Updated Building Codes Are Changing Battery Rack Certification Requirements – Design and Testing Impacts

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Abstract
Building codes affecting Seismic Battery Racks have changed significantly over the past 10 years in the United States. The simple UBC Zone 1-4 (Uniform Building Code) system that most historic VLA racks were built to no longer applies, having been replaced by the more complex IBC (International Building Code). The IBC code is more difficult to understand, having many parameters that influence what is a site compliant seismic rating. These factors make it difficult to know if a historic rack meets the new code requirements and how to design for maximum market coverage and minimal cost. State and local municipal codes like the CBC (California Building Code) and OSHPD (Office of Statewide Health Planning and Development) introduce additional requirements that impact the design and overall cost of rack systems. Industry standards such as IEEE-693 (Institute of Electrical and Electronics Engineers) can influence rack design and qualification as well. Combine the changes these various codes introduce with the ACI 318-05 (American Concrete Institute) changes for the anchoring of structures and a new criteria has been established for site compliant battery racking systems.

The changes in anchoring requirements per ACI 318-05, where the code now requires the metal anchor or structure to yield prior to the concrete, is impacting how racks are installed. Longer anchors or other anchoring designs are being required and historic anchoring schemes on racks may be insufficient.

The applicable changes in the building codes and their impact on battery rack designs are reviewed. IBC 2012 code requirements, including ASCE 7-10 Section 13 (American Society of Civil Engineers), are introduced along with the increased requirement for shake table testing, especially as it applies to essential facilities compliance. OSHPD and IEEE 693 are reviewed to highlight the impact of market specific requirements to design.

Uniform Building Code (UBC)
For over 30 years, designing battery racks for compliance and certification to UBC earthquake load requirements was relatively simple for the market to understand. The UBC code defined four primary seismic zone categories numbered 1 -4 with a simplistic map of the US to determine where these zones were and was a broad brush approach for determining the seismic requirements for structures. Battery racks could be certified by analysis, only having the requirement that they be signed and stamped by a certified Professional Engineer (PE) to be accepted in the marketplace. In addition to defining which zone the installation site was in, two other factors were needed to determine which rack design was acceptable for use at a site, these factors are whether the facility is classified as an Essential Facility (i.e. must remain operational after the earthquake) and whether the installation is at/below grade or above grade. Higher load factors were applied in the analysis for an Essential facility classification or above grade classification. For Specifying Engineers and Rack Designers, rack classifications were defined by answering the following questions:

1. What Zone is the rack to be installed in?
2. Is the installation in an Essential Facility?
3. Is the installation above grade level or is it at / below grade?

This simplicity made identifying which rack satisfied a site's requirement easy to understand in the market and was usually referred to by Rack Zone Rating. UBC was last updated as a useable code in 1997.

International Building Code (IBC) Adoption

After the 1997 UBC code update, the International Code Council (ICC) decided that supporting two different building codes in the market place created too much confusion, and decided to adopt only one common building code for the future. The ICC decided to retire the UBC code and replace it with the more widely used International Building Code (IBC) in 2000. The IBC code is more complex in the how it defines earthquake load requirements. IBC allows structural engineers and architects to design the entire structure to specific site conditions to minimize over or under designing. Unfortunately for other components mounted in those structures, like battery racks, the IBC code makes it more difficult to define seismic categories for ease of use and marketing. The simple "Zone" classification of the UBC system can no longer be used. The IBC code is updated every three years having been revised in 2000, 2003, 2006, 2009, and most recently 2012. IBC has been adopted in all 50 states, District of Columbia, and US Territories either state wide or to local levels with most being at the 2009 revision but six states have already adopted the 2012 version.[1] IBC Section 1613.5 specifically addresses Earthquake load parameters.

UBC and IBC Methodology Differences

UBC

Analysis factors for seismic events are based on a 10% Probability to exceed the event / 50 years[2]. The code uses a broad seismic map dividing the country into 4 zones. Loads did not consider a vertical component.

IBC 2000 to 2009

Analysis factors are based on a 2% Probability to exceed the event / 50 years[2]. This is a more restrictive definition than UBC had, but to offset this, the code does impose a 2/3 factor to the load making it a little less severe. IBC uses the USGS Spectral Acceleration maps (0-300%) and Site Class Factors, also referred to as Site Soil Factors, (A-F) to determine site values for the load analysis. Accelerations are applied in 3 axes. Max loads are determined by a sum of the squares calculation for loading in the primary load axes[2]. Loads are calculated per ASCE 7, Chapter 13 (American Society of Civil Engineers).

IBC 2012

The methodology for determining the analysis factors changed to 1% Probability of Collapse / 50 years[2] for this latest revision of IBC. The code still uses the same USGS maps and primary parameters of the previous IBC versions. How the loads are determined has been modified. The loads being applied to the primary lateral axes are now the maximum load of any of the axes instead of the sum of the squares approach of the previous IBC versions. Loads are still calculated per ASCE 7, Chapter equations. The change in methodology does have the following typical impact to resultant applied loads versus the 2009 version:

- Lower USGS acceleration areas (middle/eastern US): 70% to 90% of the old IBC loads[2]
- Higher USGS acceleration areas (western US): 90% to 115% of the old IBC loads[2]

IBC Code Factors

When engineers are specifying parameters for IBC rated racking systems, a variety of terms are included in the specifications. Some are applicable and some are not. Listed below are the typical parameters that may be in a rack specification for defining the IBC requirements:

- **S_S** = Short Term Acceleration (0.2 sec), obtained for the site from the USGS SS Spectral Acceleration Map. This value applies to Racking systems that are short and vibrate higher frequencies.
- **S_1** = Mapped Accelerations for 1 sec, obtained for the site from the USGS 1S Spectral Acceleration Map. This value applies to taller buildings that vibrate at low frequencies, and is not used in the rack analysis.
- **Site Class (Soil Factors)** – A through F values that determine load factors applied to the S_S/S_1 values. The factors are classified for IBC in accordance with ASCE 7, Chapter 20. The default for IBC analyses if unknown is Site Class "D" (Stiff Soil) which will be on most generic specifications.
- **S_{DS}** – Five-percent damped design spectral response acceleration at short periods, S_S
- **Risk Category (2012) or Occupancy Class (2000-2009)** – Defined in Roman numerals I to IV. Category IV is equivalent to the historical Essential Facility Classification. Risk Category and S_{DS} values define the Seismic Design Category for ASCE 7.
- **z/h:** Factor for where the rack is located in the building as a percentage of building height
    - 0.0 = at/below grade
    - 1.0 = top of building

Only S_S, Site Class, Risk Category and Location in building are required to define the rack requirements.

The S_{DS} values and other information from the IBC code is then loaded into the ASCE 7, Chapter 13 equations for earthquake loading to generate the necessary F_P values, the Design Accelerations in g's, to be used in the analysis or shake table tests. ASCE 7 is the primary force loading document referenced by IBC. Since racks are a steel construction the American Institute of Steel Construction code AISC 360 is also referenced in IBC.

Rack anchoring design requirements within IBC are defined by the American Concrete Institute's ACI 318 standards and are commented on in a following section.

IBC Impact on Rack Design

Light or Low Seismic Racks (Similar to UBC Zone 2 racks)

Historic UBC Zone 2B, essential, above grade certified racks tend to meet most of the requirements for light seismic IBC levels with minimal changes, as long as the resultant force g-levels are similar. Defining the exact IBC parameters that "light seismic" racks should be designed to is one of the biggest challenge for rack manufacturers, since no consistent standard has been set for this range. Since IBC defines an S_S in a percentage from 1% to approximately 300%, what value should be used? As designers of the racks, we try to select an S_S value that provides the broadest coverage while keeping overall structure costs to a minimum. For customers of these light seismic racks the selection gets more difficult because two different manufacturer IBC racks may be certified to two different IBC levels, so the specifications are not one to one. Selecting the rack now requires looking at the several parameters and if different, trying to determine if the rack meets the specification requirements.

One of the weak links of several historic rack designs when looking at certifying them to IBC is the end rail bracket which is incapable of supporting the entire lateral loads for the IBC conditions. A bracket design change and/or the use of tie rod assemblies have helped to resolve this deficiency. Typical frame construction is either sheet steel bent into C-channels or light tubular steel construction. Selecting an S_S level of 100% will yield a design that will typically cover 75% to 80% of the geographic continental US.

Heavy / High / Severe Seismic Racks

Traditional UBC Zone 4 racks when analyzed to the highest IBC levels, i.e. S_S levels to 300%, are frequently found to be deficient in frame design. The change in loading parameters that IBC imposes requires more robust designs, especially for essential and top of building calculations. Either new racks have to be designed or the existing racks have to be certified at a lower maximum S_S level. Heavier gauge C-Channel or tubular steel construction for the rack frames is used for these heaviest rack designs. Additional bracing, modified seismic restraint rail assemblies, and additional tie rod assemblies may be required. Spacing between the rack frames is also reduced compared to lower seismic level racks, which requires additional frames for certain lengths configurations. All these required changes drive the heavy seismic rack costs up over their lower seismic counterparts and even the UBC Zone 4 rack designs.

Again the challenge for manufacturers is - at what level should I design to? Does it make sense to create two different rack versions to handle these higher loads to minimize cost for each - a Heavy Seismic and Severe Seismic version? Since only 20% to 25% of the continental US is covered by these heavy seismic racks, geographically, manufacturers have to weigh the advantages of having two different rack lines for this category and whether the certification cost and manufacturing variability is justified for the size of the market. The cost of certifying the racks plays an important role into this decision as well, because now two certification tests would now be required.

Influence of Other Codes & Standards

When designing a new rack for high level IBC compliance, addressing other high force level codes and standards is recommended. Many of the force levels and frequency spectra that racks are subjected to significantly overlap, especially if the racks are to be certified by shake table testing.

IEEE 693

Including IEEE-693, the Institute of Electrical and Electronics Engineers' standard for the Seismic Design of Substations, requirements for those rack configurations used by that market when developing IBC rack designs makes sense. The certification to this code requires many of the same force and acceleration levels as IBC Heavy Seismic designs so this can be included at minimal cost to the new design cost. The load levels and frequency spectra of accelerations are not exactly the same as IBC, so an additional analysis or shake test needs to be conducted for certification to IEEE 693. The additional shake table run for the correct spectra with the equipment already on the fixture tends to be well worth the incremental test cost given the overall expense of the IBC shake table test. When comparing IEEE 693 to UBC Zone 4 designs, changes to the frames and other rack components had to be made to satisfy the higher loading requirements of the standard. If an IEEE 693 rack was already developed for its high seismic levels, it is likely that this design will meet many of the IBC Heavy Seismic rack requirements with little modification.

OSHPD

For the past several years OSPHD pre-approval has been a buzz word in the world of racking systems since it started showing up on many of the specifications for California sites. OSHPD stands for Office of Statewide Health Planning and Development which is an agency for the state of California that approves products for use in Hospitals and other healthcare facilities. Having a rack OSHPD pre-approved assists in getting it selected during a bid process for these facilities. OSHPD imposes additional requirements on a rack design, foremost it requires that the rack must be certified by shake table testing since all their facilities are essential or risk category IV. The shake table certification is actually a requirement imposed by California Building Code (CBC) 2010 revision which OSHPD references.

The additional item that OSHPD does impose for loading that requires racks satisfying the heaviest seismic conditions to be made more robust is that the unit under test must be tested at 45 degrees to the two horizontal directions in addition to the standard two horizontal directions that the other codes test to.[3] Alternatively, existing designs can be tested but may be limited in application if they do not reach the full test limits. This may be acceptable if the accepted parameter meet sufficient market need, thus not requiring a new design. OSHPD also requires the rack to be tested with all the actual batteries that the rack is to hold. For racks designed to hold a variety of different batteries, this is challenging to have all the different configurations included.

A key element in obtaining any OSHPD pre-approval is to have all testing and interfacing conducted through a certified California Structural Engineer. If testing a rack system to only IBC, having a CA SE consult on the test plan and be part of the test report writing and approval will help to ensure that key elements are included that will assist in any future OSHPD approval submittal of the results.

Certification: Shake Table Testing vs. Analysis

With CBC and OSHPD requiring shake table test certification, many other Authorities Having Jurisdiction (AHJs) have started specifying that racks in essential facility installation be certified by shake table testing. These requirements have been seen in specification for several western US states including WA, OR, NV, and MT with more specs being written with this requirement. For rack designs that were certified by analysis, this is an added cost for compliance and is either taken as an exception to the specification requirement, or if the opportunity is sufficient in size, the testing is conducted.

IBC 2012 does not explicitly state that shake table testing is required for certification, but with the various different agency codes referenced by IBC, the requirements become a matter of interpretation. The market appears to be moving towards shake table certification for validation of the design for essential facilities to assure that the rack will be standing after the seismic event as required by its classification. Shake table testing is the best validation of the design, but has a significant cost given the size and weight of large battery rack systems. The weight and size of these systems also limits testing to only a few test labs in the country. For example with a system that Aptus is testing, the entire system weighs over 18,000 lbs and is 8 feet long, only 3 or 4 test table nationally can handle that large of a system to the loads necessary for certification.

Anchoring changes with the ACI 318-05

IBC 2005 first referenced the American Concrete Institute's code ACI 318-05 for anchoring requirements for structures, but did not fully adopt the ACI requirement until the 2009 update. The previous ACI 318 versions only required that the anchors be strong enough to carry the load imparted on them. In ACI 318-05, the failure mode was considered in the analysis. A brittle fracture of the concrete (i.e. anchor pullout / cone cracking) is no longer permitted in the design. The connection to the slab could no longer be the weak link, the anchor or structure connected to it has to be the yielding member to failure. If the design indicates that a brittle facture will occur, the design is penalized with a 0.4 factor to the allowable load. What is the result of this?

1. Newer designs tend to have smaller anchors and more of them.
    - Upside: Distributes the loading over a larger area of the concrete minimizing the chance of a brittle fracture.
    - Downside: More anchor holes to drill

2. Longer anchors required if minimizing anchor holes or utilizing larger diameter anchors
    - Common for historic designs created and certified to earlier ACI 318 versions
    - Downside: Frequently requires 3.5 to 3.75 in anchors minimum. With the drill depth of 4 inches required for a 3.75 in. long anchor, and a typical floor concrete pour depth of 4 inches, the anchors are breaking though the floors.
        - Breakthrough requires adding plates to the floor underside and bolting the structure through the floor.
        - Alternatively, an adapter plate has to be created to change the bolt pattern and carry the load which may impact certification.
    - This is an example of where the change in anchoring requirement has led to problems with the standard concrete floor depth.

The loads imparted on traditional light seismic rack designs tend not to be severe enough to cause significant changes in their anchoring, but the configurations have to be checked for total loading at the site it is being installed.

The heavy seismic designs tend to be the most impacted as these rack versions see the highest anchor loads and a large rack being held down by only two large anchors may no longer meet the anchoring requirements of ACI 318-05.

Conclusion

The certification requirements for racks have changed with the retirement of the UBC code and the adoption of the IBC code. These changes have resulted in impacts to the rack designs especially for the heavier seismic designs, making them more robust but driving up rack costs. Other codes and standards impact rack design. Including coverage for IEEE 693 and provisions for OSHPD can help maximize rack coverage in the market place. A balance must be maintained as no single rack can cost effectively satisfy everyone. With the CBC and OSHPD requiring shake table testing of essential facility racks, and more agencies adopting this requirement in other states, shake table testing of designs is not only becoming desired, it is becoming a requirement. These are all factors to consider in developing new rack designs or in qualifying existing designs to the new requirements.

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References

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