Bridge Bearing Seismic Isolation Tests

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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 tests specified below use the load and displacement definitions of the AASHTO Guide Specification for Seismic Isolation Design, July 2010, as applicable to each bearing size and type. It is important that the AASHTO Guide Specification 13.1 System Characterization Tests are performed in addition to the tests specified below.

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. Minimum and maximum loads within +/- 30% of load value. Average test load sustained within +/- 10% of load 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.
Average (DL + LL_s)	3 cycles at TDD	3 T_{eff}

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 $T_{eff,}$ 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 is 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.
Average (DL + LL_s)	3 cycles at TDD	3 T_{eff}
Average (DL + LL_s)	20 cycles at +/- 1 inch.	40 seconds
Average (DL + LL_s)	150% TDD, 75%TDD, 25% TDD	3 T_{eff}
50% Max (DL + LL_s + OT)	150% TDD, 75%TDD, 25% TDD	3 T_{eff}
Max (DL + LL_s)	150% TDD, 75%TDD, 25% TDD	3 T_{eff}
1.2 Max (DL + LL_s + OT)	150% TDD, 75%TDD, 25% TDD	3 T_{eff}

Bearing Capacity Tests: Bearing Capacity Tests are intended to ensure that the bearings will exhibit safe structural behavior during the combined loadings that occur during maximum credible earthquake shaking, when considering the effects of both lateral and vertical ground shaking. Vertical earthquake shaking effects have caused the collapse of many bridges, and the structural failure of seismic isolation bearings, but are often ignored by bridge designers when implementing a minimum code design. Also, every year earthquakes occur that are stronger than the code defined design earthquakes. Since maintaining stability in the bearings is critical to avoiding collapse of an isolated bridge, it is very important that the bearings have the strength and stability necessary to withstand maximum credible earthquake shaking without structural bearing failures. These Bearing Capacity Tests check for significant structural degradation caused by the maximum combined vertical and shear loads, and anticipated earthquake energy input. To control lateral seismic displacements, the bearing should maintain a positive incremental lateral stiffness when laterally loaded to the maximum shear load and displacement, while supporting the maximum vertical loads. 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 bridge collapse. The uplift capacity tests check that bearings can 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. Each test should be performed in the order listed below on each of two bearings of each type. Bearings must be able to complete the tests in the order shown and 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 Test: The bearing is vertically loaded at the Max (DL + LL_s) compression load then 5 lateral displacement cycles are consecutively imposed at displacements not less than +/- TDD displacement. The total duration of the five cycles of lateral loading should not be more that 5 $T_{eff.}$ The EDC used in design should not be more than the average EDC measured for the five cycles.

Design Uplift Displacement or Tension Load: Bearings that may undergo uplift displacement shall be tested to simulate the maximum seismic uplift displacement. Bearings that may be subject to tension loading shall be tested for the maximum tension load. Starting at the center un-displaced position, the Max (DL + LL) compression load is applied and the bearing is displaced to +TDD, then the maximum MCE uplift displacement or tension load is imposed and the bearing is displaced back to the center position, then the Max (DL + LL) load is re-applied and the bearing is displaced to –TDD, 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 the bearing compression, tension or lateral load capacities.

Positive Lateral Stiffness: The bearing is vertically loaded at the Max (DL + LL + OT) compression load, then one complete lateral displacement cycle is imposed at not less than +/- 1.25 TDD displacement. The force-deflection plot shall have a positive incremental force-resisting capacity for all increases in lateral displacement away from center. At the 1.25 TDD displacement, the applied vertical load shall not be less than the Max (DL + LL + OT) compression load.

Maximum Combined Compression and Shear Loads: At a vertical load not less than 1.3 (DL + LL + OT), a lateral load of not less than 1.3(k_{max} x TDD) shall be applied and sustained for 5 seconds. The lateral and vertical displacements shall not increase more than 3% during the 5 seconds of sustained loads. The bearing shall demonstrate no loss of vertical or lateral load carrying capacity as a result of this test. The 1.3 vertical load factor provides for a reserve vertical strength capacity to safely accommodate vertical earthquake shaking effects. The 1.3 lateral load factor provides for a reserve lateral shear strength capacity to safely accommodate an earthquake stronger than the minimum code specified design earthquake.

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 Energy Dissipation Capacity test can not be performed on full scale bearings as specified, the EDC used in design 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 TDD. The reduced scale 5 cycle slow test is performed at the same test cycle period used to test the full scale bearings, then the test is performed at the real time 5 T_{eff} 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 TDD shall not be less than ¼ of the full scale TDD. The reduced scale T_{eff} shall not less than ½ the full scale T_{eff}. The EDC used in design shall be calculated as:

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

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 ξ (equivalent viscous damping ratio) used in design shall not exceed 0.05. 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 Max (DL + LL + OT), and the F (seismic force) used to design the upper structure shall be at least twice the F value calculated from a structural evaluation based on the calculated elastic properties of the bearings. If the Real Time Property Tests are not performed as specified on the prototype bearings, then the value of ξ used in design shall not exceed 0.05, and the F used in the structure design shall not be taken as less than twice the F value as calculated from the elastic properties of the full size bearings.

Comparison With AASHTO Minimum Bearing Tests and Design Requirements

The above tests are performed at higher vertical loads than the AASHTO Guide Specification 13.2 Prototype Tests, and the 15.2, 17.2, and 18.5 Quality Control Tests. The AASHTO 13.2.2 Prototype Tests are performed at the average dead load only, not including live load, or seismic overturning load, or vertical earthquake load. In practice, bearings supporting a longer than average bridge span will support a higher than the average dead load. The 13.2.2.6 Stability test for maximum vertical load uses reduced live load LL_s, and has no load for vertical earthquake shaking. The AASHTO design live load is LL, and LL_s is an arbitrarily reduced live load. Inadequate bearing vertical load capacity causes bearing damage, reduced lateral bearing stiffness, and increased lateral displacements, which can cause bearing and total bridge collapse. Seismic isolation bearings should safely maintain stability under the maximum vertical loads including full design live loads, and vertical earthquake shaking effects. It is important to recognize that although seismic isolation has been proven as a seismic design approach, there are no industry standards for the materials, manufacturing, or testing methods for the bearings. An isolated bridge designed according to the current AASHTO Guide Specifications, but using bearings procured through low bid without industry standards for bearing materials, manufacturing and testing methods, is very dangerous. Achieving seismic isolation designs that avoid bearing damage and collapse depends on using a bearing manufacturer with proven bearing materials, manufacturing, and testing methods, and also performing bearing tests as recommended above. These tests represent a recommended 20 year technical update to the AASHTO 13.2 Prototype tests, that is needed for performing tests at realistic maximum vertical loads and dynamic lateral loading conditions. The above specified tests are recommended to replace the tests specified in Sections 13.2, 15.2, 17.2, and 18.5, of the AASHTO Guide Specification.