HCAI Acceptable Test Procedures and Alternate Tests for Determining Spring Vibration Isolator Capacities and Demands to Resist Vertical and Lateral Loads Supporting Non-Structural Components

DRAFT Dated March 02, 2023

Spring Vibration Isolator Rated Capacities supporting non-structural components are defined within *ANSI/ASHRAE 171-2017: Method of Testing for Rating Seismic and Wind Restraints*.

Capacities shall be determined by cyclic testing using a cyclic loading protocol similar to force amplitude sequence in ASHRE 171, FM 1950 or a displacement protocol as defined in FEMA 461.

Demands on spring vibration isolators shall be determined in accordance with *ASCE/SEI 7-16 or 7-22: Minimum Design Loads and Associated Criteria for Buildings and Other Structures,* Section 13.3 "Seismic Demands of Nonstructural Components" as applicable.

Exception: Non-structural components on spring vibration isolators used on shake table tests may also be used without further cyclic testing; however, maximum rated capacities are limited to the demands from ASCE/SEI 7 as above mentioned.

Test Plans and Intermediate Test Result Reviews: Prior to all qualifying tests required to establish isolator capacities, spring vibration isolator test plans shall be submitted to HCAI for review and acceptance, to clarify protocol variations, if any, and other variables, i.e., selection of isolator product lines, selected bookending units, if any, variations in position on isolator for recording displacements, determination of failure modes, stages of failure, and any other variations not explicitly stated within the testing protocols. Intermediate review of test results shall be submitted to HCAI for review and acceptance to clarify initial test results used to establish rated capacity, acceptable interpolation test correlations, if any, failure modes, and overall procedural practices.

Required and Accepted Alternates

1. **Loading Sequence Deviations**: Loading sequence deviations from ASHRAE 171, FM 1950, or FEMA 461 shall be approved by HCAI prior to performing tests. Cyclic testing using a force-based protocol (ANSI/ASHRAE 171 or FM 1950), shall set a minimum of ten (10) cycles from the initial magnitude. Cyclic testing may use a displacement-based loading protocol (FEMA 461) with displacement increment steps for two consecutive cycles not greater than 1.3 times the displacement at peak force to observe and record isolator ductility.

2. **Minimum Tests:** Isolators shall be tested for tension and shear, and a combined tension and shear 45-degree vertical angle tests in each orthogonal horizontal axis, as shown in Figure 1, for a total of five tests. Manufacturers shall submit a basis to HCAI for review and acceptance for any reductions in the number of tests as above mentioned. Deviations from the 45-degree angle are permitted when different rating capacities for tension and compression are needed.

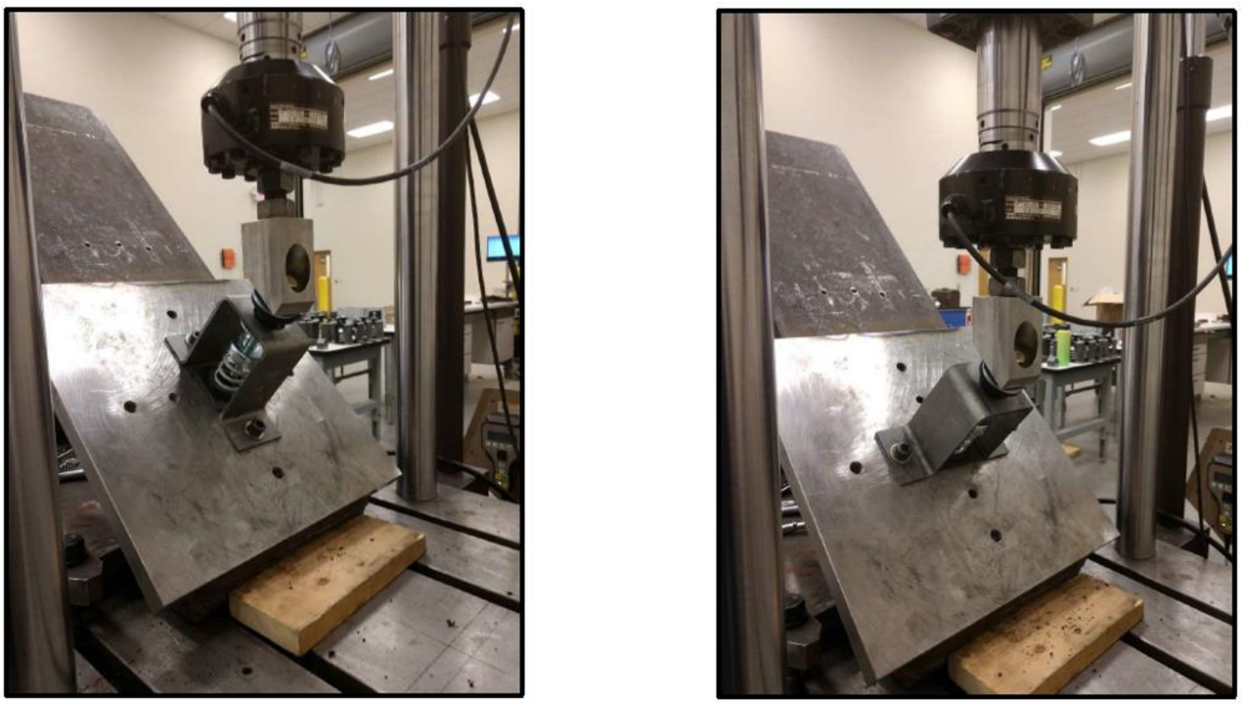

Figure 1: Orientation of isolator to capture axial load variation.

3. **Determination of Rated Capacity**: The Rated Capacity for the tested isolator shall be as follows:
   a. The lowest *maximum capacity* load value achieved among the samples tested, with similar failure modes, for all tested axes, reduced by the appropriate material resistance factor, as note below:

Lowest maximum capacity shall be reduced by the appropriate material resistance factor, Φ (LRFD), or safety factor, Ω (ASD) obtained from corresponding material standard(s). The rated capacity equals Φ x (capacity) or (capacity)/Ω; i.e., for steel, the appropriate Φ or Ω factors based on the observed behavior from testing are noted below.

Tensile yielding, Compression, Flexure or Shear	Φ=0.9	Ω=1.67
Tensile rupture or fracture	Φ=0.75	Ω=2.0

4. **Isolator Tests:** All vibration isolators shall be tested to determine their rated capacities. Alternatively, a reduction in the number of tests may be achieved by testing the largest and an intermediate spring vibration isolator (bookending isolators) using a cyclic loading protocol with interpolated and lower extrapolated isolators tested using the monotonic test procedure, as noted below. Any addition reductions, requires a manufacturer's submitted basis that shall have prior HCAI review and acceptance. All tests, regardless of outcome**,** shall be submitted for review.

5. **Monotonic Test Procedure (Pushover):** A pushover type test may be acceptable to HCAI, for establishing interpolated and lower extrapolated values for a family of isolators, if the pushover developed capacity curve indicates quantitative and qualitative results with force-based or displacement-based (hysteresis) loops from cyclic tests using bookending isolators. The monotonic tests shall be the same as in item #2.

6. **Monotonic Test Requirements and Rated Capacities:**
   - a: Use of pushover tests shall be reviewed and accepted by HCAI.
   - b: Displacement-based curve (backbone) shall be developed by defining a minimum of ten (10) displacement / force data points.
   - c: The application of a reduction or safety factor (Φ or Ω) from item 3.
   - d: Additional adjustment factors, in addition to Φ or Ω, may be necessary to obtain improved curve fitting with the cyclic test results.

Verification of Isolator Ductility

Establish Seismic Performance Parameters: From the force deformation plots of the test results, four main parameters are defined as follows:

1. Maximum lateral load capacity
2. Effective yielding displacement
3. Ultimate displacement
4. Effective ductility capacity

Figure 2 below, illustrates an example of cyclic-load test data envelope curve and response parameters.

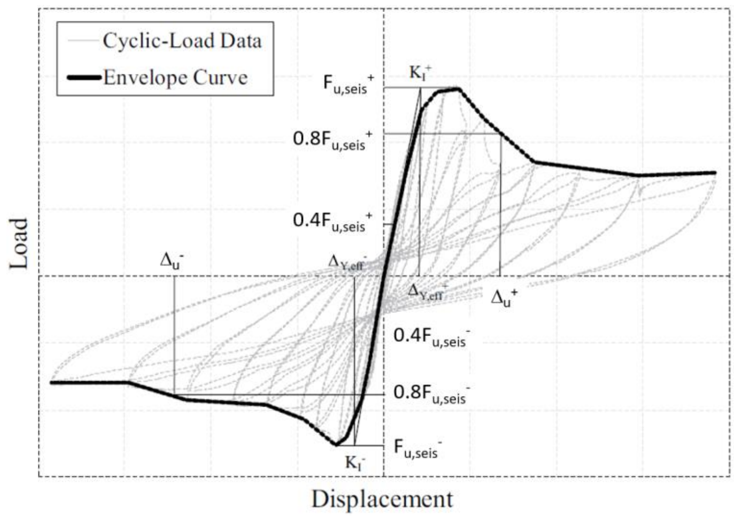

Figure 2: Determination of test response parameters

Where:

$F_{u,seis}^+$ = Ultimate tension load in the cyclic test, lb (N)

$F_{u,seis}^-$ = Ultimate compression load in the cyclic test, lb (N)

$F_{u,seis}$ = Maximum seismic strength in the cyclic test defined by the smallest of the ultimate tension and ultimate compression loads, lb (N)

K_I^+ = Initial stiffness based on force and deformation at 0.4 $F_{u,seis}^+$, lb/in. (kN/mm)

K_I^- = Initial stiffness based on force and deformation at 0.4 $F_{u,seis}^-$, lb/in. (kN/mm)

$\Delta Y_{,eff}^+$ = Effective Yield displacement defined as $F_{u,seis}^+ / K_I^+$, in. (mm), in. (mm)

$\Delta Y_{,eff}^-$ = Effective Yield displacement defined as $F_{u,seis}^- / K_I^-$, in. (mm), in. (mm)

Δu^+ = Ultimate deformation corresponding at 0.8 $F_{u,seis}^+$ in the post peak range, in. (mm)

Δ_u^- = Ultimate deformation corresponding at 0.8 $F_{u,seis}^-$ in the post peak range, in. (mm)

μ_{eff}^+ = Effective ductility defined as $\Delta u^+ / \Delta Y_{,eff}^+$
μ_{eff}^- = Effective ductility defined as $\Delta u^- / \Delta Y_{,eff}^-$

Values of each parameter shall be measured from both the positive and negative portions of the envelope curve, as illustrated in **Figure 2**.

Evaluation Performance: This criterion is also subject to an acceptable level of damage at the design earthquake intensity level. For this purpose, the effective ductility capacity is the most suitable response parameter in the performance evaluation, requiring all rated isolators shall have a minimum effective ductility capacity of $\mu_{eff} = 1.60$, otherwise the lateral load capacity shall be reduced to $\mu_{eff}/1.6$.

Restraint Capacity

Restraint maximum rated capacities indicating tension, shear, and combined 45º test results shall be reported in both table and graphical forms, after application of all reduction factors. Sample graphical format is shown in **Figure 3** below.

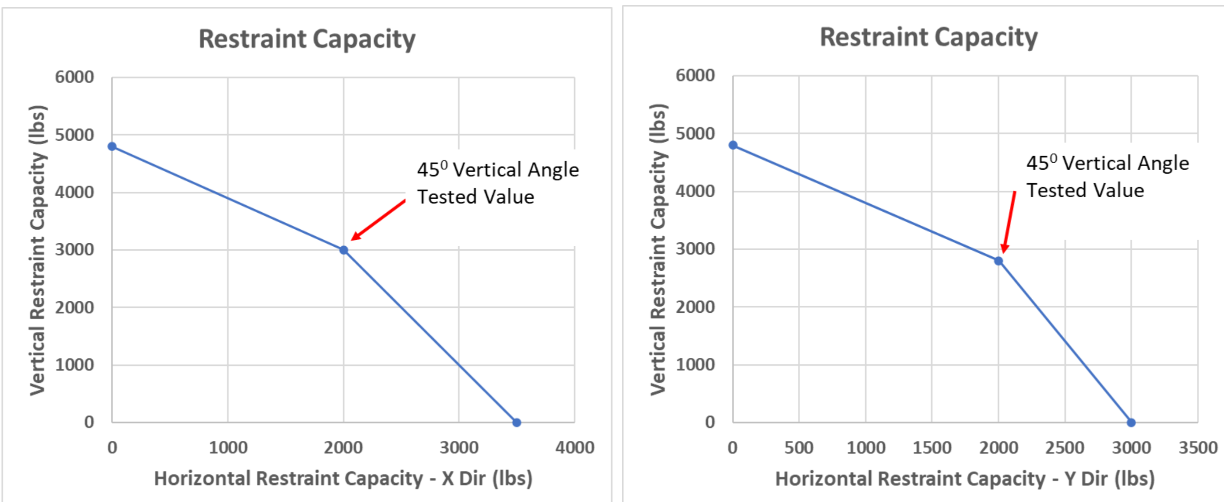

Figure 3: Isolator Restraint Capacities

Appendix A

Reporting Requirements

ASHRAE Standard 171-2017, *Method of Testing for Rated Seismic and Wind Restraints Sections 9 and Normative Annex D shall be followed for test reports and rated capacity calculations with the following modifications:*

1. **Section 9.2 Test Report Authorization:** *Add a sentence at the end of the section.* The engineer sealing and signing the report shall be a licensed Civil Engineer in the State of California.
2. **Normative Annex D – Certification, Section D2.2:** *Add the following:* All reports submitted to HCAI for review/Approval shall be sealed and signed by a Civil Engineer licensed in the State of California.
3. **Normative Annex D – Certification, Section D2.3:** Testing conducted at a manufacturer's test lab that has not been accredited to this or a similar test standard shall be supervised by a registered professional engineer not in the direct employ of the manufacturer, licensed as a Civil Engineer in the State of California and witnessed by personnel from either a test lab accredited to this or a similar test standard or an inspection body (as described in Section D2.2). The Civil Engineer shall seal and sign all documents submitted to HCAI for review/Approval. *Remainder unchanged.*

Isolator ductility basis taken from *Method of Testing for Seismic Rating of Non-Structural Components and Systems*, dated July 2021, below, which is a derivation of the *Experimental Seismic Response Evaluation of Suspended Piping Restraint Installations*, by Daniele Perrone, Andre Filiatrault et al., dated November 19, 2019.

METHOD OF TESTING FOR SEISMIC RATING OF NON-STRUCTURAL COMPONENTS AND SYSTEMS

Table of Contents

1. PURPOSE

This standard provides a test procedure for the assessment of seismic performance of non-structural components and systems by determining the maximum loads and ductility they can withstand without breakage.

2. SCOPE

2.1. This standard is limited in its application and is appropriate only for non-structural components and systems made with Ferrous metals, including those used in ductile casting, structural stainless steel, structural carbon steel, or nonferrous materials such as aluminium, copper, and brass.

2.2. This standard does not address the durability of any supported equipment, or other non-structural component and their ability to remain functional during and at the conclusion of a seismic event.

2.3. This standard does not apply to components and systems using nonductile materials

2.4. Any attachment fastener and any member in the load path on the structural side of the building-attached components are outside the scope of this standard

2.5. This standard is not appropriate for determining the capacity of devices that are used in extreme shock (e.g., blast) or long-term dynamic loading applications.

3. UNITS, DEFINITIONS, AND NOTATON

3.1. System of Units - Units of measurement used in this standard are United States (U.S.) customary units. These are followed by their arithmetic equivalents in International System (SI) units, enclosed in parentheses. The first value stated shall be regarded as the requirement. The converted equivalent value may be approximate.

3.2. DEFINITIONS

- **Allowable Strength -** Used in Allowable Stress Design (ASD), the allowable strength is the nominal strength (Rn) divided by a safety factor (Ω)

- **Allowable Stress Design (ASD) -** Is a method of comparing the allowable strength of a component to the required strength under ASD load combinations

- **Design Strength -** Used in Load and Resistance Factor Design (LRFD), the design strength is the nominal strength (R_n) multiplied by a resistance factor (ϕ)

- **Effective Ductility** - Is the ratio of effective yield displacement to the ultimate deformation when 20% decay of the maximum load bearing capacity is observed. The term is used to designate how well a component will endure large displacements imposed by seismic loads before the ultimate failure happens

- **Load at Failure -** This term relates to the actual load at which the test sample is observed to fail either by actual mechanical fracture or by exceeding a predetermined limit for displacement

- **Load and Resistance Factor Design (LRFD) -** Is a method of comparing the design strength of a component to the required strength under LRFD load combinations

- **Load Rating -** refers to the load rating assigned to a component or system as the result of testing and analysis. The load rating may be expressed with factors to account for different angles of installation. The load rating may also be expressed in terms of Allowable Stress Design, or in terms of Load Resistance Factor Design

- **Nominal Strength (R_n) -** Is the lowest load at failure for the series of tests (see Section 7.2)

- **Resistance Factor (ϕ) -** Is used in Load and Resistance Factor Design (LRFD). Resistance Factors are less than 1.0 and load factors in LRFD load combinations are commonly greater than 1.0

- **Safety Factor (Ω) -** Is used in Allowable Stress Design (ASD). Safety Factors are greater than 1.0 and the load factors in ASD load combinations are typically 1.0 or less. This is a factor, by which the nominal strength (R_n) is divided to account for deviations of the nominal strength from the actual strength, uncertainty in assumed loads, and material failure

3.3. NOTATION

$F_{u,stat}$ =	Ultimate tension load from a static test, lb (N)
$\Delta_{u,stat}$=	Displacement measured after 20% decay of the ultimate load in static test, in. (mm)
Δ_o=	The target smallest deformation amplitude of the loading history, in. (mm)
Δ_m=	The target largest deformation amplitude of the loading history, in. (mm)
n=	Number of steps in the cyclic loading history
a_i=	Displacement amplitude in cyclic test, in. (mm)
$F_{u,seis}^+$=	Ultimate tension load in the cyclic test, lb (N)
$F_{u,seis}^-$=	Ultimate compression load in the cyclic test, lb (N)
$F_{u,seis}$=	Maximum seismic strength in the cyclic test defined by the smallest of the ultimate tension and ultimate compression loads, lb (N)
$F_{u,seis,red}$=	Reduced seismic strength at which test sample satisfies the ductility requirements in Sec. 7.1, lb (N)
K_I^+=	Initial stiffness based on force and deformation at 0.4 $F_{u,seis+}$, lb/in. (kN/mm)
K_I^-=	Initial stiffness based on force and deformation at 0.4 $F_{u,seis}^-$, lb/in. (kN/mm)
$\Delta_{Y,eff}^+$=	Effective Yield displacement defined as $F_{u,seis}^+ / K_I^+$, in. (mm), in. (mm)
$\Delta_{Y,eff}^-$=	Effective Yield displacement defined as $F_{u,seis}^- / K_I^-$, in. (mm), in. (mm)
Δ_u^+=	Ultimate deformation corresponding at 0.8 $F_{u,seis}^+$ in the post peak range, in. (mm)
Δ_u^-=	Ultimate deformation corresponding at 0.8 $F_{u,seis}^-$ in the post peak range, in. (mm)
μ_{eff}^+=	Effective ductility defined as $\Delta_u^+ / \Delta_{Y,eff}^+$
μ_{eff}^-=	Effective ductility defined as $\Delta_u^- / \Delta_{Y,eff}^-$

4. TEST LABORATORY SET UP AND INSTRUMENTATION

This section defines the requirements of the test laboratory for conducting testing for rating. The range of products, and testing orientations will be specified by the testing laboratory.

4.1. **Calibration**: Each piece of equipment used to verify the test parameters shall be calibrated within an interval determined on the basis of stability, purpose and usage. The certificate shall indicate that the calibration was performed against working standards whose calibration is certified as traceable to the National Institute of Standards and Technology (NIST) or traceable to other acceptable reference standards and certified by an ISO/IEC 17025, "General Requirements for the Competence of Testing and Calibration Laboratories", calibration laboratory.

4.2. **Tolerances**: Test equipment used shall be documented to meet these minimum tolerances:

Displacement: ±0.05 in. (1mm)
Load: ±1% of maximum load tested
Temperature: ±5 °F (+/-3 °C)

4.3. **Computer Data Acquisition and Precision**: Load and displacement data shall be recorded every 0.1 seconds during testing. The test laboratory shall report its precision based on the accuracy of its equipment and data acquisition system.

4.4. **Test Data**: It is to be expected that the variation in the data across the tests for the same combination of product / size / and installation angle will be in the approximate range of 10 – 15 percent. Data outside this range may be indicative of product variations or equipment issues with the performance of the test and should be further investigated. Any decision to disregard a test run shall be discussed in the reporting including justification for doing so.

5. REQUIREMENTS FOR SAMPLES

Sample requirements are to be determined by the testing laboratory following review of the preliminary information. Sample requirements may vary depending on design features and/or the results of any testing. It is the manufacturer's responsibility to submit samples representative of production. The manufacturer shall provide following preliminary information to schedule the test programs. All documents shall identify the manufacturer's name, document number or other form of reference, title, date of last revision, and revision level.

- A complete list of all models, and sizes, for the products or services being tested;
- General assembly drawings and one complete set of manufacturing drawings;
- Materials list(s) and material specifications (such as AISI-SAE 1020 Carbon Steel);
- Anticipated marking format;
- Installation, operation and maintenance procedures; and;
- The number and location of manufacturing facilities.

6. TEST PROCEDURE

Two types of tests shall be carried out on each component/system: monotonic test and cyclic test.

6.1. The monotonic loading protocol consists of a linear ramp until the failure of the testing component or system occurs (Fig. 1). The failure is achieved when 20% decay of the maximum load-bearing capacity (after peak force) is observed. The loading rate for the monotonic test will be sufficiently slow to avoid inertia effects (loading speed equal to or below 10mm/minute). The monotonic tests shall be performed:

- in compression for components or systems which are able to bear compression forces.
- in tension for components or systems which are not able to bear compression forces.

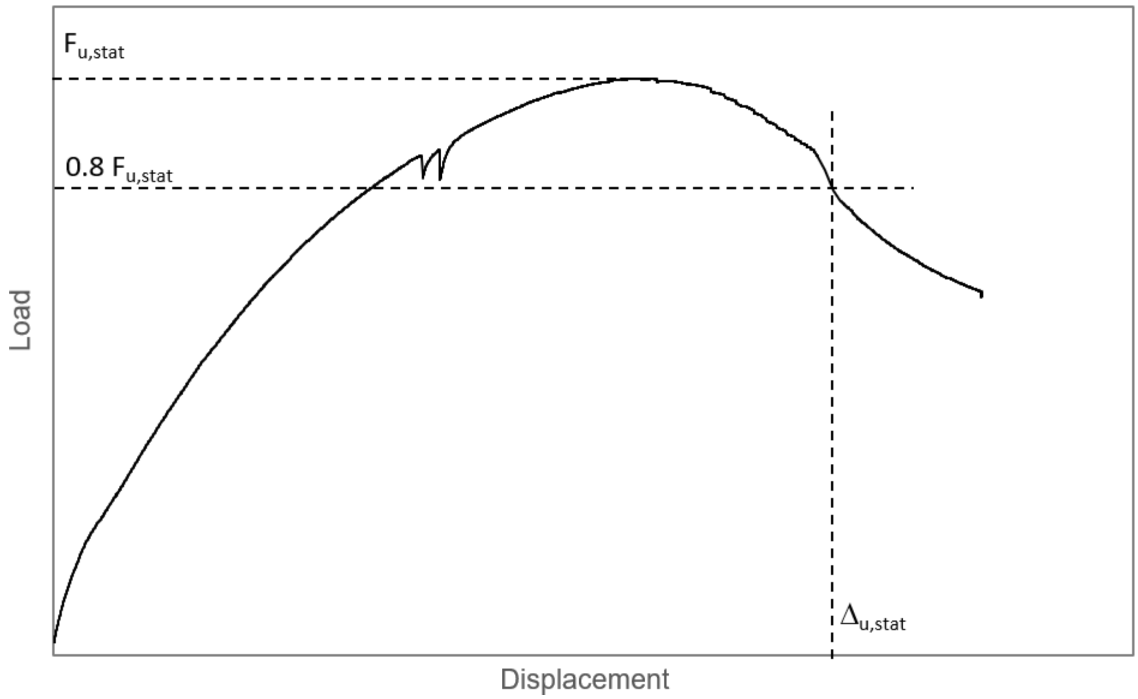

Figure 1: Determination of the displacements $\Delta_{u,stat,}$

6.2. The cyclic tests shall be carried out following the FEMA 461 2007 quasi-static cyclic loading protocol.

The loading history consists of repeated cycles of step-wise increasing deformation amplitudes (Fig. 2). Two cycles at each amplitude must be completed.

The main parameters that should be defined when applying the FEMA 461 2007 loading protocol are listed in the following:

$\Delta_{u,stat}$: displacement measured after 20% decay of the ultimate load in static test;

Δ_o : target smallest deformation amplitude of the loading history.

Δ_m : targeted maximum deformation amplitude of the loading history. It is estimated as the value at which the largest damage level is first observed. This value has to be estimated prior to the test (it can be estimated from a monotonic test, $\Delta_{u,stat}$)

n : number of steps in the loading history; It shall be 10 or larger. Each loading step includes two full loading cycles at the same deformation amplitude.

a_i : amplitude of the cycles, as they increase in magnitude, such that

$a_1 = \Delta_o$

$a_n = \Delta_m$

$a_{i+1} = 1.4 a_i$

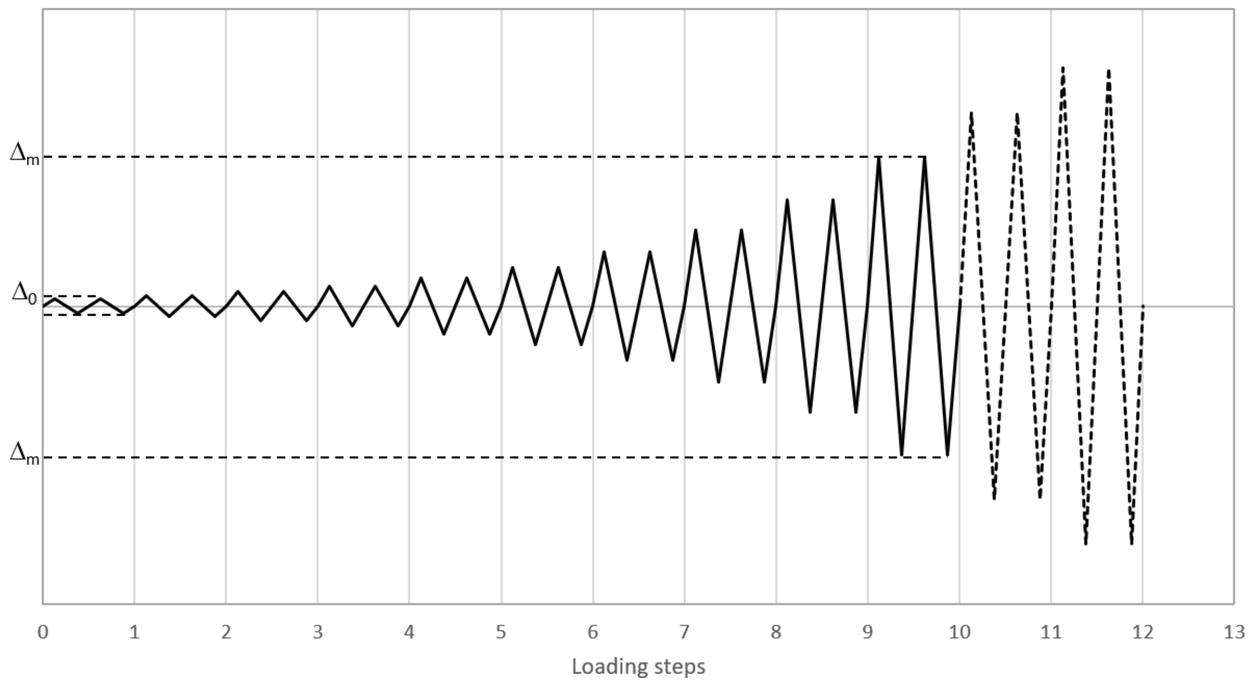

Figure 2: Example of FEMA-461 cyclic loading protocol

If the specimen has not reached the final damage state at Δ_m, the amplitude shall be increased further by constant increment of 0.3 Δ_m. If failure occurs before the 8^{th} loading step, cyclic testing must be repeated starting at smaller Δ_o. Duration for one loading cycle shall not be smaller than 20 seconds to prevent inertia effects. If tested systems or components can only bear tension, the testing cycles are to be ramped between 0 and a_i.

7. RATING METHODOLOGY

7.1. One monotonic test and minimum three cyclic tests for each load condition shall be carried out in accordance with this standard. The following response parameters shall be defined for each tested sample based on the results of the cyclic tests (see Figure 3):

- Maximum tension and compression load capacity ($F_{u,seis}^{+}$ and $F_{u,seis}^{-}$)
- Seismic strength ($F_{u,seis}$) is the minimum of $F_{u,seis}^{+}$ and $F_{u,seis}^{-}$
- Initial stiffness based on force and deformation at 0.4 $F_{u,seis+}$ (K_I^{+}) and at 0.4 $F_{u,seis-}$ (K_I^{-})
- Effective yield displacement as the ratio of $F_{u,seis}^{+}$ / K_I^{+} ($\Delta_{Y,eff}^{+}$) and $F_{u,seis}^{-}$ / K_I^{-} ($\Delta_{Y,eff}^{-}$)
- Deformation in the post peak range at 0.8 $F_{u,seis}^{+}$, (Δ_u^{+}) and at 0.8 $F_{u,seis}^{-}$, (Δ_u^{-})
- Effective ductility as the ratio of Δ_u^{+} / $\Delta_{Y,eff}^{+}$ ($\square_{eff}^{+}$) and Δ_u^{-} / $\Delta_{Y,eff}^{-}$ ($\square_{eff}^{-}$)

All samples shall satisfy the ductility requirement of min($\square_{eff}^{-}$, $\square_{eff}^{+}$) > 1.60. Otherwise, $F_{u,seis,red}$= $F_{u,seis}$ x min($\square_{eff}^{-}$, $\square_{eff}^{+}$)/1.60 shall be substitute for maximum seismic load capacity.

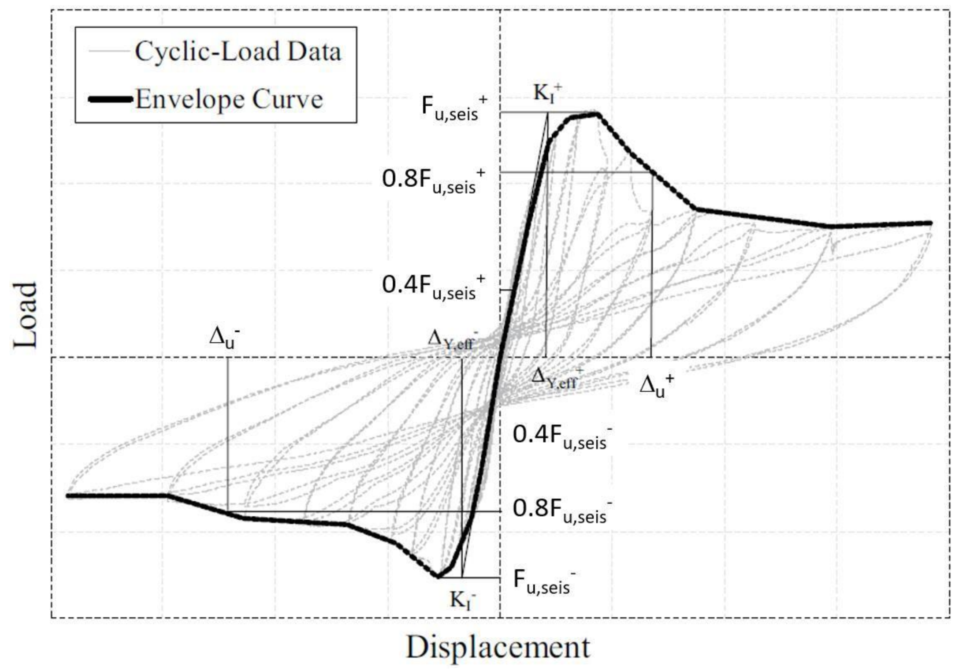

Figure 3: Definition of cyclic test response parameters

7.2. The nominal strength (R_n) for each load condition is found from examining the data and identifying the smallest seismic strength from the cyclic test samples.

7.3. Load ratings for Load and Resistance Factor Design (LRFD) shall be taken as the design strength, which is equal to the nominal strength (R_n) multiplied by a resistance factor (ϕ). Unless otherwise allowed or required by the Authority Having Jurisdiction (AHJ), the resistance factor (ϕ) shall be taken as 0.80. Document the resistance factor used.

7.4. Load ratings for Allowable Stress Design (ASD) shall be taken as the allowable strength, which is equal to the nominal strength (R_n) divided by a safety factor (Ω). Unless otherwise allowed or required by the Authority Having Jurisdiction (AHJ), the safety factor (Ω). shall be taken as 1.8. Document the safety factor used.

8. REPORTING REQUIREMENT

At the conclusion of a test program data shall be collected and organized into a final report that describes, at minimum, the following:

- Name, address of the test laboratory, as well as laboratory code and accreditation body reference if testing falls within the test laboratory's accreditation
- Description of the products tested including manufacture's model designation, dimensions, material and other relevant physical properties
- Description of the test method, outlining the equipment used, and the data collected
- Process by which the data was analyzed to determine load ratings
- A statement by the test laboratory of the precision of the reported rated capacities
- Calibration of equipment

Signature and date of final report review by the laboratory