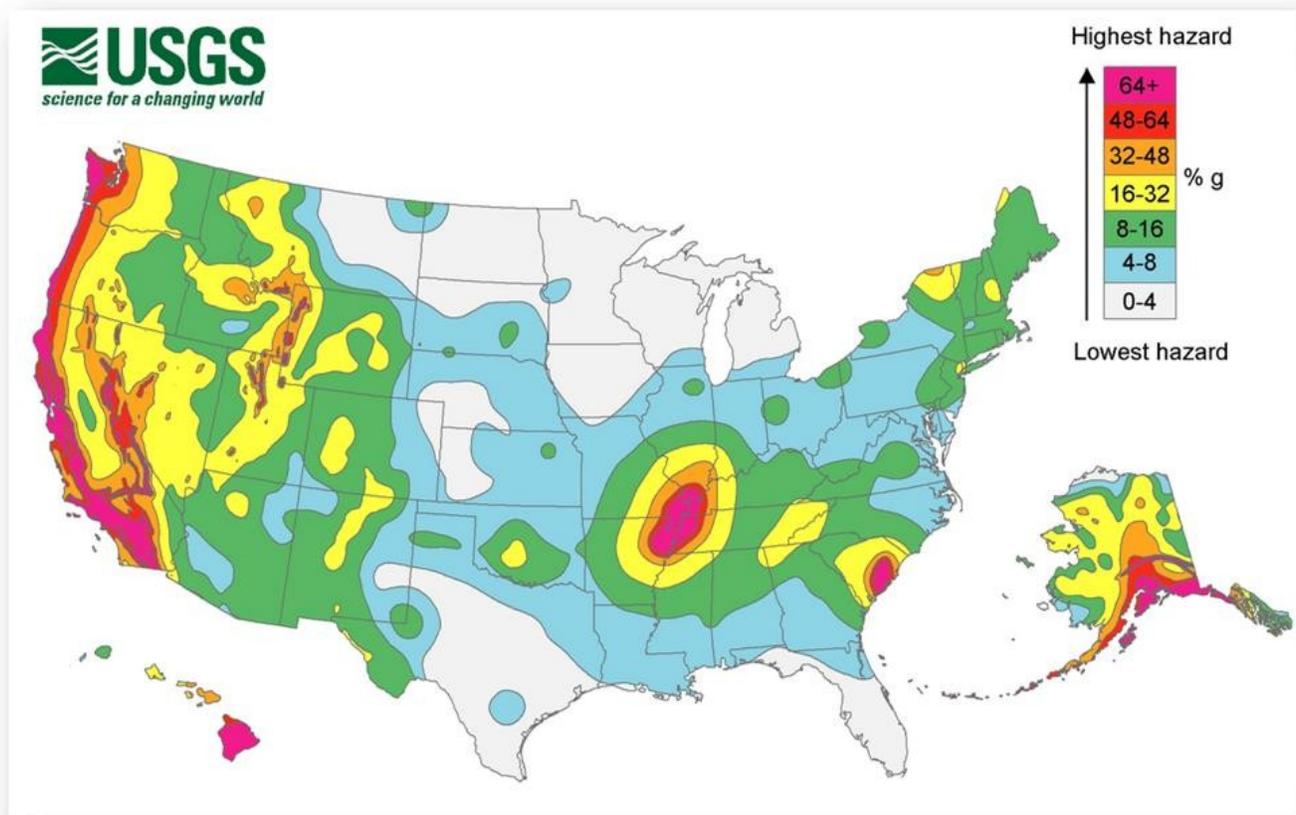


July, 2014

## Transformer Design Seismic Withstand Considerations

Over the years, there has been an ever increasing recognition of the importance of minimizing the negative impact that a seismic event could impose on transformer reliability. The United States is riddled with seismic fault areas with varying degrees of severity. The map below provides a visual.



This topic paper is timely since the U.S. Geological Survey released new earthquake hazard maps for the nation on July 17, 2014, expanding seismic risk areas along the East Coast and in California, among other areas. Following is the USGS web site on the subject: <http://pubs.usgs.gov/of/2014/1091/>

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Following is the Associated Press release on the subject.

*"The U.S. Geological Survey on Thursday updated its national seismic hazard maps for the first time since 2008, taking into account research from the devastating 2011 earthquake and tsunami off the Japanese coast and the surprise 2011 Virginia temblor.*

*The maps are used for building codes and insurance purposes and they calculate just how much shaking an area probably will have in the biggest quake likely over a building's lifetime.*

*The highest risk places have a 2 percent chance of experiencing "very intense shaking" over a 50-year lifespan, USGS project chief Mark Petersen said. Those with lower hazard ratings would experience less intense swaying measured in gravitational force.*

*"These maps are refining our views of what the actual shaking is," Petersen said. "Almost any place in the United States can have an earthquake."*

*Parts of 16 states have the highest risk for earthquakes: Alaska, Hawaii, California, Oregon, Washington, Nevada, Utah, Idaho, Montana, Wyoming, Missouri, Arkansas, Tennessee, Illinois, Kentucky and South Carolina. With the update, new high-risk areas were added to some of those states.*

*Also, Colorado and Oklahoma saw increased risk in some parts and moved up to the second of the seven hazard classifications, he said.*

*There are major faults and quake hazards along the entire west coast, with an increased concern in the Cascadia region around Oregon. Southern Alaska, the big island of Hawaii, the Missouri-Tennessee-Arkansas-Illinois New Madrid fault area and Charleston round out the biggest hazard areas.*

*But shaking hazards are nearly everywhere.*

*Much of the country west of the Rockies, along with parts of Oklahoma and Tennessee and sections of central Arkansas, northern Alabama, Georgia, South Carolina, Indiana, Illinois, Ohio, Michigan, Virginia, New York and New England saw an increase in shaking hazards for small buildings like houses.*

*At the same time much of North Carolina, the northern tip of South Carolina, patches of Texas, New Mexico, Oregon, Utah, Nebraska, Arkansas, Kentucky, Tennessee, Ohio, Pennsylvania and New York saw hazard levels lower slightly. And using a different type risk analysis for tall buildings the shaking hazard in New York City dropped ever so slightly, Petersen said.*

*Petersen said the maps sidestep the issue of earthquakes created by injections of wastewater from oil and gas drilling in Oklahoma and other states, saying those extra quakes weren't included in the analysis. So far this year, nearly 250 small to medium quakes have hit Oklahoma.*

*Much of the research and cataloging was done by the nuclear industry in response to the quake and tsunami that crippled Japan's Fukushima reactor. And researchers at the University of California, Berkeley came up with a better model to simulate shaking, Petersen said.*

*"I see it as a big improvement," said Cornell University seismologist Rowena Lohman. "They brought in more information."* “

Pacific Crest Transformers prepares customer proposals per supplied specifications. In many cases, references to a variety of standards are made within the specs that may affect the manner in which the transformer design is modified to accommodate seismic withstand capabilities.

The standards and approvals addressing seismic withstand requirements include:

IBC (International Building Code)

Provides minimum standards to insure the public safety, health and welfare insofar as they are affected by building construction and to secure safety to

life and property from all hazards incident to the occupancy of buildings, structures or premises.

#### UBC (Uniform Building Code)

The UBC was first published in 1927 by the International Council of Building Officials, which was based in Whittier, California. Updated editions of the code were published approximately every three years until its final version in 1997. The UBC was replaced in 2000 by the IBC (above).

#### IEC (International Electrotechnical Commission)

The IEC is a non-profit, non-governmental international standards organization that publishes International Standards for all electrical, electronic and related products. IEC standards cover a vast range of technologies from power generation, transmission and distribution as well as many others. The IEC also manages three global conformity assessment systems that certify whether equipment, system or components conform to its International Standards.

#### IEEE 693 (Institute of Electrical and Electronics Engineers)

Seismic design recommendations for substations, including qualification of each equipment type, are discussed. Design recommendations consist of seismic criteria, qualification methods and levels, structural capacities, performance requirements for equipment operation, installation methods, and documentation.

#### ICC-ES AC 156 (International Code Council Evaluation Services Acceptance Criteria)

Defines the specific seismic testing procedure. The criterion specifies a specific input motion to which nonstructural components are to be subjected. Input motions are required to be 30 seconds in length with a stationary input motion over a broad range of frequencies. This input motion requirement is derived based on ASCE (American Society of Civil Engineers) design provisions. The required response spectrum shape is determined by building code provisions.

#### ICC-ES AC 85

Specifies requirements for test reports and testing laboratories, and for sampling of specimens used in tests to qualify products for recognition in evaluation reports.

#### UFC 3-310-04 (Unified Facilities Criteria)

Department of Defense requirements for earthquake resistant design of new buildings, requirements for evaluating and rehabilitating existing buildings for earthquake resistance, and limited guidance on applying seismic design principles to specialized structural and non-structural elements.

#### OSHPD (Office of Statewide Health Planning and Development)

Manages OSP (OSHPD Seismic Preapproval) which is a voluntary product line preapproval program for SSC (Special Seismic Certification) for California health facilities. Due to the extreme seismic zone encompassing most of California, this preapproval certification is being increasingly requested via other entities within and outside the state.

Although all PCT products are designed and built to rigid internal quality standards, the specific design may be modified in order to meet specific customer specifications and referenced standards. In addition, modifications may also be made, depending on installation site location, to insure USGS seismic zone withstand compatibility.

Over the years, Pacific Crest Transformers has subjected its transformers to rigorous seismic testing. One such test took place at Wyle's Huntsville, Alabama laboratory, which specializes in testing and qualifying equipment for the energy and nuclear power industries, automotive companies, other high-technology industries, as well as DOD missile, aviation, ground applications, and NASA.

The transformer was energized during the tests. The final two tests were designed to simulate the worst potential earthquake in the US, the New Madrid Fault, located under a four-state area that includes Arkansas, Missouri, Tennessee, and Kentucky, but with the potential to affect an even larger region. In each of the tests, the transformer continued to operate throughout and sustained no internal or external



damage. The transformer passed Hi-Pot tests and IEEE Routine tests performed before and after the shake table testing, which substantiated that it withstood the shake tests without diminishing its operational performance.

In recent years, due to its heavy population and vulnerability to seismic events, California's Office of Statewide Health Planning and Development (OSHPD) has grown to become the primary national approval agency via its OSP (OSHPD Special Seismic Certification Preapproval )program.

To demonstrate its ability to obtain OSP certification, Pacific Crest Transformers built and submitted 2 transformers for evaluation, testing, and certification. A 300 kVA 3 phase padmount and 4000/5000 kVA secondary unit substation transformer were submitted to a third-party for shake table testing, documentation and approval submittal. Third-party product certification by an accredited listing agency reviews the product qualification records and inspects quality assurance procedures, which

provide a high level of confidence that the qualified product will consistently meet seismic requirements. This review is simplified since PCT has an ISO registered quality plan. Unlike the certification of a line of standard products, qualifying one custom product does not apply to all custom products. Inspection by an accredited listing agency serves to substantiate the credibility of the manufacturer's ability to reproduce the qualified product.

Subsequent to the third-party submittal to OSHPD, both PCT transformers were approved and OSP certified.

Pacific Crest Transformers has obtained an OSP preapproved number, OSP-0370-10. See the following OSHPD website location:

<http://www.oshpd.ca.gov/fdd/Pre-Approval/OSP-0370-10.pdf>

PCT's OSP number OSP-0370-10 is for a product model line of liquid filled transformers from 75 kVA to 5000 kVA. This range includes both padmount and substation styles. The official OSP certification number can only be placed on a nameplate on the range of transformers described with the specific design and components that were installed on the two shake-table tested units that were submitted to California's OSHPD department. The details of the components are listed in the above referenced web location. However, Pacific Crest Transformers has clearly demonstrated its ability to design and build liquid filled transformers suitable for seismic applications and subject to the scrutiny of California's seismic authorities. The fact that since 2000 PCT has been continuously certified to the ISO 9001 Quality Management Systems standard helped the process. The details of PCT's official comprehensive report submitted to OSHPD was prepared by an independent third-party California Structural Engineer who witnessed shake table testing and subsequent IEEE Routine testing. The report included the 300 kVA padmount that was shake table tested at the shake table lab at the University of California at Berkeley and the 4000/5000 kVA substation that was shake table tested at Wyle Lab in Alabama. ***The entire range of transformers from 75 kVA to 5000 kVA is certified at Sds 2.33g at ground level, the highest ground level rating for liquid filled transformers with an OSP number.***

OSHPD Special Seismic Certification						
Unit Under Test Summary						
UUT-1						
Unit Number:	UUT-1					
Manufacturer:	Pacific Crest Transformers					
Product Line:	Liquid Filled Transformer					
Product Description:	300 KVA 3-Phase Transformer, Model PCT-300KVA-ES					
Test Results:	Unit maintained structural integrity and functionality at the conclusion of shake table testing. Transformer tank was filled with content (mineral oil) during testing.					
<b>Product Construction Summary:</b>						
Mineral oil filled, steel stacked core with copper circular coils, and welded carbon steel tank.						
<b>Options and Sub-component Summary:</b>						
Trantech radiators, Krenz cooling fans, Specialty Switch Tap Changer, Central Moloney Load Break Switches						
<b>Unit Properties</b>						
Operating Weight (lbs)	Width (in)	Depth (in)	Height (in)			
6,600	57	52	69			
<b>Natural Frequencies (Hz)</b>						
Front-Back		Side-Side		Vertical		
16.5		19.7		13.8		
<b>Unit Mounting:</b>						
Rigidly mounted to shake table with four 7/8" diameter A325 bolts at tank and four 3/8" diameter Grade 5 bolts at compartment.						
						
<b>Seismic Test Parameters</b>						
<b>Building Code:</b>		2013 California Building Code				
<b>Test Criteria:</b>		ICC-ES AC156, February 2012				
<b>Sds</b>	<b>Ip</b>	<b>z/h</b>	<b>Arig (horizontal)</b>	<b>Aflex (horizontal)</b>	<b>Arig (vertical)</b>	<b>Aflex (vertical)</b>
2.33	1.5	0.0	0.93	2.33	0.62	1.55
2.0	1.5	1.0	2.40	3.20	0.62	1.55

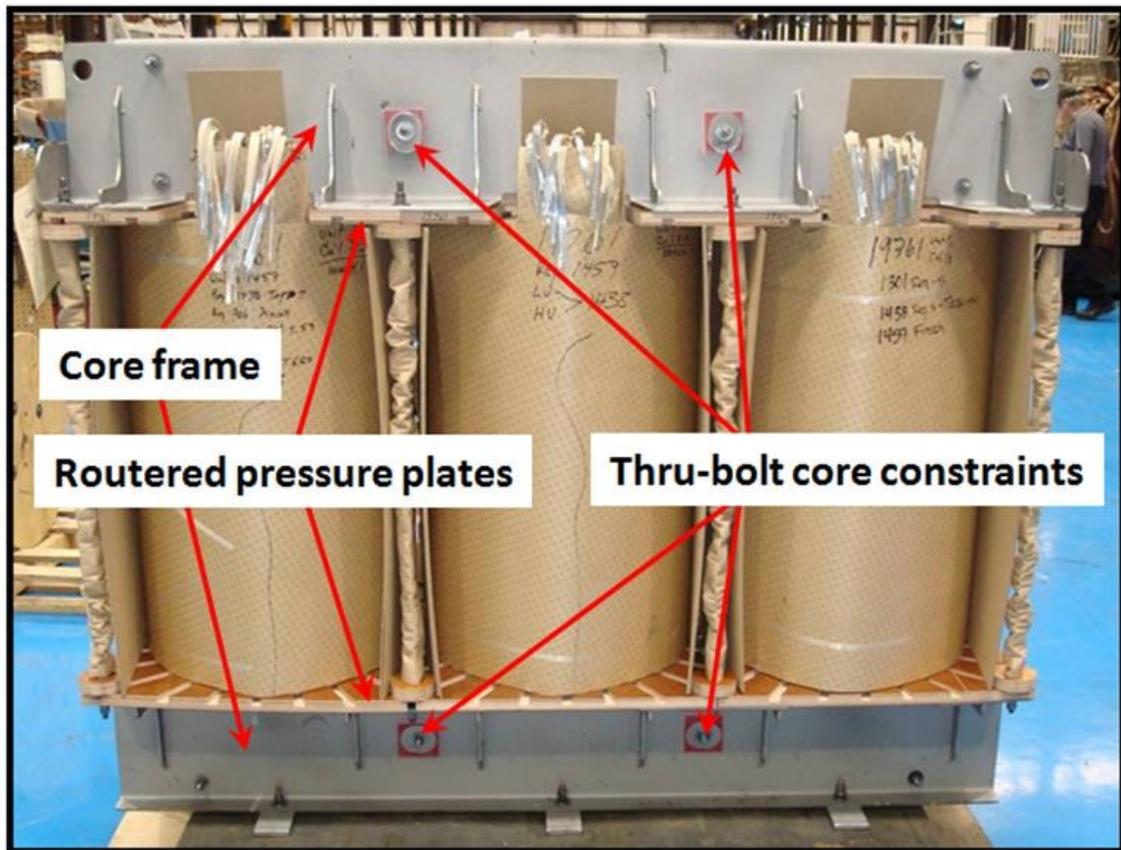
Pictured above is the test summary for the 300 kVA padmount transformer. The transformer is shown on a shake table at the test lab in Berkeley, California.

Pacific Crest Transformers' ability to consistently pass such extreme tests further serves to once again validate its commitment to customers for providing state of the art industrial strength products suitable for installation in extreme environments whether environmental and/or heavy duty cycle.

Transformers designed for installations in high and extreme seismic areas include round coils and cruciform cores. This combination coupled with appropriate bracing results in a core and coil assembly that is all but impervious to failure during seismic events.



**Assembled cruciform core legs**



**Core frame**

**Routed pressure plates**

**Thru-bolt core constraints**

**Round coil – cruciform core assembly**

Although the core & coil assembly is the “heart” of the transformer, for heavy and extreme seismic zone installations, tank construction is equally important. The tank must provide a means in which to solidly secure the core/coil assembly while also providing a means to secure the complete transformer to a solid foundation. The tank walls must be constructed of properly braced heavy gauge material to insure

that all through wall accessories may be solidly mounted. Failure to do so can lead to transformer cooling fluid leaks due to excessive vibration at gasketed areas.

If seismic withstand is a concern, one can rest assured that a transformer built by Pacific Crest Transformers can take a shaking!

*Pacific Crest Transformers: Providing innovative solutions for today's complex challenges*