SHAKE TEST:
A POP QUIZ ON SEISMIC BATTERY RACKS

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Multiple choice.
One answer per question.
10 points per question.

1. Lateral Acceleration is:

A) A highly specific means by which to specify a battery rack.
B) A measure of testosterone in the movie Top Gun.
C) The resultant of multiple variables used to express a quantifiable design load for the resistance of seismic forces.
D) All of the above.

2. The term FEA stands for:

A) Federal Emissions Agency
B) Future Earnings Aggregate
C) Finite Element Analysis
D) Fire Engineer's Alliance

3. A 16-foot NEBS certified rack has been subjected to which of the following:

A) A shaker table test
B) An FEA analysis
C) A physical inspection by a Telcordia certified laboratory
D) All of the above

4. Battery rack specifications should utilize NEBS for:

A) Installations in Zone 4
B) Any telecom installation
C) Installations in NEBS certified buildings
D) None of the above

5. For a given seismic rack system, the weight of the system and the lateral acceleration are:

A) A direct proportion
B) An inverse proportion
C) Equal
D) Completely unrelated variables

6. The 1997 Uniform Building Code expresses values using what form of analysis:

A) Allowable Stress Design
B) Unity Checks
C) Ultimate Strength Design
D) Yield Point Design

7. The most common point of failure in structural systems like battery racks would be:

A) The point of connection to the building structure.
B) The base of the frame.
C) The midpoint of the span between frames.
D) The crossbraces.

8. To properly anchor a battery rack, the code requires:

A) A Hilti "Red Head"
B) A complete analysis by an engineer
C) A bolt that is certified along with the rack
D) None of the above

9. The installation of a battery rack over a material of an indeterminate spring value, such as a flexible liner, has which of the following effects on the rack:

A) It makes it bouncy and thereby helps it to survive an earthquake.
B) It helps to evenly spread the weight of the rack and thereby reduces floor loading.
C) It fundamentally changes the dynamic response of the rack and thereby negates the seismic certification.
D) Nobody really knows because credible testing has yet to emerge on the subject.

10. In addition to the verification of the rack and anchorage certification, a specifying engineer should verify the floor loading conditions under which of the following circumstances:

A) Three-tier vented installations
B) All installations above grade
C) Installations in older buildings
D) All of the above

1. Lateral Acceleration is:

A) A highly specific means by which to specify a battery rack.
B) A measure of testosterone in the movie Top Gun.
C) The resultant of multiple variables used to express a quantifiable design load for the resistance of seismic forces.
D) All of the above.

Answer: D

Answer A is correct. Building codes are continually adding new variables to the calculations for seismic forces, especially in Zone 4. In addition to the zone location, an engineer must know the soil profile type, the seismic importance factor, the proportional elevation within the building, and the distance to, and type of, the nearest seismic source. Specification by zone alone is inadequate for correctly determining the lateral acceleration and does not comply with the requirements of the code.

Answer B is correct. For battery racks, the design magnitude of the earthquake is expressed in lateral acceleration and is quantified in units of "g". The unit "g" is also used to quantify forces experienced in other fields such as aviation. If you don't believe me, watch the movie one more time and see if "g's" aren't for bragging rights.

Answer C is correct. This resultant is then multiplied by the weight of the system to determine the overall force. For a more detailed version, see equations 32-1 and 32-2 in section 1632 of the 1997 UBC.

2. The term FEA stands for:

A) Federal Emissions Agency
B) Future Earnings Aggregate
C) Finite Element Analysis
D) Fire Engineer's Alliance

Answer: C

Finite Element Analysis is a virtual means by which design stresses are analyzed in a computer model. FEA is widely used as a design and verification tool for all sorts of structures, including battery racks. Properties of structural members are loaded into the model. Specified forces, from codes and/or standards, are then virtually applied. Mathematical resultants indicate areas of both weakness and overdesign. This methodology is highly important because most structures are too large for physical testing. Most important, it allows for a means by which to predict the dynamic response of a building or a structure prior to its construction.

3. A 16-foot NEBS certified rack has been subjected to which of the following:

- **A) A shaker table test**
- **B) An FEA analysis**
- **C) A physical inspection by a Telcordia certified laboratory**
- **D) All of the above**

Answer: B

Contrary to urban legends of the telecom world, 16 ft NEBS certified racks have never been subjected to a shaker table test. At present, Wiley Labs and Southwest Research Institute operate two of the largest shaker table laboratories in the country. Both labs have tables that are 8' x 8' and have a 10,000 lbs test limit. All 16 ft. racks would be precluded by size alone. The loading for most 8 ft. racks comes close to, or exceeds, the 10,000 lbs restriction. Most NEBS certified racks are approved through means of interpolation of FEA results from a smaller "test article". A company will typically submit FEA results for a 5', 8' and 16' rack. The 5' will serve as the test article. If the 5' passes the shaker table test, then the results from that successful test are used to adjust the FEA model such that their results are in close statistical proximity. The same adjustments are made to the 8' and 16' models. The adjusted virtual model is then subjected to the forces prescribed in NEBS and if they pass, then they are certified based on their success in the adjusted FEA model.

If you don't trust FEA results, for large-scale products, you don't trust NEBS results either.

4. Battery rack specifications should utilize NEBS for:

- **A) Installations in Zone 4**
- **B) Any telecom installation**
- **C) Installations in NEBS certified buildings**
- **D) None of the above**

Answer: C

Answer A is incorrect. All building codes have a means by which they deal with high seismic areas and reverting to the use of NEBS in Zone 4 is unnecessary.

Answer B is incorrect. NEBS stands for Network Equipment Building Standard and as such is closely associated with, but not exclusively used by, the telecom industry. Furthermore, many telecom installations do not utilize NEBS in certain applications.

Answer C is correct. NEBS is far more than a battery rack standard. In fact, it is practically a building code unto itself. As the name implies, the standard is not just for the equipment, such as racks, but for the building as well. If the money has been spent to build a structure to NEBS, it seems appropriate that the specifications for all equipment within that building should conform to NEBS as well.

However, to place NEBS certified equipment in a building that conforms to the building code rather than NEBS is most likely a waste of money. The appropriate specification for such an application would be for the equipment specifications to match the same standards as the building itself. At the point in which a seismic event causes a building structure to fail, the battery rack is fairly irrelevant no matter what standard it is specified to.

5. For a given seismic rack system, the weight of the system and the lateral acceleration are:

- **A) A direct proportion**
- **B) An inverse proportion**
- **C) Equal**
- **D) Completely unrelated variables**

Answer: B

The concept is based on Newton's Second Law of Motion. Force equals mass times acceleration (F=ma). As "m" goes up, "a" goes down. As "a" goes up "m" goes down, etc.

For a battery rack, the F represents the force that the rack can withstand. Once a rack is designed and built, it becomes a constant. The "m" relates to the total weight of the battery system and the "a" relates to the lateral force.

So with the rack as a constant, the other variables may change in inverse proportion. If the battery weight goes up, the earthquake that the rack will withstand goes down. If the battery weight goes down, the resistance to lateral force goes up.

Rack ratings are intrinsically tied to the model of battery that is being placed on them and the associated weight of that battery. Battery rack certifications must specify which battery the rack is designed for or they can simply specify the weight that they are rated for. This is typically expressed in pounds per inch per tier (Weight of Battery/length of battery + a spacer).

6. The 1997 Uniform Building Code expresses values using what form of analysis:

- **A) Allowable Stress Design**
- **B) Unity Checks**
- **C) Ultimate Strength Design**
- **D) Yield Point Design**

Answer: C

The 1997 Uniform Building Code expresses values that are derived using Ultimate Strength Design. However, the more typical analysis method is Allowable Stress Design. If the rack is rated using Allowable, the code allows for a 1.4 factor to be used for conversion to Ultimate. If the rack is rated using Ultimate, no conversion is necessary.

It is important to understand this conversion. Without it, rack specifications will be 1.4 stronger than required by code.

7. The most common point of failure in structural systems like battery racks would be:

- **A) The point of connection to the building structure.**
- **B) The base of the frame.**
- **C) The midpoint of the span between frames.**
- **D) The crossbraces.**

Answer: A

Engineering experience indicates that the most common point of failure of assembled steel structural systems is at the connection to the building structure.

From FEA analysis, we understand that the second most common point of failure is at the base of the frame. Rigidity can be compromised by shape, strength of material, and a lack of appropriate welding.

Deflections in spanning members and tension in bracing elements are rarely points of failure.

8. To properly anchor a battery rack, the code requires:

- **A) A Hilti "Red Head"**
- **B) A complete analysis by an engineer**
- **C) A bolt that is certified along with the rack**
- **D) None of the above**

Answer: D

Although answers A, B and C can all be effectively used under certain circumstances to meet the provisions of the code, none of these are specifically called for by the code.

However, the 1997 UBC Section 1632 has extremely specific language as it relates to anchorage or "attachments".

> "Elements of structures **and their attachments**, permanent nonstructural components **and their attachments, and the attachments** for permanent equipment supported by a structure shall be designed to resist the total design seismic forces prescribed in Section 1632.2. Attachments for floor- or roof-mounted equipment weighing less than 400 pounds (181kg), and furniture need not be designed.
>
> **Attachments shall include anchorages** and required bracing. Friction resulting from gravity loads shall not be considered to provide resistance to seismic forces." (Emphasis added.)

This clearly indicates that "attachments" are a design issue on par with that of the structure itself.

A bolt that is analyzed along with the rack is convenient and inexpensive. It helps to prevent delays in installation and assures the user of a designed attachment as required by the code. However, any anchorage analysis is highly dependant on the strength of the concrete. Specifying engineers should verify the minimum assumptions used in the analysis prior to final approval.

Without a bolt analyzed along with the rack, the code still requires designed attachment and as such an engineer should be hired to conduct an analysis for the site. This will cost a lot of money.

9. The installation of a battery rack over a material of an indeterminate spring value, such as a flexible liner, has which of the following effects on the rack:

- **A) It makes it bouncy and thereby helps it to survive an earthquake.**
- **B) It helps to evenly spread the weight of the rack and thereby reduces floor loading.**
- **C) It fundamentally changes the dynamic response of the rack and thereby negates the seismic certification.**
- **D) Nobody really knows because credible testing has yet to emerge on the subject.**

Answer: D

Once a system has been analyzed using certain materials, such as steel and concrete, it is not a recommended practice to introduce new materials of differing durometers* into the mix. Without rerunning the analysis, there is no way of fully knowing how the new materials will affect the connections.

The answer C is the worse case scenario, which assumes the introduction of the material would change the dynamic response and thereby dismiss the claims of the rack certification made under the assumptions of the original analysis.

It is possible that the introduction of such materials is of so little consequence that their effect would fall within the parameters of the safety factors inherent in any rack analysis and thereby leave the validity of the analysis in tact.

What is clear is that unless the certification of the rack specifically allows for the introduction of these types of materials, they should only be utilized in a manner that does not interject them between the base of the frame and the floor. Claims that the use of such materials is acceptable can only be valid from one source: the engineer who is certifying the rack.

*Durometer: The degree of hardness; especially, the relative hardness of steel rails and the like.

10. In addition to the verification of the rack and anchorage certification, a specifying engineer should verify the floor loading conditions under which of the following circumstances:

- **A) Three-tier vented installations**
- **B) All installations above grade**
- **C) Installations in older buildings**
- **D) All of the above**

Answer: D

Often the slab is designed to code, but it is not designed specifically for a battery room. This does not generally cause a problem for one-tier, two-step or two-tier racks on grade, but is often a major headache for three-tier racks on grade, or any installation above grade.

With three-tier racks, the point loading is often greater than what the slab is designed for. In this situation, load dissipation plates may be required.

For above grade applications, especially in high seismic areas, the slab is frequently not thick enough for proper embedment of appropriately sized anchors. In these cases, a new anchoring system must be designed specifically for the situation.

Slabs in older buildings may not have the PSI required for the anchoring system as designed and thereby merit special attention.

Contact: The author of this paper welcomes your comments and questions. He may be contacted at 800-247-2257 x130 or via email at rrobbins@acran.com.

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