Building Bearing Seismic Isolation Tests

Seismic isolation bearings must have adequate strength to safely support the maximum structure loads that occur during severe earthquakes. Also, verifying the dynamic bearing properties used in design requires that bearings be tested at the natural vibration period of the isolation system ("real time testing"). Quality Control real time tests verify the dynamic bearing properties when vertically loaded at the average bearing dead plus reduced seismic live load. Bearing Capacity Tests on two prototype bearings verify that the bearings will avoid instability and collapse during a maximum credible earthquake event. Real Time Property Tests on two prototype bearings measure the dynamic properties for the full range of loads and displacements applicable in the design. The Energy Capacity Test verifies the bearing's ability to dissipate the earthquake's energy under realistic seismic loading conditions. The test parameters specified below use the ASCE 7-10 definitions, nomenclature, and defined load combinations.

Quality Control Tests: Performed on 100% of all bearings, as specified below. Each bearing's effective stiffness, effective damping, and restoring force stiffness values, shall be within the tolerances established for the quality control tests of production bearings. All force-deflection loops shall show a positive incremental force-carrying capacity for all incremental displacements away from the bearing's centered, un-displaced position. Bearings shall not be damaged as a result of this test.

Applied vertical bearing load. Average test load sustained within +/- 10% of listed value. Minimum and maximum loads within +/- 30% of listed value.	Lateral displacement cycles, imposed at +/- the displacements listed. Displacements are the minimum positive and negative displacement amplitudes for each cycle. Cycles are applied continuously.	Maximum test duration for total number of cycles listed.
Section 17.8.2.2 Load	3 cycles at D_D	3 T_D

Real Time Property Tests: These property tests are performed on two bearings of each type, and are used to measure the dynamic properties of a bearing over the range of loads and displacements used in the design. These tests are conducted at the isolated structure period $T_{M,}$ in order to characterize the dynamic stiffness and damping properties, and energy dissipation capacities at a rate of energy input representative of seismic conditions. Modeling of the bearing properties in the design and analysis of the structure should be based on the measured bearing properties from the Real Time Property Tests. The Real Time Property tests should be performed as specified below on the same two prototype bearings in the order listed. All force-deflection loops shall show a positive incremental force-carrying capacity for all incremental displacements away from the bearing's center position. Bearings shall have no structural damage as a result of these tests, but may not be used for construction.

Applied vertical bearing load. Average test load sustained within +/- 10% of listed value. Minimum and maximum loads within +/- 30% of listed value.	Lateral displacement cycles, imposed at +/- the displacements listed. Displacements are the minimum positive and negative displacement amplitudes for each cycle. Cycles are applied continuously.	Maximum test duration for total number of cycles listed.
Section 17.8.2.2 Load	3 cycles at D_D	3 T_D
Section 17.8.2.2 Load	20 cycles at +/- 1inch	40 seconds
Section 17.8.2.2 Load	100% $D_{M,}$ 75% $D_{M,}$ 100% D_D, 50% D_D	4 T_M
50% Section 17.8.2.2 Load	100% $D_{M,}$ 75% $D_{M,}$ 100% D_D, 50% D_D	4 T_M
75% Section 2.3.2, Load Comb 5	100% $D_{M,}$ 75% $D_{M,}$ 100% D_D, 50% D_D	4 T_M
Section 2.3.2, Load Comb 5	100% $D_{M,}$ 75% $D_{M,}$ 100% D_D, 50% D_D	4 T_M
Section 17.8.2.2 Load	3 cycles at D_D	3 T_D

Bearing Capacity Tests

The intent of the ASCE 7-10 structure design requirements is to limit the probability of structure collapse to 10% for the code Maximum Considered Earthquake (MCE) shaking. However, every year earthquakes stronger than the code MCE earthquakes cause many structure collapses. These stronger “maximum credible earthquakes” need to be considered for the safe implementation of seismic isolation. When seismic isolation bearings experience earthquake demands greater than their displacement capacity, complete structure collapse can easily occur. The Bearing Capacity Tests specified herein verify safe structural behavior during the combined bearing loads that occur during maximum credible earthquake shaking. The adequate strength and lateral stability of a bearing under the combined design compression and shear loads is verified by these tests, as well as the ability to dissipate the earthquake’s energy when tested at the isolated natural period T_M. Bearings also need to be able to safely accommodate short duration uplift displacements or tension loads, and afterwards maintain their lateral strength and stiffness when loaded again at the design compression loading. While supporting the design vertical load, the bearing should maintain a positive incremental lateral stiffness as the lateral loads are incrementally increased up to the calculated MCE shear load and displacement. If a positive incremental lateral stiffness is not maintained, bearing displacements larger than the calculated design displacement will occur, which may cause isolation system instability and complete structure collapse. Each test should be performed in the order listed below on each of two bearings of each type. Bearings must meet the acceptance criteria as specified for each test. Bearings may be damaged as a result of these tests. The capacity tested bearings may not be used for construction.

Energy Dissipation Capacity – The bearing is vertically loaded at the ASCE 7-10 Section 17.8.2.2 compression load then 5 lateral displacement cycles are consecutively imposed at displacements not less than +/- D_M displacement. The total duration of the five cycles of lateral loading should not be more that 5 $T_{M.}$ The effective damping β_m used in design should not be more than the average damping measured for the five cycles.

Design Uplift Displacement or Tension Load – Bearings that may undergo uplift displacement shall be tested to simulate the maximum MCE uplift displacement. Bearings that may be subject to tension loading shall be tested for the maximum MCE tension load. Starting at the laterally un-displaced position, the Section 17.8.2.2 compression load is applied and the bearing is displaced to $+D_{TM}$, then the maximum MCE uplift displacement or tension load is imposed and the bearing is displaced back to the starting position, then the Section 17.8.2.2 compression load is re-applied and the bearing is displaced to $-D_{TM}$ and then back to the starting position. The uplift displacement or tension load, and lateral displacement movements, shall not result in a permanent loss of bearing compression, tension or lateral load capacity.

Positive Lateral Stiffness – The bearing is vertically loaded at the load combination 5 of ASCE 7-10 Section 2.3.2. One complete lateral displacement cycle is imposed at not less than +/- D_{TM} displacement. The force-deflection plot shall have a positive incremental force-resisting capacity for all increases in lateral displacement. At the +/- D_{TM} displacements, the applied vertical load shall not be less than the specified load combination.

Combined Design Compression and Shear Loads – At a vertical load not less than 1.2 times Load Combination 5 of ASCE 7-10 Section 2.3.2, a lateral load of not less than 1.2 times k_{Mmax} times D_{TM} shall be applied and held for 5 seconds. The lateral and vertical displacements shall not increase more than 3% during the 5 seconds of sustained loads. These test loads account for the maximum combined dead load, live load, and vertical loads caused by vertical earthquake shaking effects, and shear and vertical overturning loads from lateral seismic movements, as reasonably estimated for maximum credible earthquake shaking.

Tests Performed at Reduced Test Rates or on Reduced Scale Bearings

Seismic isolation bearings are sometimes tested very slowly, imposing the code specified lateral cyclic displacements at a "quasi-static" rate. Quasi-static tests are adequate for testing a bearing's strength, but misrepresent the ability of a bearing to dissipate the earthquake's energy within the realistic time duration of an earthquake. If the above Energy Dissipation Capacity test can not be performed on full scale bearings within the maximum time specified, the β_m for real time dynamic cycling may be calculated from the results of slower velocity tests performed on full scale bearings, adjusted according to slow velocity and real time tests performed on reduced scale bearings. Reduced scale bearings must be of the same type and exactly the same materials, and not smaller than ¼ scale. Reduced scale bearings are tested for 5 cycles in real time at the reduced scale $D_{M.}$ First, the 5 cycle slow test is performed at the same test duration used in testing the full scale bearings, then the test is performed at the real time 5 T_M for the reduced scale bearings. The reduced scale bearing vertical load shall not be less than $^1/_8$ of the full scale vertical load. The reduced scale D_M shall not be less than ¼ of the full scale D_M. The reduced scale T_M shall not less than ½ the full scale T_M. The β_m used in design shall be calculated as:

$$\beta_m \text{ (used in design)} = \beta_m \text{ (full size slow) } [\beta_m \text{ (reduced scale real time)} / \beta_m \text{ (reduced scale slow)}]^2$$

If the slow velocity Energy Dissipation Capacity test is not performed on full scale bearings, or if reduced scale real time tests are not performed, then the value of β_m used in design shall not exceed 2.0.

If the Combined Design Compression and Shear, or Positive Lateral Stiffness, or Uplift Displacement, or Tension Load tests are not performed as specified on the prototype bearings, then the bearing's ultimate vertical strength capacity must be at least three times the load Combination 5, and the V_s used to design the upper structure shall be at least twice the V_s load demand calculated from a structural evaluation based on the elastic properties of the bearings.

If the Real Time Property Tests are not performed as specified on the prototype bearings, then the value of β_m used in design shall not exceed 2.0, and the V_s used in the structure design shall not be less than twice the V_s as calculated from the elastic properties of the full size bearings.

ASCE 7-10 Bearing Tests and Structure Design Requirements

The above specified bearing tests are more stringent than the ASCE 7-10 required seismic isolation bearing tests, yet these tests are necessary to protect against bearing and structure collapse, and adequately define the dynamic bearing properties for use in the isolated structure design. The ASCE 7-10 prototype tests were developed to measure bearing effective stiffness and damping values at average vertical loads. The ASCE 7-10 structure design code requires isolation bearings to be designed to resist the compression, shear, and tension loads as specified above, yet the specified prototype tests do not verify the strength capacities of the bearings under the combined loadings. The section 17.8.2.2 lateral property tests are specified at the "average downward force on all isolator units of a common type", and do not measure the lateral strength or stiffness properties under the combined design compression loads. The maximum vertical load test 17.8.5.2 is conducted at the design compression load as specified by load combination 5 of Section 2.3.2. However, this is specified as a static load test to be performed with the bearing lateral displacement held fixed at D_{TM}. Since the lateral displacement is held fixed, this static load test cannot check for any loss of lateral load capacity, nor any loss of lateral stiffness. ASCE 7-10 Table C.1.3.1b specifically allows for a 10% probability of total or partial collapse for the MCE level shaking. Moreover, the design and testing requirements for isolation bearings specified in ASCE 7-10 do not differentiate between ordinary structures and essential facilities, leading to a 10% probability of collapse for seismically isolated essential facilities during MCE shaking. The majority of project engineers and owners, however, expect that all seismically isolated structures will withstand the strongest earthquakes without collapse.