. When installing, rebar interference must be considered.

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 antivibration mounts should also 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.

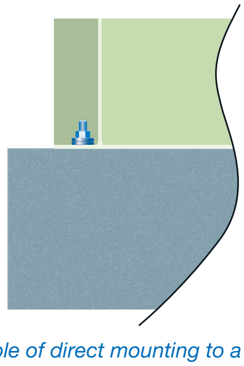

Figure 5: Example of direct mounting to a foundation.

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.

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 generator 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, always mount the product as the prints specify.

CONCLUSION

For critical applications in which it is imperative for the standby or emergency power system to survive a seismic event or other disaster, seismically rated power systems are available for earthquake-prone areas of the U.S. 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.

ABOUT THE AUTHORS

Mike Little is a Principal Engineer with Kohler Power Systems. He holds a bachelor's degree in mechanical engineering from Marquette University and has been with Kohler in the Automatic Transfer Switches and Controls engineering groups since 2005. He has 15 years prior experience designing and developing commercial and industrial controls (contactors, overload relays, soft-starters and switches).

A global force in power solutions since 1920, Kohler is committed to reliable, intelligent products; purposeful engineering and responsive after-sale support. Kohler's acquisition of SDMO in 2005 created one of the world's largest manufacturers of industrial generators. The companies have a combined 150 years experience in industrial power and now benefit from global R&D, manufacturing, sales, service and distribution integration.

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