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Requirements for Seismic Qualification of HVACR Equipment

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Note:

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TABLE OF CONTENTS

Section 1. Purpose 1

Section 2. Scope 1

Section 3. Definitions 1

Section 4. Symbols 4

Section 5. Equipment 4

Section 6. Seismic Demand 8

Section 7. Seismic Capacity of Equipment by Analysis 10

Section 8. Seismic Capacity of Equipment by Testing 13

Section 9. Report Requirements 18

Section 10. Seismic Rating of Equipment 21

TABLES

Table 1. Seismic Performance Level; Functionality (per ASCE 7 Section 13.2.2) 6

Table 2. Seismic Performance Level; Structural Integrity (per ASCE 7 Section 13.2.1) 7

Table 3. Load Combinations 12

Table 4. Analytical Procedures 3

Table 5. Functional Requirements For Designated Seismic Systems 15

Table 6. Allowable Minor Damage States for Designated Seismic Systems 16

Table 7. Allowable Minor Damage States for Components of Designated Seismic System Equipment 17

APPENDICIES

Appendix A. References – Normative 2

Appendix B. References – Informative 23

Appendix C. ASCE 7 Commentary C13 Seismic Design Requirements for Nonstructural Components - Infomative 25

Appendix D. Seismic Design of Liquid Storage Tanks-Informative 26

Appendix E. Software Validation-Normative 28

FIGURES

Figure 1. Qualification Flowchart…………………………………………………………………………...5

Figure 2. RRS, Normalized For Equipment 8

REQUIREMENTS FOR SEISMIC QUALIFICATION OF HVACR EQUIPMENT

Section 1. Purpose

1.1 *Purpose.* The purpose of this standard is to define the requirements for seismic qualification of mechanical HVACR Equipment. The 2012 International Building Code® (IBC) includes a number of provisions for seismic design and certification of nonstructural components. These provisions are intended to improve the performance of non-essential and essential nonstructural systems subject to strong ground shaking. Both the IBC and the American Society of Civil Engineers Standard SEI/ASCE 7 (ASCE 7) contain requirements for qualification of Equipment.

Section 2. Scope

2.1 *Scope*. This standard applies to the following Equipment: Fan Coil Units, Unit Ventilators, Air Handling Units, Coils, Air-to-Air Heat Exchangers, Vertical Packaged Air Conditioners and Heat Pumps, Packaged Terminal Equipment, Dehumidifiers, Flow and Contaminant Controls, Furnaces, Humidifiers, Liquid Chillers, Thermal Storage Equipment, Unitary Air Conditioners and Heat Pumps (including Ductless Equipment), and Water-Source Heat Pumps. This standard does not apply to any other products. This standard describes the methods for equipment qualification and the process to determine equipment Seismic Capacity.

The applicability of this standard to equipment not specifically listed in the scope has not been considered.

Section 3. Definitions

All terms in this document shall follow the standard industry definitions in the current edition of ASHRAE Terminology website (https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology) or the International Code Council Evaluation Services (ICC-ES) Acceptance Criteria AC156 (AC156), unless otherwise defined in this section.

3.1 *Active Component.* A component or sub-assembly that is critical to the functional performance of the equipment that includes moving or rotating parts, electrical parts such as switches or relays, or other internal components that are sensitive to earthquake forces.

Examples of Active Components include: fans, variable frequency drives, control panels, and damper assemblies.

3.2 *Active Equipment.* Equipment that contains Active Components.

3.3 *Allowable Stress Design (ASD).* A comparison of the stresses in the connections/elements defined in the Equipment Force-Resisting System (EFRS) determined by analysis from the effects of design loads to the allowable stresses for the material used in the EFRS.

3.4 *Attachments.* The devices or hardware used to secure or restrain the Equipment to the building structure. Attachments or restraints of the Equipment include anchor bolts, welded connections, and mechanical fasteners.

3.5 *Attachment Point.* The point at which the Equipment is connected to the building structure. This connection point is designed to transfer seismic forces between the structure and the Equipment.

3.6 *Certificate of Compliance.* A certificate stating the Seismic Capacity of Equipment determined using methods of this standard.

3.7 *Certification Response Spectrum (CRS).* For shake table testing, certification will be performed based on a Required Response Spectrum (RRS) which determines the input motion at the equipment attachment. For this application, the CRS is the RRS. For dynamic analysis certification of Equipment, the CRS defines the forcing function in terms of octaves used by the analysis program to define the input of motion at the equipment attachment. The CRS constitutes the Seismic Capacity of the Equipment if it satisfies the acceptance criteria as defined in this standard.

3.8 *Component.* Devices that can be individually qualified per this standard and joined with other Pre-Qualified Components or EFRS qualified separately for multi-component Equipment such as motors, coils, fans, valves, dampers, etc.

3.9 *Component Amplification Factor.* A factor for a component that is not attached to the Equipment's substructure at the base, but somewhere above in the unit. The unit may have some internal amplification because of the response to the dynamic forcing functions. For example, a fan on top of a cooling tower may see higher seismic shaking than if it was attached to the base. This higher demand must be defined so the fan (Component) will need to have a higher capacity in order for the cooling tower itself to be rated at the demand at the attachment point.

3.10 *Damping.* Energy dissipation mechanism that reduces amplification and broadens the vibratory response. Damping is expressed as a percentage of critical Damping applied near the natural frequency of the Equipment.

3.11 *Design Earthquake*. The earthquake effects that are two-thirds of the corresponding maximum considered earthquake effects.

3.12 *Designated Seismic System.* The architectural, electrical and mechanical systems and their Equipment and components that require design in accordance with Chapter 13 of ASCE 7 and for which the importance factor, I_p, is equal to 4 cm accordance with Section 13.1.3 of ASCE 7.

3.13 *Equipment.* Products manufactured to perform HVACR functions. These products are manufactured by combining components with an EFRS. In context of this standard, these products are evaluated to determine the maximum Seismic Demand that the HVACR Equipment will survive and continue to function following a seismic event.

3.14 *Equipment Qualified by Test (EQT).* Equipment identified to be qualified by shake table test.

3.15 *Equipment Force-Resisting System (EFRS).* A system of elements within the Equipment that include brackets, braces, frames, and struts that provides the seismic load path transmitting seismic forces to the equipment Attachment Points.

3.16 *Flexible Equipment.* Equipment, including its attachment and force-resisting structural system, that has a fundamental period greater than 0.06 second (frequency less than 16.67 Hz).

3.17 *Functional Requirements.* High level actions that the Equipment must achieve that define the Equipment to be functional.

3.18 *Load and Resistance Factor Design (LRFD).* Comparison of the load on the connections/elements defined in the EFRS determined by analysis from the effects of design loads to the allowable strength for the configuration of the connection and material used in the EFRS.

3.19 *Performance Requirements.* Parameters that can be measured such as pressure, revolutions per minute (RPM), flow rates, and physical dimensions. The Performance Requirements are measured before and after a shake table test and must be equivalent or within tolerance for the Functional Requirements to be met.

3.20 *Pre-Qualified Component.* Active or energized components seismically pre-qualified to a specific g-level used in multi-component Equipment.

3.21 *Required Response Spectrum (RRS).* The response spectrum as defined by AC156 to create the required demand on the Equipment. The response spectrum is generated from formulas available in AC156 and is used as the Seismic Capacity in the certification of Equipment.

3.22 *Rigid Equipment.* Equipment, including its Attachments and EFRS, that has a fundamental period less than or equal to 0.06 second (frequency greater than or equal to 16.67 Hz).

3.23 *Rugged Component*. Component judged to survive a design earthquake motion without Significant Loss of Function and qualified by engineering judgment such that the Component does not require further testing or analysis.

3.24 *Rugged Equipment.* A nonstructural component that has been shown to consistently function after design earthquake level or greater seismic events based on past earthquake experience data or past seismic testing when adequately anchored or supported. The classification of a nonstructural component as rugged shall be based on a comparison of the specific component with components of similar strength and stiffness. Common examples of rugged components include: AC motors, compressors and base mounted horizontal pumps.

3.25 *Seismic Capacity.* The maximum analytical or test acceleration at which the Equipment can satisfy the performance criteria as defined in Section 5.

3.26 *Seismic Demand.* Seismic forces resulting from ground motion that are defined in the IBC. The maximum design acceleration of the seismic forces is the demand. The Seismic Demand can be a single value that corresponds to the maximum value of the RRS.

3.27 "Shall," "Should," "Recommended," or "It Is Recommended." "Shall," "should," "recommended," or "it is recommended" shall be interpreted as follows:

3.27.1 *Shall*. Where "shall" or "shall not" is used for a provision specified, that provision is mandatory if compliance with the standard is claimed.

3.27.2 *Should, Recommended, or It Is Recommended*. "Should," "recommended," or "it is recommended" is used to indicate provisions which are not mandatory but which are desirable as good practice.

3.28 *Significant Loss of Function.* The functional state of Equipment or Components that cannot be restored in a timely fashion to their original function by competent technicians after a design earthquake motion because the Equipment or Components require parts that are not normally stocked locally or not readily available.

3.29 *Test Response Spectrum (TRS).* The acceleration response spectrum developed by the motion of the shake table to provide an input motion that simulates an earthquake for the qualification of Equipment. This motion is created to develop the CRS at the equipment attachment point. The TRS shall envelope the RRS with limited exceptions.

3.30 *Transmissibility.* A non-dimensional ratio that defines the force amplitude factor of load path in the EFRS in terms of steady-state forced vibration. The ratio may be expressed in terms of force, displacement, velocity, or acceleration and is used to characterize resonant modes of structural vibration.

3.31 *Zero Period Acceleration (ZPA).* The maximum peak acceleration used to derive a specific applied time history spectrum (the peak acceleration A_{FLX} is greater than the ZPA).

Section 4. Symbols

4.1 *Symbols.* The following symbols are used in this document. Refer to ASCE 7 and AC156 for additional information.

A_{FLX-H} = The probable maximum horizontal spectral acceleration that Flexible Equipment will experience in a seismic event defined by AC156.

A_{FLX-V} = The probable maximum vertical spectral acceleration that Flexible Equipment will experience in a seismic event defined by AC156.

a_p = In-structure equipment amplification factor. The a_p represents a comparison of the equipment's natural frequency to the fundamental frequency of the building structure as determined in ASCE 7 Section 13.6-1.

A_{RIG-H} = Horizontal spectral acceleration that Rigid Equipment will experience in a seismic event defined by AC156.

A_{RIG-V} = Vertical spectral acceleration that Rigid Equipment will experience in a seismic event defined by AC156.

D = Dead Load as used in the load combination formulas.

F = Load due to fluids with well-defined pressures and maximum heights.

F_p = An equivalent horizontal static force that represents the dynamic accelerations of a seismic event used in the prescriptive method identified by ASCE 7 Section 13.3.1. The horizontal seismic design force is applied at the equipment's center of gravity.

H = Load due to lateral earth pressure, ground water pressure or pressure of bulk materials.

h = Average building/structure roof height with respect to grade as defined in ASCE 7 Section 13.3.1.

I_p = Equipment importance factor. I_p represents the life-safety importance factor of the Equipment or Component as defined in ASCE 7 Section 13.1.3.

L = Live load.

ρ =Redundancy factor based on the extent of structural redundancy present in a structure as defined in ASCE 7, Section 12.3.4. ρ = 1.0 for nonstructural components.

Q_E = Earthquake Load as used in the load combination formulas.

R_p = Equipment response modification factor. R_p represents the capability of the Equipment and attachment to absorb energy, as defined in ASCE 7 Section 13.6.1.

S = Snow load.

S_{DS} = Design spectral response acceleration at short period (0.2 secs), as determined in ASCE 7 Section 11.4.4.

W_p = Equipment operating weight, including all contents, as defined in ASCE 7 Section 13.3.1.

z = Height of the equipment attachment to the structure with respect to grade (ground level) as defined in ASCE 7 Section 13.3.1. For items at or below grade, z shall be 0.0 and not negative.

Section 5. Equipment

5.1 *Applicability.* Equipment shall be seismically qualified per the requirements contained in this standard. The qualification processes are shown in Figure 1. For each piece of Equipment, the seismic qualification method shall be identified as provided in Tables 1 and 2. As the complexity of Equipment increases, the methods allowed to qualify Equipment become more limited. Components can be qualified separately for multi-component Equipment. Component complexity may require the component to be qualified separately from the equipment EFRS especially for electronic components. Components that are deemed rugged are exempt from qualification.

For Equipment and Components to meet the special qualification requirements for Designated Seismic Systems, the device shall be shown to be functional after an earthquake as required by Section 13.2.2 in ASCE 7. When the Equipment is not part of a Designated Seismic System, the device's structural integrity shall be qualified in accordance with Table 2. In both cases, Attachments are not included in the qualification. The qualification of the Equipment shall include the loads applied at the Attachment Points.

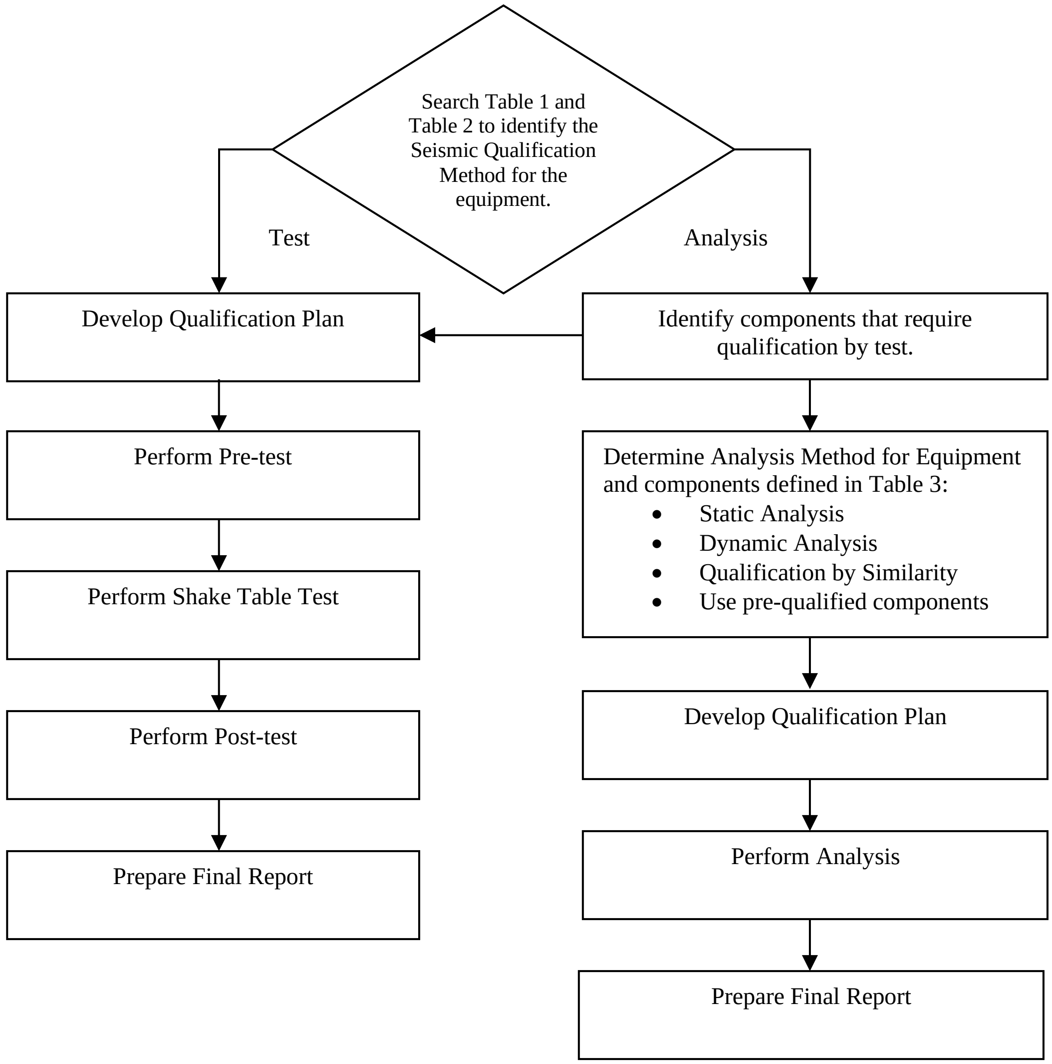

Figure 1. Qualification Flowchart

Table 1. Seismic Performance Level[5]; Functionality (per ASCE 7 Section 13.2.2)

Component Description	Qualification Method	Qualification Focus	a_p	R_p	I_p
Non-vibration Isolated Rugged Component[4]	Static Analysis	Attachment Point	1.0	See Note 6	1.5
	Dynamic Analysis	Attachment Point	RRS	See Note 6	1.5
	Shake Table Test	Attachment Point	per Standard AC156		
Vibration Isolated Rugged Component[4]	Static Analysis	Attachment Point	1.0	See Note 6	1.5
	Dynamic Analysis	Attachment Point	RRS	See Note 6	1.5
	Shake Table Test	Attachment Point	per Standard AC156		
Non-vibration Isolated Active or Energized Component	Shake Table Test[3]	Component Functionality and Attachment Point	per Standard AC156		
Vibration Isolated Active Component	Shake Table Test w/Isolation Mounts	Component Functionality and Attachment Point	per Standard AC156		
Equipment Description	**Qualification Method**	**Qualification Focus**	**a_p**	**R_p**	**I_p**
Rugged Equipment[4]	Static Analysis	EFRS and Attachment Point	2.5	See Note 6	1.5
	Static Analysis w/Natural Frequency[1]	EFRS and Attachment Point	1.0 or 2.5[2]	See Note 6	1.5
	Dynamic Analysis	EFRS and Attachment Point	RRS	See Note 6	1.5
	Shake Table Test	EFRS and Attachment Point	per Standard AC156		
Non-vibration Isolated Active Equipment	Static Analysis of EFRS and Dynamic Analysis[4] (Component Qualification also required)	Equipment Functionality and Attachment Point	1.0 or 2.5[2]	See Note 6	1.5
	Dynamic Analysis of EFRS (Component Qualification also required)	Equipment Functionality and Attachment Point	RRS	See Note 6	1.5
	Shake Table Test	Equipment Functionality and Attachment Point	per Standard AC156		
Vibration Isolated Active Equipment	Shake Table Test w/Isolation Mounts	Equipment Functionality and Attachment Point	per Standard AC156		
Liquid Storage Tanks[4]	Static Analysis w/Sloshing Effects	Equipment Functionality and Attachment Point	ASCE 7		
	Dynamic Analysis	Equipment Functionality and Attachment Point	ASCE 7		

Notes:
1. Natural frequency can be determined by dynamic analysis or other means.
2. The value of a_p equal to 1.0 is for rigid Components and Equipment. The value of a_p equal to 2.5 is for flexible Components and Equipment. See Section 2 for definitions of rigid and flexible.
3. Dynamic analysis required to determine amplification factors for shake table testing of active or energized Components.
4. ASME pressure vessels are considered rugged but still require an evaluation of the EFRS
5. The local authority having jurisdiction may have more stringent requirements.
6. The R_p factor for all equipment with an importance factor $I_p = 1.5$ shall be a value of 1.5.

Table 2. Seismic Performance Level[5]; Structural Integrity (per ASCE 7 Section 13.2.1)

Component Description	Qualification Method	Qualification Focus	a_p	R_p	I_p
Non-vibration Isolated Rugged Component[4]	Static Analysis	Attachment Point	1.0	See Note 6	1.0
	Dynamic Analysis	Attachment Point	RRS	See Note 6	1.0
	Shake Table Test	Attachment Point	per Standard AC156		
Vibration Isolated Rugged Component[4]	Static Analysis	Attachment Point	1.0	See Note 6	1.0
	Dynamic Analysis	Attachment Point	RRS	See Note 6	1.0
	Shake Table Test	Attachment Point	per Standard AC156		
Non-vibration Isolated Active or Energized Component	Static Analysis	Attachment Point	2.5	See Note 6	1.0
	Static Analysis w/Natural Frequency[1]	Attachment Point	1.0 or 2.5[2]	See Note 6	1.0
	Dynamic Analysis	Attachment Point	RRS	See Note 6	1.0
	Shake Table Test	Attachment Point	per Standard AC156		
Vibration Isolated Active Component	Static Analysis	Attachment Point	2.5	2.0	1.0
	Dynamic Analysis	Attachment Point	RRS	2.0	1.0
	Shake Table Test[3]	Attachment Point	per Standard AC156		
Equipment Description	Qualification Method	Qualification Focus	a_p	R_p	I_p
Rugged Equipment[4] (motor HP < 10; heat transfer capacity < 200 MBH)	Static Analysis	Attachment Point	2.5	See Note 6	1.0
	Static Analysis w/Natural Frequency[1]	Attachment Point	1.0 or 2.5[2]	See Note 6	1.0
	Dynamic Analysis	Attachment Point	RRS	See Note 6	1.0
	Shake Table Test	Attachment Point	per Standard AC156		
Non-vibration Isolated Active Equipment	Static Analysis	EFRS and Attachment Point	2.5	See Note 6	1.0
	Static Analysis w/Natural Frequency[1]	EFRS and Attachment Point	1.0 or 2.5[2]	See Note 6	1.0
	Dynamic Analysis	EFRS and Attachment Point	RRS	See Note 6	1.0
	Shake Table Test	EFRS and Attachment Point	per Standard AC156		
Vibration Isolated Active Equipment	Static Analysis	EFRS and Attachment Point	2.5	2.0	1.0
	Dynamic Analysis	EFRS and Attachment Point	RRS	2.0	1.0
	Shake Table Test	EFRS and Attachment Point	per Standard AC156		
Liquid Storage Tanks[4]	Static Analysis w/Sloshing Effects	EFRS and Attachment Point	ASCE 7		
	Dynamic Analysis	EFRS and Attachment Point	ASCE 7		

Notes:
1. Natural frequency can be determined by dynamic analysis or other means.
2. The value of a_p equal to 1.0 is for rigid Components and Equipment. The value of a_p equal to 2.5 is for flexible Components and Equipment. See Section 2 for definitions of rigid and flexible.
3. Dynamic analysis required to determine amplification factors for shake table testing of active or energized Components.
4. ASME pressure vessels are considered rugged but still require an evaluation of the EFRS
5. The local authority having jurisdiction may have more stringent requirements.
6. Refer to ASCE 7 Table 13.6-1.

Section 6. Seismic Demand

6.1 *Seismic Demand.* The Seismic Demand for Equipment is based on the design spectral response acceleration at short periods, S_{DS}. This acceleration value is modified based on many factors and results in the total horizontal acceleration at the center of gravity of Equipment and its Components in terms of g-levels. AC156 is the accepted document that defines the acceleration demand as shown in Figure 2, which is used for dynamic testing and dynamic analysis of Equipment. ASCE 7 defines an equivalent static horizontal force F_P based on the design spectral acceleration that is used in static analysis discussed later in this section.

6.2 *Derivation of Seismic RRS.* The equipment earthquake response spectra for testing Equipment are defined in AC156 and are applied in the horizontal and vertical directions. The spectra are applied simultaneously at the Attachment Points of the Equipment. The shake table testing input is adjusted so that the response at the Attachment Points meets the criteria established in AC156. The RRS for horizontal and vertical accelerations shall be developed based on the normalized response spectra shown in Figure 2 (Reference from AC156). The RRS for the vertical direction shall be two-thirds of the horizontal acceleration at ground level. The horizontal accelerations (A_{FLX} and A_{RIG}) shall be calculated as specified in equations 1 through 4 (Reference AC156). The RRS has an assumed 5 percent damping value of critical Damping for Equipment.

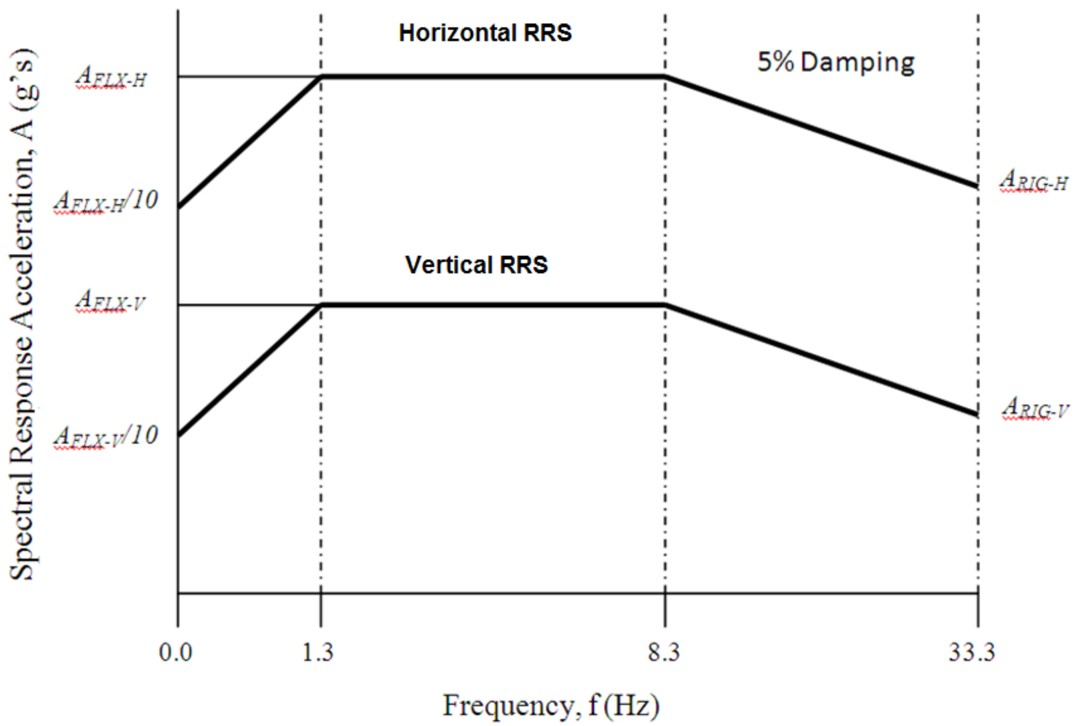

Figure 2. RRS, Normalized for Equipment

These assumptions allowed by AC156 result in normalizing the acceleration factors that define the horizontal acceleration RRS.

Horizontal: $A_{FLX-H} = S_{DS} \cdot (1 + 2z/h)$ 1

$A_{RIG-H} = 0.4\ S_{DS} \cdot (1 + 2z/h)$ 2

Vertical: $A_{FLX-V} = 2/3\ S_{DS}$ 3

$A_{RIG-V} = 0.4 \cdot 2/3\ S_{DS}$ 4

A_{FLX-H} is limited to a maximum value of 1.6 times S_{DS} (Equation 5). A_{RIG-H} is limited to 3 times 0.4 or 1.2 times S_{DS} (Equation 6). The 1.2 times S_{DS} can be applied to Equipment that is considered rigid with a natural frequency above 33.3 Hz.

$A_{FLX\text{-}H}\,(MAX) = 1.6 \cdot S_{DS}$ 5

$A_{RIG\text{-}H}\,(MAX) = 1.2 \cdot S_{DS}$ 6

Logarithmic interpolation can be used between the $A_{FLX\text{-}H}$ and $A_{RIG\text{-}H}$ using the 1.6 and 1.2 factors for the acceleration with 8.3 Hz and 33.3 Hz for the frequency. A good approximation for Equipment that has a natural frequency of 16 Hz is 1.4 times S_{DS}. However, some Equipment may have a natural frequency above 16 Hz. This provides a small reduction in demand from the 1.6 times S_{DS} to 1.4 times S_{DS} as shown in Equation 7.

$A_{RIG\text{-}H}\,(MAX) = 1.4 \cdot S_{DS}$ 7

For Equipment restricted to at grade locations, $A_{FLX\text{-}H}$ is limited to a maximum value of 1.0 times S_{DS} as shown in Equation 8 where z in Equation 1 is set at 0.0. For Rigid Equipment restricted to at grade locations, $A_{RIG\text{-}H}$ is limited to a maximum value of 0.4 times 1.4 times S_{DS} resulting in Equation 9. For some applications, the Equipment may be restricted to be installed “at grade” to take advantage of lower demands if the Equipment does not have capacity that meets the criteria in Equations 5 and 6.

$A_{FLX\text{-}H}\,(MAX\ at\ Grade) = 1.0 \cdot S_{DS}$ 8

$A_{RIG\text{-}H}\,(MAX\ at\ Grade) = 0.4 \cdot 0.14 \cdot S_{DS} = 0.56 \cdot S_{DS}$ 9

The acceleration g-level demand to qualify Equipment is defined in Equations 5 and 8 for Flexible Equipment or Rigid Equipment installed on isolation springs. The acceleration g-level demand to qualify Equipment is defined in Equations 7 and 9 for Rigid Equipment (natural frequencies above 16 Hz) rigidly attached to the building structure. The vertical acceleration value is not used in the comparison for demand versus capacity. It is assumed that the vertical acceleration is included in the equipment qualification at a 2/3 fraction of the horizontal acceleration at ground level. So the capacity of the Equipment will be provided for the horizontal g-level that the Equipment can survive and, if necessary, function after the design earthquake seismic event to be compared with the demand g-levels as determined by Equations 5 and 8 or Equations 7 and 9.

6.3 *Derivation of Seismic CRS.* The Seismic Demand of Equipment defined in Section 6.1 is based on AC156 for qualifying Equipment by test. Further discussion defines the Seismic Demand based on natural frequencies to be used to qualify Equipment by analysis. The Seismic Demand derived by the requirements in Section 6.1 for either test or analysis is defined as the CRS.

6.4 *Seismic Demand.* The Seismic Demand on the equipment is selected depending on the type of qualification.

6.4.1 *Demand for Qualification by Testing.* The demand will be provided by the motion of the shake table and the response measured at the equipment attachment. The measured table motion is the demand. This measured table motion shall be in terms of a spectrum as identified in Figure 2 where the peak of the response spectra demand curve will be $A_{FLX\text{-}H}$. This qualification method allows the equipment to yield and approach the strength failure without loss of function.

6.4.2 *Demand for Qualification by Dynamic Analysis.* The maximum horizontal acceleration and coincident vertical acceleration is applied at the equipment attachment. As an example, the demand input for floor mounted equipment would be applied at the base. The dynamic analysis model will result in the applicable responses of the EFRS based on the natural frequencies of the equipment. The shape of the input demand shall match the demand as depicted in Figure 2 where the peak of the response spectra demand curve will be $A_{FLX\text{-}H}$.

This method limits the stress levels below yield. Conservatism of this method to show operability maintains the structure below yield and results in a safety factor of 1.4 from the testing method. The modeling analysis does not accurately account for materials beyond yield. Conditions where yield is present in the results, other methods must be performed to evaluate the elastic behavior. Comprehensive documentation shall be recorded for evaluations of elastic conditions.

6.4.3 *Demand for Qualification by Static Analysis*. The Seismic Design Force equation from ASCE 7 provides a prescriptive approach to determine the horizontal seismic force acting on the center of gravity to be used for equipment attached to the building structure and evaluation of the attachment. The relative horizontal seismic design force can be calculated as a function of S_{DS} as follows:

$$F_P = \frac{0.4\, a_P S_{DS} W_P}{\left({R_P}/{I_P}\right)}\left(1 + 2\frac{z}{h}\right) \qquad 10$$

F_p is not required to be taken as greater than

$$F_P = 1.6\, S_{DS} I_P W_P \qquad 11$$

And F_p shall not be taken as less than

$$F_P = 0.3\, S_{DS} I_P W_P \qquad 12$$

The R_p factor for all equipment with an importance factor I_p = 1.5 shall be a value of 1.5, to assure that the structure remains linear elastic.

6.5 *Seismic Capacity*. The Seismic Capacity shall be determined as prescribed in Section 7 and Section 8.

6.5.1 *Capacity of Equipment When Qualified by Testing or Dynamic Analysis.* The Seismic Capacity shall be the maximum demand value of A_{FLX-H} at which the item of equipment continues to function satisfactorily. For example, if the equipment was qualified to be acceptable and functional when A_{FLX-H} =1.0 g, then the Seismic Capacity is 1.0 g's. Seismic Capacity of equipment does not decrease when elevated in a building, the demand increases. If the equipment is elevated above grade, then the value of the demand A_{FLX-H} shall be calculated per Equation 5 and then compared to the Seismic Capacity. So the demand varies based on equipment location within a building while the capacity of the same item of equipment is a constant.

6.5.2 *Capacity of Equipment When Qualified by Static Analysis.* The Seismic Capacity shall be the F_P/W_P in terms of g-levels and is equal to the largest F_P/W_P that meets the stress limits on the EFRS as defined by industry standards. These stress limits are lower than yield, and result in a conservative methodology. For some cases, the capacity can be expressed in terms of the short period Seismic Capacity that appropriately corresponds to F_P/W_P.

Section 7. Seismic Capacity of Equipment by Analysis

7.1 *Scope and Purpose.* This section establishes the minimum requirements to qualify Equipment by analysis. The purpose is to establish the Seismic Capacity of the Equipment so that the Equipment is operable after a seismic event and maintains structural integrity.

The complexity of the Components and EFRS that transfers the forces generated by motion through the Attachment Points and EFRS will govern the design and the ability to perform the analysis that can qualify the Equipment. Static analysis can only be performed if each force (static equivalent load) can be tracked through the EFRS and the stresses can be calculated for each element and connection of the EFRS to include stresses developed from bending. For more complex Equipment, a dynamic analysis model may be required where the EFRS is modeled and the Components are defined as point loads (masses) or distributed loads on the EFRS.

Analysis shall be performed with the demand applied on the equipment EFRS and Components. The demand shall include load combinations as defined in Section 7.2.9. The operating aspects of the Equipment shall be included in the demand loads to include operating conditions and the state of fluids (e.g. vapor, liquid, solid or ice).

There are many different types of dynamic finite element analysis programs available. These programs can model Equipment using shapes, solids, or shells. The application of the different programs is based on the complexity and elements used to comprise the Equipment structure. Not all Equipment can be defined in terms of structural shapes such as beam elements. Each dynamic finite element analysis program shall be capable to evaluate the structure and determine a response based on a non-linear forcing function.

7.2 *Analysis.* The maximum horizontal acceleration with the coincident vertical acceleration in g-levels shall be applied to each of the Components and the equipment EFRS. The calculated stresses/strengths shall be less than or equal to the allowable stresses/strengths in each Component, each EFRS connection, and each EFRS element.

7.2.1 *Allowables.* Allowable stresses/strengths shall be justified from industry standards (see Section 7.9)

7.2.2 *Demand.* The maximum horizontal acceleration and coincident vertical acceleration is determined from Section 6, Seismic Demand. For a rigid Seismic Demand to be applied, the natural frequency shall be determined by dynamic analysis or other means.

7.2.3 *Verification of Software.* Each dynamic analysis program is required to have independent software verification using sample structures as prescribed in Section 7.5.

7.2.4 *Brackets and Legs.* Analysis of the structural elements shall include brackets that transfer the load from the Components to the EFRS. For example, this includes transfer elements of smaller coils in a face and by-pass arrangement in an air handling unit. Structural elements include the legs integral with elevated Equipment. Thus, the analysis shall address the attachment of the Equipment to the legs and the legs to the building structure and evaluate all forces and moments at each connection. Structural system parameters of the EFRS shall be defined in terms of weight per linear distance, area, moment of inertia, and/or section modulus as applicable.

7.2.5 *Spliced Sections.* The splice sections of modular units shall have an increased factor of safety of 2.0 at the seam of each module. Alternatively the load on the seam from each module shall be evaluated with the load moving in opposite directions, both adding directly to the fastening system of the seam for loads applied perpendicular and loads that apply parallel to the seam.

7.2.6 *Components.* Components may be deemed rugged as identified in Section 5. If Components are not deemed rugged, then these Components shall be evaluated or tested. Component qualification shall be performed as defined in Section 5.

7.2.7 *Elastic Deflections.* All deflections must be maintained below yield unless noted by exception in this section. Dynamic analysis programs cannot evaluate plastic deformation. Deformations shall be determined at all component connection points in relation to all other connection points of the Component. Relative displacement of component Attachments shall be evaluated. If deformation is detected, then other methods, including engineering judgment, shall be performed to determine if the deformation will cause the equipment to be considered not functional. The deflection is permitted to exceed yield as listed in Sections 7.2.7.1 and 7.2.7.2.

7.2.7.1 If plastic deformations (yielding) of the EFRS will not impair the operability of the Equipment.

7.2.7.2 Interpretation of yield response resulting from dynamic analysis programs can be allowed if the yield can be determined using a different method, provided the yield response is less than 1.15 times yield. Failure of the connection is assumed to be at 1.4 times yield resulting in a margin of 20% versus 40% above the yield allowed values.

7.2.8 *Weight.* The total operating weight (100%) shall be accounted for in a reasonable distribution on the EFRS. Additional weight can be added to the Equipment to account for additional devices such as a variable frequency drives or controls.

7.2.9 *Load Combinations.*

The load combination formulas shown in Table 3 are based on two different methods to evaluate EFRS connections. LFRD is a strength based analysis. ASD is a stress based analysis. The demand as defined in the IBC is in terms of LFRD. Conversion is required to apply ASD analysis methods. Use of the vertical demand is in Section 6 (Equation 3 and Equation 4).

Table 3. Load Combinations

ASD	LRFD
$(1.0+0.14 \cdot S_{DS}) \cdot D+H+F+0.7 \cdot \rho \cdot Q_E$	$(1.2+0.2 \cdot S_{DS}) \cdot D+ \rho \cdot Q_E+L+0.2 \cdot S$
$(0.6+0.14 \cdot S_{DS}) \cdot D+0.7 \cdot \rho \cdot Q_E+H$	$(0.9-0.14 \cdot S_{DS}) \cdot D+ \rho \cdot Q_E+1.6 \cdot H$

7.2.10 *Demand Application.* The demand is applied in horizontal and vertical directions. A two-dimensional analysis shall be used for evaluations of Equipment that requires certification to ASCE 7 13.2.1. One horizontal and the vertical are combined in each orthogonal direction. A three-dimensional analysis shall be used for evaluations of Equipment that requires certification to ASCE 7 Section 13.2.2. Two horizontal and the vertical loads are applied simultaneously.

7.3 *Qualification of Components.* The Components shall be evaluated at the elevation where the Component attaches to the EFRS. If the elevation is above the Attachment Point, then an acceleration amplification factor (Component Amplification Factor) shall be added to the demand for the Component. The amplification factor can be determined by dynamic analysis or by shake-table test.

7.4 *Natural frequency.* The identification of the Equipment capacity can take advantage of reduced demand if the Equipment is deemed rigid (natural frequencies above 16 Hz) with a rigid attachment configuration. Evaluation of Equipment to identify the natural frequency requires the use of a dynamic analysis program. The dynamic analysis output will identify the natural frequencies of the equipment's EFRS. If any of the frequencies are below 16 Hz, then the Equipment is considered flexible.

7.5 *Software Verification.* Many commercial software programs such as ANSYS, NASTRAN, GTSTRUDL, SAP2000 and ETABS, that are capable of performing structural analysis, come with a suite of verification problems that are run and compared against known solutions to verify that the software is performing correctly as installed on a given computer and operating system. Often times, however, these problems are very simple and only test certain features of the program.

7.6 *Qualification by Similarity.* In this case, the active or energized Equipment is proven to be inherently rugged by analysis supported by previously qualified Equipment. Equipment can be shown to be rugged by analysis with similarity to other previously qualified Equipment if the Components are similar to previous qualified Equipment and the EFRS can be shown to be linear elastic. As long as the EFRS does not yield from the demand, the Components will not see higher accelerations compared to the previously qualified Equipment. New Components must be qualified to 1.25 times the maximum demand or as required by the amplification factor determined by a dynamic analysis.

7.7 *Analytical Procedures.* There are several analytical procedures that can be used to qualify Equipment defined in Table 4. These analytical procedures are defined in ASCE 7 in detail.

Table 4. Analytical Procedures

Qualification Analysis	Seismic Demand on Nonstructural Components (ASCE 7 Section 13.3)	Equivalent Static Force Procedure (ASCE 7 Section 12.8)	Modal Response Spectrum Analysis (ASCE 7 Section 12.9)[1]	Seismic Response History Procedure (ASCE 7 Chapter 16)
Qualification by Static Analysis without Natural Frequency	X			
Qualification by Static Analysis for Rigid Equipment		X		
Qualification by Dynamic Analysis			X	X

Note:
1. Modal Response Spectrum Analysis shall be used for static Components.

7.8 *Load factors.* The following load factors shall be used for analysis.

7.8.1 Load factor on combined Earthquake effect (E) when using LRFD =1.00
7.8.2 Load factor on combined Earthquake effect (E) when using ASD = 0.70

7.9 *Allowable stresses/strengths*. The design of materials shall be in accordance with the material design chapters of the IBC. The seismic effects (i.e., forces, stresses) under the CRS must be shown to be less than or equal to the design strengths calculated in accordance with one of the applicable standards listed in Appendices A and B.

7.10 *Deformations and Deflections*. The deformation or deflection of the EFRS shall be determined. Relative displacements shall be defined and applied to internal components (i.e. piping and conduit) and included as an additional demand load on the components affected by the deformations.

Section 8. Seismic Capacity of Equipment by Testing

8.1 *Scope and Purpose.* This section establishes the minimum requirements for Equipment Qualification by Testing (EQT) for Equipment identified in Section 5. The purpose is to establish the desired input motion that defines the capacity of the Equipment to withstand seismic events and maintain their Functional Requirements. AC156 is the governing document for qualification by testing. Additional requirements and allowances are provided in this section.

8.2 *Qualification Test Plan.* This section details the necessary equipment information to be provided by the manufacturer to the laboratory performing the test.

8.2.1 *Manufacturer Information.* Provide manufacturer's information per AC156.

8.2.2 *EQT Description.* A description of the EQT shall be provided, including the following items:

8.2.2.1 Product Name.
8.2.2.2 Equipment model number and serial number of specific product tested.
8.2.2.3 Functional Requirements.
8.2.2.4 Detailed description of the equipment's EFRS to include all subassemblies.
8.2.2.5 Overall dimensions and weight of Equipment.

8.2.2.6 Any restrictions or limitations on equipment use.

8.2.3 *Code Parameters.*

8.2.3.1 *Building Code.* List the version of the IBC.

8.2.3.2 *Importance Factor.* Specify the importance factor. The I_p value will dictate the functionality requirements.

8.2.4 *Performance Requirements.* Detailed description of the Performance Requirements, or operational test parameters, used to verify Functional Requirements before and after the test. See Table 5.

8.2.5 *Equipment Product Line Extrapolation and Interpolation.* For equipment product line information as required per AC156.

8.2.6 *Installation Instructions.* A description shall be provided that describes how the Equipment is installed in the field and how the Equipment shall be installed on the shake table that represents the field installation.

8.2.7 *Special Test Requirements.* The equipment manufacturer shall list test requirements that may be deemed special or beyond normal seismic qualification testing (i.e., specific EFRS displacements, acceleration monitoring, etc.).

8.3 *Testing Laboratories.* Testing laboratories as defined per AC156.

8.4 *Product Sampling.* Product sampling as defined in AC156.

8.5 *Seismic Qualification Test Procedure*

8.5.1 *Test.* AC156 shall be strictly adhered to for completion of the test.

8.5.2 *Post-test Performance Inspection and Verification.* For Equipment with an importance factor of 1.5, the Equipment being qualified must be capable of performing its Functional Requirements after the seismic event. The Equipment shall be visually examined and results documented upon completion of the shake table tests. The Equipment shall not pose a life-safety hazard due to collapse or major subassemblies becoming separated. Structural integrity of the anchorage system shall be maintained. Structural damage, such as local yielding of the force-resisting members is acceptable and structural members and joints comprising the force-resisting system shall be allowed minor fractures and anomalies. Allowable minor damage shall be reviewed against the criteria in Table 5

8.5.3 *Alternative Post-test Performance Test.* Alternative Performance testing requirements performed on the Equipment to verify post-test compliance may be performed by the testing laboratory or at the equipment manufacturing facility. The Equipment shall satisfy the Performance Requirements and/or tests specified by the manufacturer. Results shall be equivalent to those of the pre-test functional compliance testing or within tolerances defined in Table 5 and Table 6. Materials deemed to be hazardous shall not have been released into the environment in quantities greater than the exempted amounts listed in the applicable codes. Any repairs shall be documented and included in the final test report.

Table 5. Functional Requirements for Designated Seismic Systems[1,2,3,4]

Equipment	Functional Requirements
Vertical Packaged AC Units Packaged Terminal AC Units Water Source Heat Pumps Unitary Small AC Units Unitary Large AC Units (above 19,050 Watts) Dehumidifiers	Controls operate by restoring power and reset. Functional test the controls capability to reposition Components or start/stop Components. Electric motors shall be functional. Rotating air moving Components shall be functional. Refrigerant flow Components shall be functional. Liquid flow Components shall be functional. Heat exchangers shall be functional.
Large Water or Air Cooled Chillers with Screw or Centrifugal Compressors Water or Air Cooled Chillers with Screw or Scroll Compressors in a framed structure	Controls operate by restoring power and reset. Functional test the controls capability to reposition Components or start/stop Components. Electric motors shall be functional. Rotating air moving Components shall be functional. Refrigerant flow Components shall be functional. Liquid flow Components shall be functional. Heat exchangers shall be functional.
Air Handling Units Furnaces Fan-Coils Unit Unit Ventilators Air-to-Air Exchangers Fans	Controls operate by restoring power and reset. Functional test the controls capability to reposition Components or start/stop Components. Electric motors shall be functional. Rotating air moving Components shall be functional. Liquid flow Components shall be functional. Heat exchangers shall be functional.
Humidifiers	Controls operate by restoring power and reset. Functional test the controls capability to reposition Components or start/stop Components. Electric motors shall be functional. Rotating air moving Components shall be functional. Liquid flow/containment Components shall be functional.
Tanks	Liquid flow/containment Components shall be functional.

Notes:

Performance requirement testing can be performed as an alternative to Functional Requirements to ensure Equipment meets the Functional Requirements defined in Table 2. Performance Requirements are defined as follows:

1. Allow a maximum of 20% air flow reduction by leakage through housing or access doors or fan performance.
2. Allow a variance from the design performance for heat removal or addition of +/- 15%.
3. Allow a variance from the design performance for adding moisture of +/- 15%.
4. Allow a variance from the design performance for removing moisture of +/- 15%.

Table 6. Allowable Minor Damage States for Designated Seismic Systems

Equipment	Allowable Minor Damage States[1,2]
Vertical Packaged AC Units Packaged Terminal AC Units Water Source Heat Pumps Unitary Small AC Units Unitary Large AC Units (above 19,050 Watts) Dehumidifiers	Component freely rotates and has no visible deformation of the Component's Equipment Force Resistance System (EFRS). Equipment that provides airflow has no visible deformation of the EFRS/housing (envelope) and no visible separation of access doors or EFRS/housing (envelope). No visible or minimal deformation of the piping systems (with no leakage), refrigerant retaining Components and EFRS. No visible deformation of the piping system, water retaining Components and EFRS. Failure of personnel lighting and minor deformation of electrical power/control conduit. Minor deformation of standing seems construction is allowed only if the deformation does not affect the functionality of any required Component.
Large Water or Air Cooled Chillers with Screw or Centrifugal Compressors Water or Air Cooled Chillers with Screw or Scroll Compressors in a framed structure	No visible or minimal deformation of the piping systems (with no leakage), refrigerant retaining Components and EFRS. No visible deformation of the piping system, water retaining Components and EFRS. Failure of personnel lighting and minor deformation of electrical power/control conduit. Minor deformation of standing seems construction is allowed only if the deformation does not affect the functionality of any required Component.
Air Handling Units Furnaces Fan-Coils Unit Unit Ventilators Air-to-Air Exchangers Fans	Component freely rotates and has no visible deformation of the Components EFRS. Equipment that provides airflow has no visible deformation of the EFRS/housing (envelope) and no visible separation of access doors or EFRS/housing (envelope). Failure of personnel lighting and minor deformation of electrical power/control conduit. Minor deformation of standing seam construction is allowed only if the deformation does not affect the functionality of any required Component.
Humidifiers	Component freely rotates and has no visible deformation of the Components EFRS. Equipment that provides airflow has no visible deformation of the EFRS/housing (envelope) and no visible separation of access doors or EFRS/housing (envelope). No visible deformation of the piping system, water retaining Components and EFRS. Failure of personnel lighting and minor deformation of electrical power/control conduit. Minor deformation of standing seam construction is allowed only if the deformation does not affect the functionality of any required Component.
Tanks	No visible deformation of the piping system, water retaining Components and EFRS.

Notes:

1. Allowable minor damage states define the effects from the qualification test which may result in lower equipment performance and still meets a minimal functional requirement and is considered operable.
2. Allowable minor damage states are applicable for inspection of shake table testing. Equipment is defined by ASCE 7 Section 13.2.2 to be operable after an earthquake. Importance factor shall be 1.5.

Table 7. Allowable Minor Damage States for Components of Designated Seismic System Equipment[3]

Components	Class	Functional Requirements[1]	Allowable Minor Damage States[2]
ASME Pressure Vessels	Rugged	Specification not required	Specification not required
Coils	Rugged	Specification not required	Specification not required
Control Panels	Energized	Provide electrical, pneumatic and electronic signals to Equipment	Allow control reset using control panel when power is restored.
Dampers	Simple	Damper blades continue to rotate as demanded by actuator.	No plastic deformation of damper blades or framing material.
Flow and Contamination Controls	Rugged	Specification not required	Specification not required
Gas Manifolds	Simple	Provide control and ignition of flammable material in a metal heat exchanger.	No plastic deformation of base material. No leakage of gas is allowed.
Internal Piping	Simple	Transfer a fluid medium within Equipment.	Minor permanent bending of ductile pipe without leaking.
Internal Conduits	Simple	Transfer a fluid medium within Equipment.	Minor permanent bending of ductile conduit without parts separating exposing cables to be damaged.
Motors	Rugged	Specification not required	Specification not required
Refrigeration Compressors	Rugged	Specification not required	Specification not required
Variable Frequency Drives	Energized	Provide varying electric power signal to motors.	Allow control reset using control panel when power is restored.

Notes:

1. Functional Requirements defines the functions that the Equipment performs when in operation. Performance Requirements are measurable parameters that when performed during a functional test proves that the Functional Requirements are met.
2. Allowable minor damage states define the effects from the qualification analysis or test which may result in lower equipment performance and still meets a minimal functional requirement to be operable.
3. Equipment is defined per ASCE 7 Section 13.2.2 to be operable after an earthquake. Importance factor shall be 1.5.

Section 9. Report Requirements

9.1 *Purpose.* The purpose of this section is to establish requirements for final test/analysis certification reports.

9.2 *Analysis Report.* The report shall have the following information.

9.2.1 *Executive Summary.*

9.2.1.1 *Analysis Agent.* Agent's name, address, contact information, and phone number.

9.2.1.2 *Analysis Agent Qualification.* Provide qualification documentation of analysis agent.

9.2.1.3 *Signatures.* Signatures (dated) and titles (or equivalent identification) of persons approving the analysis report.

9.2.1.4 *Objective.* State the objective of the analysis which is usually to establish the maximum horizontal and vertical spectral accelerations that can be imposed on the Equipment and satisfy the acceptance criteria.

9.2.1.5 *Methodology.* Provide a complete explanation of the methods used to apply the demand and the analysis techniques used to determine the performance of the EFRS of the Equipment or Component. Describe the analysis used to evaluate the loads at the Attachment Points of the Equipment to the building structure and the Components to the EFRS.

9.2.1.6 *Assumptions.* List assumptions used in the analysis and their justification.

9.2.1.7 *Conclusions.* Provide the results of the analysis and include a statement of functionality. For designated seismic system Equipment, results of the Performance Requirements that prove the Functional Requirements are maintained shall be summarized. An explanation of any deficiencies shall be provided with justification if the Equipment is still qualified.

9.2.1.8 *Structural Features.* A rationale shall be provided explaining why the equipment structural configuration is representative of the product line and options included in the seismic qualification. The force-resisting structural configurations shall be similar to all products within the product line. If the structural configuration or EFRS is not represented by the selected sample for analysis, then these unit(s) shall be analyzed separately.

9.2.2 *Manufacturer Information.*

9.2.2.1 *Equipment Manufacturer Information.* Manufacturer's name, manufacturer's address, primary contact, and phone number for all correspondence regarding the seismic qualification per this procedure.

9.2.2.2 *Functional Requirements.* Provide a description of the equipment's overall function.

9.2.2.3 *Model Number/Serial Number.* Supply the manufacturer's unique identification number and/or serial number.

9.2.2.4 *Equipment Designation.* Short designator used for the analysis

9.2.2.5 *Product Description.* A detailed description of the Equipment

9.2.2.6 *Dimensions.* Height, width, and depth

9.2.2.7 *Weight.* Operating weight of the Equipment and all associated additional weights included in the analysis

9.2.2.8 *Restrictions.* Provide restrictions or limitations on use of the Equipment.

9.2.3 *Code Parameters.*

9.2.3.1 *Building Code.* List the version of the IBC

9.2.3.2 *Importance Factor.* Specify the importance factor. The I_p value will dictate the functionality requirements.

9.2.4 *Performance Requirements.* Detailed description of the Performance Requirements, or operational parameters, used to verify Functional Requirements for $I_p = 1.5$.

9.2.5 *Installation Instructions.* A description shall be provided that describes how the Equipment is installed in the field.

9.2.6 *Details.*

9.2.6.1 General arrangement drawings

9.2.6.2 Provide the inputs used in the calculation to include but not limited to the Seismic Demand, assumed flexibility of the equipment, restrictions (e.g. not allowed to be isolated or installed above grade) and materials (properties and allowable loads/stresses) used in the construction of the Equipment or Component. All options that are available on the Equipment included in the certification.

9.2.6.3 Location of Components and Attachment Points

9.2.6.4 Details of all connections

9.2.6.5 Qualification of Components

9.2.6.6 Assemblies

9.6.2.7 Modular sections (including splice bolting/welding requirements)

9.6.2.8 Internal piping affected by motion to include piping that crosses splice connections

9.2.7 *Results.* This section is used for the actual calculations. Results shall include the stresses and deflections from the seismic loads and other loads. Identify all locations where the dynamic analysis results show deflections or deformations that suggest that the EFRS has exceeded yield.

9.2.8 *Computer Programs.* Provide validation documentation of computer programs.

9.2.9 *Specific Report Requirements.* Reports shall be submitted in their entirety and shall include at least the following:

9.2.9.1 *Report Identification Number.* Each report shall have a unique identification number. Each page of the report shall include this identification number to ensure that each page is part of the same test report.

9.2.9.2 *Page Numbers.* The report shall be paginated and the total number of pages indicated on the first page.

9.2.9.3 *Date*. The report date shall be included.

9.2.10 *Appendices.* The report shall provide additional information that is pertinent to the analysis, such as graphs, calculations, drawings, photographs, and interpretation of results, if required.

9.3 *Seismic Shake Table Test Report.* The report shall have the following information.

9.3.1 *Executive Summary.*

9.3.1.1 *Laboratory Information.* Test laboratory's name, address, contact information and phone number

9.3.1.2 *Laboratory Qualification.* Provide qualification documentation in the form of a certificate for accredited or approved laboratories or provide documentation of compliance to this standard for laboratories that are not approved.

9.3.1.3 *Signatures.* Signatures (dated) and titles (or equivalent identification) of persons approving the test report.

9.3.1.4 *Assembly of test specimen.* Report shall identify the parties constructing the assemblies.

9.3.1.5 *Test results and conclusions.* Provide the results of the testing and include the verification of functionality for I_p = 1.5. Results of the Performance Requirements that prove the Functional Requirements are maintained after the shake table test shall be summarized. A statement shall indicate whether the product passed or failed. Failure shall be described to include the specific items that failed and the failure mode. An explanation of any deviation or anomalies shall be provided with justification if the Equipment is still qualified.

9.3.2 *Manufacturer Information.*

9.3.2.1 *Equipment Manufacturer Information.* Manufacturer's name, manufacturer's address, primary contact, and phone number for all correspondence regarding the seismic qualification testing per this procedure

9.3.2.2 *Functional Requirements.* Provide a description of the equipment's overall function.

9.3.2.3 *Model Number/Serial Number.* Supply the manufacturer's unique identification number and/or serial number.

9.3.2.4 *Equipment Designation.* Short designator used for plotting and test run purposes.

9.3.2.5 *Product Description.* A detailed description of the Equipment. This shall include major subassemblies and Components (e.g., bills of material) and any other applicable product information.

9.3.2.6 *Dimensions.* Height, width, and depth

9.3.2.7 *Weight.* Weight of the Equipment and all associated additional weights provided for the test.

9.3.2.8 *Restrictions.* Provide restrictions or limitations on use of the Equipment.

9.3.3 *Code Parameters*.

9.3.3.1 *Building Code.* List the version of the IBC.

9.3.3.2 *Importance Factor.* Specify the importance factor. The *Ip* value will dictate the functionality requirements.

9.3.4 *Performance Requirements.* Detailed description of the Performance Requirements, or operational test parameters, used to verify Functional Requirements before and after the test for I_p = 1.5.

9.3.5 *Equipment Product Line Extrapolation and Interpolation.* Reporting requirements as defined in AC156.

9.3.6 *Installation Instructions.* A description shall be provided that describes how the Equipment is installed in the field and how the Equipment shall be installed on the shake table that represents the field installation.

9.3.7 *Special Test Requirements.* The equipment manufacturer shall list test requirements that may be deemed special or beyond normal seismic qualification testing (i.e., specific EFRS displacements, acceleration monitoring, etc.).

9.3.8 *Product sampling.* Provide evidence that the Equipment is in compliance to Section 8.4.

9.3.9 *Seismic Qualification Test Procedure.* Provide a description of the test procedure and documentation in compliance with Section 8.5.

9.3.10 *Specific Report Requirements.* Test reports shall be submitted in their entirety and shall include at least the following:

9.3.10.1 *Report Identification Number.* Each report shall have a unique identification number. Each page of the report shall include this identification number to ensure that each page is part of the same test report.

9.3.10.2 *Page Numbers*. The report shall be paginated and the total number of pages indicated on the first page.

9.3.10.3 *Date*. The report shall include the date of testing and report date.

9.3.11 *Test data*. Test data shall include proof of performance, TRS plots, acceleration time histories of the shake table input motion, 5% damped response spectra of the table motion compared with the qualification spectra, transmissibility plots, EQT weight, test monitoring calibrations, etc.

Section 10. Seismic Rating of Equipment

10.1 *Scope.* Seismic rating of the Equipment is based on testing or analysis that defines the maximum earthquake acceleration in terms of Seismic Capacity g-values that the Equipment can withstand and maintain its structural integrity and, if required, be functional after the Design Earthquake. The Equipment is rated up to the CRS value based on analysis or test.

APPENDIX A. REFERENCES – NORMATIVE

A1 Listed here are all the standards, handbooks, and other publications essential to the formation and implementation of the standard. All references in this appendix are considered part of this standard.

A1.1 2012 *International Building Code®*, International Code Council, 4051 West Flossmoor Road, Country Club Hills, IL 60478.

A1.2 AC156, *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components and Systems*, 2007, ICC Evaluation Service, Inc. Whittier, California: ICC-ES.

A1.3 ASCE Standard SEI/ASCE 7-10. Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers. 1801 Alexander Bell Drive, Reston, Virginia 20191.

A1.4 *ASHRAE Terminology*, https://www.ashrae.org/resources--publications/free-resources/ashrae-terminology, 2015, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

APPENDIX B. REFERENCES – INFORMATIVE

B1 Listed here are standards, handbooks, and other publications which provide additional information.

B1.1 AA ADMI-05, "Aluminum Design Manual". The Aluminum Association, 1525 Wilson Blvd. Suite 600, Arlington, VA 22209.

B1.2 AA ASM 35-00, "Aluminum Sheet Metal Work in Building Construction". The Aluminum Association, 1525 Wilson Blvd. Suite 600, Arlington, VA 22209.

B1.3 ACI 371R, *Guide to the Analysis, Design, and Construction of Concrete-Pedestal Water Towers*, 1998, applies to ASCE 7 Section 15.7.10.7. American Concrete Institute, 38800 Country Club Drive, Farmington Hills, MI 48331.

B1.4 ANSI/IEEE Standard 344-1987, *IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations* (1987), Institute of Electrical and Electronics Engineers, Inc. American National Standards Institute, 25 West 43rd Street, Fourth Floor, New York, NY 10036.

B1.5 ANSYS, Inc., *ANSYS*, 275 Technology Drive Canonsburg, PA 15317.

B1.6 API 12B, *Bolted Tanks for Storage of Production Liquids, Specification 12B, 14th edition*, 1995, applies to ASCE 7 Section 15.7.8.2. American Petroleum Institute, 1220 L Street, NW Washington, DC 20005.

B1.7 API 620, *Design and Construction of Large, Welded, Low Pressure Storage Tanks, 10th edition*, 2002, applies to ASCE 7 Sections 15.4.1, 15.7.8.1 and 15.7.13.1. American Petroleum Institute, 1220 L Street, NW Washington, DC 20005.

B1.8 API 650, *Welded Steel Tanks for Oil Storage, 10th edition*, Addendum 4, 2006, applies to ASCE 7 Sections 15.4.1, 15.7.8.1 and 15.7.9.4. American Petroleum Institute, 1220 L Street, NW Washington, DC 20005.

B1.9 API 653, *Tank Inspection, Repair, Alteration, and Reconstruction, 3rd edition*, 2001, applies to ASCE 7 Sections 15.7.6.1.9. American Petroleum Institute, 1220 L Street, NW Washington, DC 20005.

B1.10 AWWA D100, *Welded Steel Tanks for Water Storage*, 2006, applies to ASCE 7 Sections 15.4.1, 15.7.7.1, 15.7.9.4, 15.7.10.6 and 15.7.10.6.2. American Water Works Association, 6666 W. Quincy Ave., Denver CO 80235.

B1.11 AWWA D103, *Wire and Strand-Wound Circular Pre-stressed Concrete Water Tanks*, 1995, applies to ASCE 7 Sections 15.7.7.3. American Water Works Association, 6666 W. Quincy Ave., Denver CO 80235.

B1.12 AWWA D115, *Circular Pre-stressed Concrete Tanks with Circumferential Tendons*, 1995, applies to ASCE 7 Section 15.7.7.3. American Water Works Association, 6666 W. Quincy Ave., Denver CO 80235.

B1.13 Computers and Structures, Inc., *ETABS*, 1995 University Avenue, Suite 540 Berkeley, CA 94704.

B1.14 Computers and Structures, Inc., *SAP2000*, 1995 University Avenue, Suite 540 Berkeley, CA 94704.

B1.15 Georgia Tech Univeristy, *GTSTRUDL*, Structural Design & Analysis Software, Atlanta, Georgia 30332-0355.

B1.16 IEEE Standard 693-1997, *IEEE Recommended Practice for Seismic Design of Substations* (1997), Institute of Electrical and Electronics Engineers, Inc. 3 Park Avenue, 17th Floor New York, NY 10016.

B1.17 MSC Software, *NASTRAN*, Accurate, Efficient & Affordable Finite Element Analysis, 2 MacArthur Place Santa Ana, CA 92707.

B1.18 NFPA 59A, *Production, Storage, and Handling of Liquefied Natural Gas (LNG)*, 2006, applies to ASCE 7 Section 15.4.8. National Fire Protection Association, 1, Battery Park, Quincy, Massachusetts, 02169.

APPENDIX C. ASCE 7 COMMENTARY C13 SEISMIC DESIGN REQUIREMENTS FOR NONSTRUCTURAL COMPONENTS - INFORMATIVE

The following commentary is included in ASCE/SEI 7-10.

C13.2.2 Special Certification Requirements for Active Designated Seismic Systems:

This section addresses the qualification of active designated seismic equipment, its supports, and attachments with the goal of improving survivability and achieving a high level of confidence that a facility will be functional following a Design Earthquake. Active equipment has parts that rotate, move mechanically, or are energized during operation. Active designated seismic equipment constitutes a limited subset of designated seismic systems. Failure of active designated seismic equipment itself may pose a significant hazard. For active designated seismic equipment, failure of structural integrity or loss of function are to be avoided.

Examples of active designated seismic equipment include mechanical (HVAC & refrigeration) or electrical (power supply distribution) equipment, medical equipment, fire pump equipment, and uninterruptible power supplies for hospitals.

Evaluating post-earthquake operational performance for active equipment by analysis generally involves sophisticated modeling with experimental validation and may not be reliable. Therefore, the use of analysis for active or energized components is not permitted unless a comparison can be made to components that have otherwise been deemed as rugged. As an example, a transformer is energized but contains components that can be shown to remain linearly elastic and are inherently rugged. On the other hand, switch equipment that contains fragile components is similarly energized but not inherently rugged, and therefore cannot be certified solely by analysis. For complex components, testing or experience may therefore be the only practical way to ensure that the equipment will be operable following a Design Earthquake. Past earthquake experience has shown that most active equipment is inherently rugged. Therefore, evaluation of experience data together with analysis of anchorage is adequate to demonstrate compliance of active equipment such as pumps, compressors and electric motors. In other cases, such as for motor control centers and switching equipment, shake table testing may be required.

As a rule of thumb, active mechanical and electrical equipment to be considered under 13.2.2 can be limited to equipment that contains an electric motor greater than 7.5kW or heat transfer capacity greater than 59kWh. Components with lesser motor hp and thermal exchange capacity are generally considered to be small active components and are deemed rugged. Exceptions to this rule may be appropriate for specific cases, such as elevator motors that have higher horsepower but have been shown by experience to be rugged. Analysis is still required to ensure the structural integrity of the non-active component. For example, a 53kW condenser would require analysis of the load path between the condenser fan and coil to the building structure attachment.

APPENDIX D. SEISMIC DESIGN OF LIQUID STORAGE TANKS - INFORMATIVE

D1.1 *Scope*. This appendix is limited to the evaluation of liquid storage tanks and does not address the design of their foundations or supporting structures. For tanks supported within building structures on elevated levels (ASCE 7 Section 15.3), appropriate building amplification of seismic ground motion should be considered when deriving the seismic forces on the tank. This section does not apply to small metal housings used in humidifiers.

D1.2 *General.* Any structure having a primary purpose of retaining a significant volume of liquid within its boundaries is considered to be a liquid storage tank. The perimeter may be of any shape but will be approximated as cylindrical, rectangular or a combination of both for analysis purposes within the scope of this appendix. The structure may be of any material, may be located above or below ground and may be internal or external to building structures.

The ability of a liquid storage tank to retain the liquid within its boundaries is a passive function determined by the structural and leak integrity of the tank under the loads to which it is subjected. There may also be active functions associated with keeping the liquid within the tank boundaries, such as the closure of open isolation valves on piping penetrating the tank boundaries or shutting down pumps that could otherwise empty the tank. A tank could also be part of system that has passive and active functional requirements in addition to liquid retention.

Those tank structures having full covers are considered closed. The covers of closed tanks may be subject to internal forces resulting from liquid sloshing caused by seismic excitation if adequate freeboard height is not provided.

Tanks without full covers are considered open. Sloshing could result in some of the liquid spilling over the walls of the tank during a seismic event if adequate freeboard height is not provided.

D1.3 *Description***.** Liquid storage tanks may contain structures such as internal structural elements, roof supports, piping, baffles or heat exchanger tube bundles within their boundaries. Normally wetted structures such as baffles and heat exchanger tube bundles are likely to inhibit liquid sloshing by creating significant resistance to relative fluid movement. Structures that are contained within liquid-containing structures are defined in ASCE 7 Section 15.6.4 as “Special Hydraulic Structures” and are required in Section 15.6.4.1 Design Basis to be designed for the hydrodynamic rigid body and sloshing forces that result from seismic excitation.

A complete or partial loss of liquid inventory could result from the loss of tank structural integrity and/or liquid sloshing. For hazardous liquids such a loss could result in a significant safety hazard. For non-hazardous liquids a loss of inventory could result in a significant safety hazard where, for instance, drowning or electrocution could result from contact with the escaping liquid. In addition, the loss of liquid inventory could adversely impact the function of nearby structures and/or equipment that are important to safety.

ASCE 7 Chapter 13 Seismic Design Requirements for Nonstructural Components, Section 13.1.5 Applicability of Nonstructural Component Requirements, defines “non-building structures” as being those nonstructural components whose weight is greater than or equal to 25% of the effective seismic weight of the building to which they are attached. This section defers to Chapter 15 for the design of non-building structures (including storage racks and tanks) that are supported by other structures. This is interpreted to include all tanks regardless of weight since Chapter 15 provides special requirements for these structures in Section 15.7 Tanks and Vessels. Tanks that are self-supported are also included within the scope of Chapter 15.

Liquid storage tanks are considered, herein, to be “Non-building Structures not Similar to Buildings” whose design requirements are specified in ASCE 7 Chapter 15 rather than “Nonstructural Components” whose design requirements are specified in Chapter 13.

D1.4 *Liquid Seismic Mass*.

D1.4.1 Where wetted structures internal to a tank are expected to offer little resistance to fluid movement the contained liquid mass shall be partitioned into a convective and impulsive component determined in accordance with standard methods. Sloshing due to the convective component shall be considered.

D1.4.2 If wetted structures internal to a tank are expected to offer significant resistance to fluid movement (such as baffles or heat exchanger tube bundles) then the liquid mass bounded by the internals shall be considered entirely impulsive.

D1.4.2.1 Sloshing can be ignored if there is no liquid above the wetted internal structures. Otherwise, that portion of the liquid above the internals shall be considered convective and sloshing will be considered.

D1.4.2.2 That portion of the liquid mass outside the bounds of the internal structures shall be added to the tank mass.

D1.4.2.3 That portion of the liquid mass bounded by the internal structures shall be added to the mass of the internals when the relative movement between the internals and the tank can be shown to be small (i.e. rigid behavior).

D1.4.2.4 That portion of the liquid mass bounded by the internal structures shall be added to the mass of the tank when the relative movement between the internals and the tank are expected to be significant (i.e. flexible behavior).

D1.4.2.5 Alternatively the entire liquid mass may be added to either the internal structures or the tank whichever is more limiting.

APPENDIX E. SOFTWARE VALIDATION - NORMATIVE

E1.1 *Representative Solutions.* It is the end users responsibility to verify that software used in analysis produces results that are reasonable for problems similar to those for which it is being used. This can be accomplished by finding representative problems with known solutions from literature or from the results of other previously verified programs. Representative problems must use program features similar to those for which a solution is desired. For instance, a typical dead weight and seismic analysis of simple equipment or structures will use beam elements for modeling, static methods for the dead weight analysis and dynamic response spectrum methods for the seismic analysis. The response spectrum method requires that modal analysis be performed. The seismic forces, moments and stresses for each mode will be typically post processed into a combined load set using square root sum of squares (SRSS) or complete quadratic combination (CQC) methods. The individual load sets for X, Y & Z directions of loading may then be combined by SRSS into a final load set. The stress results of analysis will typically be post-processed for comparison to allowables for a structural code such as AISC. Therefore, a representative set of problems shall include all of these features individually or in combination.

E1.2 *Processing Results.* The post processing of results can often be verified manually with a sampling of results. For instance, the SRSS combination of X, Y & Z seismic results can be verified when the individual results are available. Likewise, stress comparisons to AISC allowables can be manually verified when the individual components of stress are available.

E1.3 *Model Samples.* Models that use solid and/or shell elements can be compared to known solutions from a source such as "Roark's Formulas for Stress and Strain". A collection of verification problems is available from http://www.comp-engineering.com/manuals.htm or from SAP2000 "Manuals and ETABS Manuals sections". The "Software Verification Examples" for the ETABS program are well suited for frame analysis problems and include some shell type solutions as well. The example problems "Problem A thru Problem Z" for SAP2000 are for models such as simple cantilevered beams and walls but include other more complex examples of shell element models.