ACCEPTANCE CRITERIA FOR SEISMIC CERTIFICATION BY SHAKE-TABLE TESTING OF NONSTRUCTURAL COMPONENTS

AC156

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PREFACE

Evaluation reports issued by ICC Evaluation Service, LLC (ICC-ES), are based upon performance features of the International family of codes and other widely adopted code families, including the Uniform Codes, the BOCA National Codes, and the SBCCI Standard Codes. Section 104.11 of the *International Building Code*® reads as follows:

> The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

Similar provisions are contained in the Uniform Codes, the National Codes, and the Standard Codes.

This acceptance criteria has been issued to provide all interested parties with guidelines for demonstrating compliance with performance features of the applicable code(s) referenced in the acceptance criteria. The criteria was developed and adopted following public hearings conducted by the ICC-ES Evaluation Committee, and is effective on the date shown above. All reports issued or reissued on or after the effective date must comply with this criteria, while reports issued prior to this date may be in compliance with this criteria or with the previous edition. If the criteria is an updated version from the previous edition, a solid vertical line (|) in the margin within the criteria indicates a technical change, addition, or deletion from the previous edition. A deletion indicator (→) is provided in the margin where a paragraph has been deleted if the deletion involved a technical change. This criteria may be further revised as the need dictates.

ICC-ES may consider alternate criteria, provided the report applicant submits valid data demonstrating that the alternate criteria are at least equivalent to the criteria set forth in this document, and otherwise demonstrate compliance with the performance features of the codes. Notwithstanding that a product, material, or type or method of construction meets the requirements of the criteria set forth in this document, or that it can be demonstrated that valid alternate criteria are equivalent to the criteria in this document and otherwise demonstrate compliance with the performance features of the codes, ICC-ES retains the right to refuse to issue or renew an evaluation report, if the product, material, or type or method of construction is such that either unusual care with its installation or use must be exercised for satisfactory performance, or if malfunctioning is apt to cause unreasonable property damage or personal injury or sickness relative to the benefits to be achieved by the use of the product, material, or type or method of construction.

Acceptance criteria are developed for use solely by ICC-ES for purposes of issuing ICC-ES evaluation reports.

ACCEPTANCE CRITERIA FOR SEISMIC CERTIFICATION BY SHAKE-TABLE TESTING OF NONSTRUCTURAL COMPONENTS (AC156)

1.0 INTRODUCTION

1.1 Purpose: The purpose of this criteria is to establish minimum requirements for the seismic certification by shake-table testing of nonstructural components to be recognized in ICC Evaluation Service, LLC, evaluation reports in accordance with the 2006 or 2009 *International Building Code*® (IBC). The basis of recognition is IBC Section 104.11.

The reason for the development of this criteria is to provide detailed procedures for seismic certification by testing of nonstructural components as an alternative to code-prescribed requirements.

1.2 Scope: This acceptance criteria is applicable for shake-table testing of nonstructural components that have fundamental frequencies greater than or equal to 1.3 Hz, as permitted by Section 13.2.5 of ASCE 7. This criteria is not intended to evaluate effects of relative displacements on nonstructural components as required by Section 13.3.2 of ASCE 7. Testing done in accordance with this criteria is intended to support data for the seismic certification of architectural, mechanical, electrical and other nonstructural systems, components, and elements permanently attached to structures, as specified in Section 1708.4 of the 2009 IBC or Section 1708.5 of the 2006 IBC, and Section 13.2 of ASCE 7.

1.3 Codes and Referenced Standards:

1.3.1 2009 and 2006 *International Building Code*® (IBC), International Code Council.

1.3.2 ASCE Standard, SEI/ASCE 7-10, Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers.

1.3.3 ASCE Standard, SEI/ASCE 7-05, Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers.

1.3.4 FEMA 461, Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components, June 2007, Federal Emergency Management Agency.

1.3.5 IEEE Standard 344-2004, *IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations*, IEEE.

2.0 NOMENCLATURE:

The following symbols and notations have the noted meaning in this document:

S_{DS} = Design spectral response acceleration at short period, as determined in Section 1613.5.4 of the IBC.

z = Height of structure (in feet or mm) with respect to grade, at point of attachment of the component. For items at or below the base, z shall not be taken to be less than 0.0.

h = Average building/structure roof height (in feet or mm) relative to the base elevation.

z/h = Height factor ratio. For nonstructural components located at grade or below, z/h = 0.

R_p = Component response modification factor. R_p represents the energy absorption capability of the component structure and its attachments, set forth in Table 13.5-1 or 13.6-1 of ASCE 7.

I_p = Component importance factor, as set forth in Section 13.1.3 of ASCE 7.

$A_{FLX\text{-}H}$ = Horizontal spectral acceleration calculated for flexible components.

$A_{FLX\text{-}V}$ = Vertical spectral acceleration calculated for flexible components at z/h = 0.

$A_{RIG\text{-}H}$ = Horizontal spectral acceleration calculated for rigid components.

$A_{RIG\text{-}V}$ = Vertical spectral acceleration calculated for rigid components at z/h = 0.

a_p = In-structure component amplification factor. The a_p represents the dynamic amplification of the component at the fundamental frequency of the building structure.

F_p = Horizontal seismic design force centered at the component's center of gravity, and distributed relative to the equipment's mass distribution (lbf or N).

W_p = Component operating weight (lbf or N).

3.0 DEFINITIONS:

3.1 Attachments: The means by which components are secured or restrained to the supporting structure or foundation. Examples may include anchor bolting, welded connections, mechanical fasteners and isolators.

3.2 Biaxial Test: A dynamic test in which the test specimen is subjected to acceleration in one principal horizontal axis and the vertical axis simultaneously. The horizontal and vertical acceleration components are derived from two different input signals that are phase-incoherent.

3.3 Build-hold-decay (BHD): The time interval envelope (5 + 0 / – 3 seconds, 20 + 6 / – 0 seconds and 5 + 0 / – 3 seconds, respectively) imposed on the drive signal of the shake table to simulate the nonstationary nature of an earthquake event. The build time includes time necessary for acceleration ramp-up, the hold time represents the earthquake strong motion time duration, and the decay time includes the de-acceleration ring down time. A straight linear approximation is acceptable.

3.4 Damping: An energy dissipation mechanism that reduces the amplification and broadens the vibratory response in the region of resonance in the frequency domain. Damping is expressed as a percentage of critical damping. This criteria is based on 5 percent of critical damping.

3.5 Flexible Component: Component, including its attachments and force-resisting structural members, having a fundamental period greater than 0.06 second (less than 16.67 Hz).

3.6 Component Force-resisting System: Those members or assemblies of members, including braces, frames, struts and attachments that provide structural stability for the connected components and transmit all loads and forces between the component and the supporting structure or foundation.

3.7 Octave: The interval between two frequencies that have a frequency ratio of 2.

3.8 One-third Octave: The interval between two frequencies that have a frequency ratio of $2^{1/3}$.

3.9 One-sixth Octave: The interval between two frequencies that have a frequency ratio of $2^{1/6}$.

3.10 Required Response Spectrum (RRS): The response spectrum generated using the formulas and normalized spectra detailed in Section 6.5.1 of this acceptance criteria. The RRS constitutes a requirement to be met.

3.11 Ring-down Time: The time required for vibration of the shake table to decrease to a negligible level following excitation.

3.12 Rigid Component: A component, including its attachments and force-resisting structural members, having a fundamental period less than or equal to 0.06 second (greater than or equal to 16.67 Hz).

3.13 Subassemblies: A grouping or assemblage of sub-components and/or structural elements that require attachment to the component's primary force resisting system to achieve structural stability.

3.14 Seismic Capacity: Seismic capacity of a component, for the purposes of this criteria, is defined as capacity, associated with the component's internal structure and its attachments, to resist seismically induced forces and deformations, and maintain structural integrity. Post-test functionality shall be maintained for components with I_p = 1.5,

3.15 Test Response Spectrum (TRS): The acceleration response spectrum that is developed from the actual time history of the motion of the shake table test as measured by reference control accelerometers mounted on the shake table at a location near the base of the UUT.

3.16 Transmissibility: The nondimensional ratio of the response acceleration amplitude of a system in steady-state forced vibration to the excitation amplitude and is used to characterize resonant modes of structural vibration. One approach to estimating this value is the ratio of the Fourier Transform of the system's acceleration to that of the excitation.

3.17 Triaxial Test: A dynamic test in which the test specimen is subjected to acceleration in two principal horizontal axes and the vertical axis simultaneously. The two horizontal and the vertical acceleration components are derived from three different input signals that are phase-incoherent.

3.18 Uniaxial Test: A dynamic test in which the test specimen is subjected to acceleration in one principal axis. The acceleration components are derived from a single input signal.

3.19 Unit Under Test (UUT): The component item to be certification-tested.

3.20 Zero Period Acceleration (ZPA): The peak acceleration of motion time-history that corresponds to the high-frequency asymptote on the response spectrum. This acceleration corresponds to the maximum peak acceleration of the time history used to derive the spectrum. For use in this acceptance criteria, the ZPA is assumed to be the acceleration response at 33.3 Hz or greater.

4.0 UUT REQUIRED INFORMATION

Sections 4.1 through 4.6 detail the necessary information to be provided for each UUT. Section 4 shall be a complete document, submitted by the UUT manufacturer or the manufacturer's representative and included as an appendix to the Test Plan described in Section 6.1.

4.1 Manufacturer and Testing Laboratory Contact Information: The following contact information shall be specified:

4.1.1 Manufacturer's contact information as follows:

Manufacturer: Company name.

Address: Company address.

Primary contact: Representative's name.

Phone number: Representative's phone number.

E-mail: Representative's e-mail address.

4.1.2 Testing laboratory's contact information as follows:

Testing Laboratory: Laboratory name.

Address: Laboratory address.

Primary contact: Representative's name.

Phone number: Representative's phone number.

E-mail: Representative's e-mail address.

4.2 UTT Description: A description of the UTT shall be provided, including the following items:

Name: Product name

UUT designation: Short alphanumeric UUT designator used for plotting and test run purposes.

UUT function: A general description of the primary function or end use of the product.

Description: A detailed description of the UUT configuration. This should include a listing of major subassemblies and sub-components (e.g., bills of material) and any other applicable product differentiation.

Identification no.: Supply UUT's unique identification number or serial number.

Dimensions: Height = xx in. (mm); Width = xx in. (mm); Depth = xx in. (mm).

Weight: Approximately xxx lbs. (kg) and, if known, center of mass.

Restrictions: Provide any product restrictions or limitations on use.

UUT mounting: Description of mounting method and configuration, including fastenings as applicable.

Component Importance Factor for Test: Ip = X.X

4.3 Seismic Parameters

The seismic parameters used to establish maximum UUT seismic test requirements shall be provided as shown in Table 1 below.

TABLE 1—SHAKE TABLE TEST PARAMETERS

BUILDING CODE	TEST CRITERIA	S_{DS} (g)	z/h	HORIZONTAL		VERTICAL	
				A_{FLX-H}	A_{RIG-H}	A_{FLX-V}	A_{RIG-V}
IBC 20**	ICC-ES AC156						

4.4 Functionality Requirements: A listing and detailed description shall be provided of the functionality requirements and/or tests used to verify pre- and post-seismic-testing functional compliance of components.

Each test and/or requirement should be listed as a separate line item.

4.5 Component Product Line Extrapolation and Interpolation: Testing every single configuration of a given component product line may not be feasible. Therefore, it may be necessary to select test specimens that adequately represent the entire component product line.

Details for establishing a test plan shall taken from requirements set forth in the applicable acceptance criteria for product.

The following criteria shall be used to establish UUT configuration requirements for representing a component product line (UUT configuration rationale shall be provided):

4.5.1 Structural Features: A rationale shall be provided explaining that the selected UUT's structural configurations are offering the least seismic capacity compared to other options that are available within the product line being qualified. The UUT's force-resisting systems shall be similar to the major structural configurations being supplied in the product line. If more than one major structure is a configurable option, then these other structural configurations shall be considered in the component product line extrapolation and interpolation rationalization process.

4.5.2 Mounting Features: A rationale shall be provided that explains that the selected UUT's mounting configurations are offering the least seismic capacity compared to other mounting options that are available within the product line being qualified. The configuration mounting of the UUT to the shake-table shall simulate mounting conditions for the product line. Seismic testing of components may be conducted using the smallest diameter tie-down bolt size (or minimum weld size) that can be accommodated with the provided tie-down clearance holes (or base structural members) on the components. If several mounting configurations are used, they shall be simulated in the test.

Use of specific test results shall be limited to the mounting type and configuration. Where individual components of a multi-component system are certified by test, the flexibility of the supporting structure in the component to point of anchorage shall be replicated in the test setup. Alternately, the input motions for the test setup may be modified to account for this flexibility using a rational analytical method. The components from the mounting brackets to the supporting structure shall have equivalent flexibility and strength to what is used in the component certification test and may be certified by a supporting analysis.

4.5.3 Subassemblies: A rationale shall be provided explaining that the selected UUT's subassemblies are representative of production hardware and offer the least seismic capacity of the UUT compared to other subassembly options that are available within the product line being qualified. The major subassembly components shall be included in the UUT. These components shall be mounted to the specimen structure at locations similar to those specified for proposed installations. The components shall be mounted to the structure using the same type of mounting hardware specified for proposed installations. Substitution of nonhazardous materials and fluids is permitted for verification of components or subassemblies that contain hazardous materials or fluids, provided the substitution does not reduce the functional demand on the component or subassembly.

4.5.4 Mass Distribution: A rationale shall be provided explaining that the selected UUT's mass distribution is one contributing to the least seismic capacity of the UUT compared to other mass distribution options that are available within the product line being qualified. The weight and mass distribution shall be similar to the typical weight and mass distribution of the component being represented. Weights equal to or greater than the typical weight shall be acceptable.

4.5.5 Component Variations: A rationale shall be provided explaining that the selected UUT's overall variations contribute to the least seismic capacity of the UUT compared to other variations that are available within the product line being qualified. Other component variations, such as number of units/components in production assemblies, indoor and outdoor applications, etc., shall be considered in the component product line extrapolation and interpolation rationalization process.

4.6 Installation Instructions: Instructions shall include the following items:

1. Description of how the UUT will be installed in the field.

2. Description of how the UUT will be installed during the certification test.

5.0 TESTING LABORATORIES AND REPORTS OF TESTS:

5.1 Testing Laboratories: Testing laboratories shall comply with Section 2 of the ICC-ES Acceptance Criteria for Test Reports (AC 85) and Section 4.2 of the ICC-ES Rules of Procedure for Evaluation Reports.

5.2 Test Reports:

5.2.1 General: Test reports shall comply with AC 85**.**

5.2.2 Specific: Reports of all tests noted in Section 6 are required. In addition, the following items must be reported:

5.2.2.1 Identification of component being qualified along with their dimensions and weights.

For a custom product line, where subcomponents in each assembled product can potentially be different, all qualified subcomponents along with their dimensions and weights shall be listed. If there is more than one manufacturer or material for any subcomponent, each manufacturer's subcomponent for each material shall be treated as a separate product. Different operating conditions for components for which equipment is certified shall be listed.

5.2.2.2 Seismic parameters and derived RRS levels for the component that is being qualified in accordance with Section 4.3.

5.2.2.3 Results of pre- and post-test structural integrity and functionality requirements and/or testing.

5.2.2.4 Testing facility location and a list of observers present for test/functionality verification.

5.2.2.5 Testing equipment description, including size and capacity of the shake table and verification of calibration of instruments used in the test.

5.2.2.6 Component mounting details, including all interface connections.

Photographs of component set-up on the shake table before and after test including detailed photographs of anomalies observed during or after test.

5.2.2.7 Results of test data, including proof of performance, TRS plots, acceleration time histories of the shake table motion, acceleration transmissibility plots, UUT dimensions and measured weight, etc.

5.2.2.7.1 TRS plots in each of the three directions shall show corresponding RRS, 90 percent RRS, and 130 percent of RRS. Damping ratio used in generating RRS and TRS shall be indicated on the TRS plots.TRS plots for each certification test conducted shall be provided. For traceability, the TRS plots shall reference the name the corresponding data file.

5.2.2.7.2 The resonance frequency in each of the three directions for each UUT shall be included in the report similar to Table 2 below.

TABLE 2—UNIT UNDER TEST (UUT) RESONANCE FREQUENCY

UUT	RESONANCE FREQUENCY (Hz)		
Identification	Front-to-Back	Side-to-Side	Vertical

5.2.2.7.3 Verification that simultaneous shake table motion in three orthogonal directions are phase-incoherent (statistically independent) shall be provided.

5.2.2.8 Test results and conclusions including any anomalies observed during or after the test, and justification that the component is still qualified. Resolution of all significant anomalies, which affect either component force resisting system or functionality of components with I_p = 1.5, shall be addressed in the test report.

5.2.2.9 UUT required information in accordance with Section 4.0 shall be added to the test report as an appendix.

5.3 Product Sampling: Sampling of components for tests under this criteria shall comply with Section 3.1 of AC85.

6.0 SEISMIC CERTIFICATION TEST PROCEDURE

6.1 Seismic Certification Test Plan: The UUT shall be subjected to a seismic certification test program, considering all elements noted in this section. The seismic certification test plan is intended to satisfy the requirements of Section 1708.4 of the 2009 IBC or Section 1708.5 of the 2006 IBC and Section 13.2 of ASCE 7 for components. References for setting the test plan and objectives include ANSI/IEE 344 and FEMA 461.

6.2 Pre-test Inspection: Upon arrival at the test facility, the UUT shall be visually examined and results documented by the testing laboratory, to verify that no damage has occurred during shipping and handling.

6.3 Pre-test Functional Compliance Verification: Functionality requirements and/or tests, as specified in Section 4.4, shall be performed by an accredited testing laboratory to verify pre-test functional performance. Functional testing could be performed at either the test facility or at the UUT manufacturing facility. Test description and results shall be documented in accordance with Section 5.2 (Test Reports).

6.4 Seismic Simulation Test Setup: Seismic ground motion occurs simultaneously in all directions in a random fashion. The requirement is to perform qualification testing in all three principal axes, two horizontal and vertical. However, for certification test purposes, uniaxial, biaxial or triaxial test machines are allowed in accordance with the following test requirements.

6.4.1 Triaxial, Biaxial, and Uniaxial Testing Requirements: The preferred method of performing testing is using a triaxial shake table. However, it is recognized that capable triaxial testing facilities are limited in number, and this may restrict testing access. Use of biaxial or uniaxial testing shall consider component configuration in determining orientations that permit the largest response to shake table accelerations. The following requirements shall be used when performing triaxial, biaxial, or uniaxial testing.

6.4.1.1 Triaxial Testing: If a triaxial test is performed, the test shall be performed in one stage with the two principal horizontal axes and the vertical axis of the UUT simultaneously tested.

6.4.1.2 Biaxial Testing: If a biaxial test is performed, the test shall be performed in two stages, with the UUT rotated 90 degrees about the vertical axis for the second stage.

6.4.1.3 Uniaxial Testing: If a uniaxial test is performed, the test shall be performed in three distinct stages, with the UUT rotated after each stage, such that all three principal axes of the UUT have been tested.

6.4.2 Weighing: The UUT shall be weighed prior to performing the Seismic Simulation Tests. The measured UUT weight shall be recorded in the Test Report as set forth in Section 5.2.

6.4.3 Mounting: The UUT shall be mounted on the shake table in a manner that simulates the intended service mounting in accordance with Section 4.5.2. The mounting method shall be the same as that recommended for actual service, and shall use the minimum recommended bolt size, bolt type, bolt torque, configuration, weld pattern and type (if applicable), etc. The orientation of the UUT during the tests shall be such that the principal axes of the UUT are collinear with the axes of excitation of the shake table. A description of any interposing fixtures and connections between the UUT and the shake table shall be provided.

6.4.4 Monitoring: Sufficient vibration response monitoring instrumentation shall be used to allow determination of the applied acceleration levels in the principal horizontal and vertical axes of the shake table. Reference control accelerometers shall be mounted on the shake table at a location near the base of the UUT. Vibration response monitoring instrumentation shall also be used to determine the response of the UUT, at those points within the structure that reflect the UUT's response associated with its structural fundamental frequencies. Placement locations for the response sensors shall be at the discretion of the UUT manufacturer or the manufacturer's representative and approved by the test laboratory prior to testing. Sensors shall be installed, calibrated and approved by the test laboratory prior to testing. The accredited laboratory shall document the location, orientation, and calibration of all vibration monitoring sensors.

6.4.5 Resonant Frequency Search: The resonant frequency search test is for determining the resonant frequencies and damping of components. The data obtained from the search test is an essential part of an component certification; however, the search test does not constitute a seismic test certification by itself. A low-level amplitude (0.1± 0.05 g peak input; a lower input level may be used to avoid component damage) single-axis sinusoidal sweep from 1.3 to 33.3 Hz shall be performed in each orthogonal UUT axis to determine resonant frequencies. The sweep rate shall be two octaves per minute, or less, to ensure adequate time for maximum response at the resonant frequencies. Transmissibility plots of the in- line UUT response monitoring sensors shall be provided along with a table showing resonant frequencies in accordance with Section 5.2.2.7.2.

6.5 Multifrequency Seismic Simulation Tests:

6.5.1 Derivation of Seismic RRS: The component earthquake effects shall be determined for combined horizontal and vertical load effects. The required response spectra for the horizontal direction shall be developed based on the normalized response spectra shown in Figure 1, and the formula for total design horizontal force, F_p. The required response spectra for the vertical direction shall be developed based on two-thirds of the ground-level base horizontal acceleration. The seismic parameters specified in Section 4.3 shall be used to calculate the RRS levels as defined by A_{FLX-H}, A_{RIG-H}, A_{FLX-V}, and A_{RIG-V}. The RRS shall be defined using a damping value equal to 5 percent of critical damping.

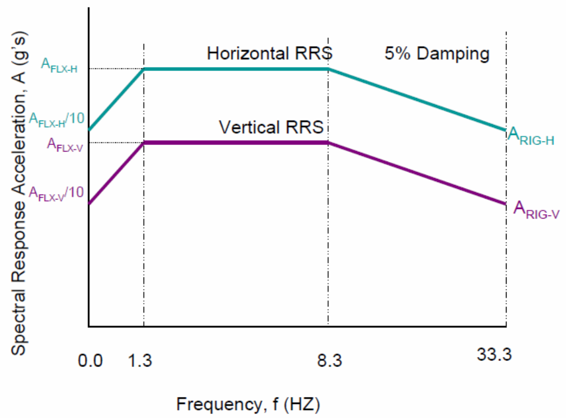

FIGURE 1—REQUIRED RESPONSE SPECTRUM, NORMALIZED FOR THE COMPONENT

The required response spectra for both horizontal and vertical directions shall be developed based on the formula for total design horizontal force, F_p, as follows:

When the building dynamic characteristics are not known or specified, the horizontal force requirements shall be as determined using Equation 13.3-1 of ASCE 7, which reads as follows:

$$F_p = \frac{0.4 a_p S_{DS}}{(R_p / I_p)} \left(1 + 2\frac{z}{h}\right) W_p$$

The height factor ratio (z / h) accounts for above grade-level component installations within the primary supporting structure and ranges from zero at grade–level to one at roof level, essentially acting as a force increase factor to recognize building amplification as you move up within the primary structure. The site-specific ground spectral acceleration factor, S_{DS}, varies per geographic location and site soil conditions. The S_{DS} factor is used to define the general design earthquake response spectrum curve and is used to determine the design seismic forces for the primary building structure. The ratio of R_p over I_p (R_p / I_p) is considered to be a design reduction factor to account for inelastic response and represents the allowable inelastic energy absorption capacity of the component's force-resisting system. During the seismic simulation test, the UUT will respond to the excitation and inelastic behavior will naturally occur. Therefore, the ratio (R_p / I_p) shall be set equal to 1, which is indicative of an unreduced response. The importance factor, I_p, does not increase the seismic test input motion but does affect the requirement for the UUT to demonstrate a level of functionality following seismic simulation testing, and is used in this criteria to determine post test UUT functionality compliance in accordance with Section 6.7. The component amplification factor, a_p, acts as a force increase factor by accounting for probable amplification of response associated with the inherent flexibility of the nonstructural component. The component amplification factor, a_p, shall be taken from the formal definition of flexible and rigid components. By definition, for fundamental frequencies less than 16.7 Hz the component is considered flexible (maximum amplification a_p = 2.5), which corresponds to the amplified region of the

RRS. For fundamental frequencies greater than 16.7 Hz the component is considered rigid (minimum a_p = 1.0), which corresponds to the ZPA. This results in two normalizing acceleration factors, that when combined, defines the horizontal component certification RRS:

$$A_{FLX-H} = S_{DS}\left(1+2\frac{z}{h}\right) \text{ and } A_{RIG-H} = 0.4S_{DS}\left(1+2\frac{z}{h}\right)$$

where A_{FLX-H} is limited to a maximum value of 1.6 times S_{DS}.

For vertical response, *z* may be taken to be 0.0 for all attachment heights, which results in:

$$A_{FLX-V} = 0.67{*}S_{DS} \text{ and } A_{RIG-V} = 0.27{*}\ S_{DS}$$

In lieu of determining the spectral acceleration as described in this section, equivalent provisions based on ASCE 7 Equation 13.3.4 shall be permitted for structure-specific applications.

6.5.2 Derivation of Test Input Motion: To meet the required response spectra as defined in Section 6.5.1, the corresponding shake-table drive signals shall be nonstationary broadband random excitations having an energy content ranging from 1.3 to 33.3 Hz. The drive signal composition shall be multiple-frequency random excitations, the amplitudes of which adjusted either manually or automatically based on multiple-frequency bands. The exact bandwidth of individual bands employed shall be left to the discretion of the test laboratory. Typically, one-third-octave bandwidth resolution is used with analog synthesis equipment. However, the use of digital synthesis equipment may require narrower frequency bands on the order of one sixth-octave bandwidth. The process involves use of an aggregate of multiple narrowband signals that is input to the shake-table with each band adjusted until the TRS envelops the RRS according to the criteria specified in Section 6.5.3. The total duration of the input motion shall be 30 seconds (nominal), with the non-stationary character being synthesized by an input signal build-hold-decay envelope specified in Section 3.3. The input duration of the time history tests shall contain at least 20 seconds of strong motion. Strong motion durations greater than 20 seconds shall be considered acceptable. Independent random signals that result from an aggregate of the narrowband signals shall be used as the excitation to produce phase incoherent motions in the principal horizontal and vertical axes of the shake table.

6.5.3 Test Response Spectrum Analysis: The test response spectrum (TRS) shall be computed using either justifiable analytical techniques or response spectrum analysis equipment using the control accelerometers located at the UUT base per Section 6.4.3. The TRS shall be calculated using a damping value equal to 5 percent of critical damping. The TRS must envelop the RRS based on a maximum-one-sixth octave bandwidth resolution over the frequency range from 1.3 to 33.3 Hz. The amplitude of each narrowband signal shall be independently adjusted in each of the principal axes until the TRS envelops the RRS. It is recommended that the TRS should not exceed the RRS by more than 30 percent over the amplified region of the RRS. Any acceleration-signal filtering performed within the range of analysis must be defined. The general requirement for the enveloping of the RRS by the TRS can be modified under the following conditions:

6.5.3.1 Amplified Region of RRS: In the performance of a test program, the TRS may not fully envelop the amplified region of the RRS (frequencies less than or equal to 8.3 Hz). The general requirement for a retest may be exempted if the following criteria are met:

6.5.3.1.1 In those cases in which it can be shown by use of the resonance search in Section 6.4.5 that no resonance response phenomena exist below 5 Hz, the TRS is required to envelop the RRS only down to 3.5 Hz. Excitation must continue to be maintained in the 1.3 Hz to 3.5 Hz range, within the limitations of the shake table.

6.5.3.1.2 When resonance phenomena exist below 5 Hz, the TRS is required to envelop the RRS only down to 75 percent of the lowest frequency of resonance.

6.5.3.1.3 When the absence of resonance response phenomena below 5 Hz cannot be justified, the general requirement applies and the low-frequency enveloping should be maintained down to 1.3 Hz.

6.5.3.1.4 A single point of the TRS may fall below the RRS (for frequencies less than or equal to 8.3 Hz) by 10 percent or less, provided the adjacent one-sixth-octave points are at least equal to the RRS.

6.5.3.1.5 A maximum of two of the one-sixth-octave analysis points may be below the RRS (for frequencies less than or equal to 8.3 Hz), as under the same constraints as noted in 6.5.3.1.4.

6.5.3.2 ZPA Region of RRS: In the performance of a test program the TRS may not fully envelop the ZPA region of the RRS (frequencies greater than 8.3 Hz). The general requirement for a retest may be exempted if the following criteria are met:

6.5.3.2.1 A single point of the TRS may fall below the RRS (for frequencies greater than 8.3 Hz) by 10 percent or less, provided the adjacent one-sixth-octave points are at least equal to the RRS.

6.5.3.2.2 A maximum of two of the one-sixth-octave analysis points may be below the RRS (frequencies greater than 8.3 Hz), as under the same constraints as noted in Section 6.5.3.2.1.

6.5.3.2.3 To achieve the minimum acceleration requirements specified by ASCE 7, the peak shake table acceleration shall equal or exceed 90 percent of A_{RIG}.

6.6 Post-test Inspection: The UUT shall be visually examined and results documented upon completion of the multifrequency seismic simulation tests performed in accordance with Section 6.5 to determine whether the UUT has adequate seismic capacity. The following conditions shall apply:

6.6.1 Structural integrity of the component attachment system shall be maintained. Limited yielding of the attachments shall be acceptable. Component design must ensure that the anchored UUT will not leave its mounting and cause damage to other building components or injury to personnel during the seismic event.

6.6.2 Components **Force-resisting System:** Structural integrity of the component force-resisting system shall be maintained. Structural damage, such as limited yielding, to UUT force-resisting members is acceptable and structural members and joints not comprising the UUT force-resisting system shall be allowed minor fractures and anomalies.

6.7 Post-test Functional Compliance Verification: Based upon the specified UUT importance factor in Section 4.2, the component being qualified must be capable of performing its intended functions after the seismic event.

6.8 Functionality requirements and/or tests, as specified in Section 4.4, shall be performed on the UUT to verify post-test functional compliance. Functional testing may be performed by an accredited testing laboratory at either the test facility or at the UUT manufacturing facility when required test equipment is not available at the test facility. Requirements of this section are satisfied if one of the following criteria is met.

6.8.1 Components with I_p = 1.0: At the completion of the seismic testing, the UUT does not pose a life or limb safety hazard due to collapse or due to major subassemblies becoming separated. Structural integrity of anchorage system and component force-resisting system shall be maintained. Structural damage, such as limited yielding, to UUT force-resisting members is acceptable and structural members and joints not comprising the UUT force-resisting system shall be allowed minor fractures and anomalies.

6.8.2 Components with I_p = 1.5: The component is deemed to be essential to the continued operation of a facility, and/or essential to maintaining critical life support systems, and/or contains materials deemed to be hazardous, to humans or the environment, in quantities greater than the exempted amounts listed in the code. After completion of the seismic testing, the UUT shall satisfy the functional and requirements and/or tests specified in Section 4.4, with equivalent results to those of the pre-test functional compliance testing of Section 6.3. UUT materials deemed to be hazardous shall not have been released into the environment in quantities greater than the exempted amounts listed in the code. In addition, at the completion of the seismic testing, the UUT does not pose a life-safety hazard due to collapse or major subassemblies becoming separated. Structural integrity of anchorage and component force-resisting system shall be maintained. Structural damage, such as limited yielding, to UUT force-resisting members is acceptable and structural members and joints not comprising the UUT force-resisting system shall be allowed minor fractures and anomalies. Minor repairs to the UUT (such as replacing a bulb) are allowed for the component to satisfy this section. Any repairs shall be documented and included in the final test report noted in Section 5.2. ■