A Test Plan for the Characterization and Qualification of Highway Bridge Seismic Isolator and Damping Devices

Energy Technology Engineering Center
Highway Innovative Technology Evaluation Center
California Department of Transportation

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Table of Contents

1.0 Discussion 1

2.0 Approach 2

3.0 Manufacturer's Responsibility. 2

4.0 Test Plan. 6

4.1 Material Characterization 6
4.2 Component Characterization. 6

5.0 Reporting Requirements 15

6.0 Test Apparatus 16

7.0 Suitability of Proposed Test Conductor 26

Figures and Tables i
Appendix A 32
Glossary 38

Figures

1. Bearing Test Rig Structural Elements 17
2. Photograph of Bearing Test Rig 18
3. Bearing Test Fixture Performance Envelope. . . .20
4. Telescoping Device Test Set Up 22
5. Bearing Test Fixture Test Article Opening. . . .23
6. Bearing Test Fixture Adapter Arrangement 24
7. Test Rig Instrumentation 27

Tables

3.1 Isolator Requirements 4
3.2 Energy Dissipator Requirements 5
4.1 Category Selection Criteria. 8
4.2 Device Categorization 9
4.3 Category I - Elastomeric Device Test Matrix. . . 9
4.4 Category II - Slider & Roller Device Test Matrix 9
4.5 Category III - Spherical Slider Test Matrix. . .10
4.6 Category IV - Energy Dissipator Test Matrix. . .10
5.1 Reporting Requirements 16
6.1 Bearing Test Rig Performance Limits. 21
6.2 Test Instrumentation 26

Test Plan for Characterizing Highway Bridge Seismic Isolators and Damping Devices

1.0 Discussion

A test program is proposed to develop key data on the performance and quality of isolation and energy dissipating devices designed for highway bridge applications. The tests are intended to provide state and federal agencies with information to assist in assessing the suitability of these devices for specific applications. The term "energy dissipator" used herein refers to hydraulic and friction devices used primarily for energy dissipation.

The objectives of the Program are:

1) To develop and apply a program of testing, including full scale dynamic tests, sufficient to characterize the fundamental properties and performance characteristics of the devices evaluated.

2) To develop suggested guide specifications for the use of isolation and energy dissipating devices in new bridge construction and retrofit applications.

3) To provide guidance regarding the selection, design and use of seismic isolation and energy dissipating devices for different levels of performance.

2.0 Approach

A comprehensive test program to evaluate the important properties and performance characteristics of isolator and energy dissipating devices is presented. The test program examines characteristics such as: 1) stability, 2) range, 3) capacity, 4) resilience, 5) resistance to service loads, 6) energy dissipation, 7) survivability in extreme environment, 8) resistance to aging and creep, 9) predictability of response, 10) fatigue and wear, and 11) size effects. These properties provide the bridge designer with critical information on the suitability of these devices for specific design applications, and also provide insight into the reliability, longevity, and

predictability of response. Furthermore, the Program addresses the ability of the vendor or manufacturer to provide a quality product, understand and predict product response, and provide hardware in a timely manner.

Acceptable ranges or limits have not been established for isolator or energy dissipator test performance since these requirements are typically specified on a project-by-project basis. However, target values are defined for selected parameters so that the manufacturer can provide the appropriate component for testing.

The Program consists of two parts:

Part 1: Materials Test Review

> To assess by review the suitability of materials to meet certain minimum environmental requirements. ASTM or equivalent testing of selected materials is required.

Materials Test Review (Part 1) examines the ability of materials used to fabricate the test devices to satisfy certain requirements for properties such as hardness, tensile strength, shear modulus, heat resistance, compression set, brittleness, ozone resistance, elongation, corrosion, fatigue, creep, temperatures extremes, etc.

Part 2: Component Testing

> To assess the performance characteristics of isolators and energy dissipators subjected to motion-controlled harmonic loadings.

Component Testing (Part 2) quantifies performance characteristics and properties such as stiffness and energy dissipation, aging and temperature effects, fatigue and wear, and environmental degradation. Motion-controlled loads are applied to full-size devices. This information will be used for characterizing and describing the devices for analytical design.

3.0 Manufacturer's Responsibility

Cooperation of the manufacturer in supplying hardware in a timely manner for testing is essential to the success of the Program. Delivery dates will be provided to the manufacturer after initial planning and scheduling is completed. The manufacturer will be responsible for delivering hardware to the test site, working drawings, material specifications, design and test data, locations of manufacturing

sites, and response predictions described in this section. Test articles damaged during testing or handling will be replaced or repaired by the manufacturer at no cost or expense to the HITEC Program. The test devices submitted for evaluation shall be representative of the production devices that the manufacturer intends to market.

Test Requirements

The manufacturer must specify information to define the limits for testing pursuant to requirements provided in Tables 3.1 and 3.2. **Considerable thought should be exercised in defining design loads, design displacements, movement ratings, and operational temperature limits since these values reflect on the suitability of these devices for specific applications that may vary from state to state.** The following design parameters shall be specified and used throughout this Plan.

Design Compressive Load (DCL): The maximum design vertical load (dead load, live load, overturning, etc.) for weight-bearing devices. (Project goals will be met without differentiating between these loads.)

Design Displacement (DD): The maximum lateral displacement of seismic isolators and the maximum displacement of energy dissipators under seismic loadings.

Design Velocity (DV): The maximum velocity expected under seismic loading. (Except Isolators)

Movement Rating (MR): The small displacement **range** (lateral) of the device due to temperature and live load fluctuations (excluding earthquakes).

Design Lateral Load (DLL): The maximum lateral load expected under seismic loadings. (Except Energy Dissipators)

Design Rating (DR): The maximum axial load expected under seismic loadings. (Energy Dissipators Only)

Hardware and Test Materials

The manufacturer shall submit the following information:

1) Any test data generated prior to shipping the test hardware.

2) Material Specifications used to manufacture or purchase the devices supplied for testing, and a written summary (<5 pages) of the manufacturer's quality control program to assure that all component materials and fabrication processes comply with the submitted working drawings.

3) ASTM test data for materials. (See Section 4.1)

4) Environmental Requirements used to assess aging such as ultraviolet, ozone, salt spray, moisture, sand or dust, etc.

5) Drop test data used to confirm performance of energy dissipators (if used).

6) Analytical methods used to predict test article response for displacement or velocity load response, stiffness, and damping. The predicted performance shall be placed on the working drawings.

7) Working drawings

Hardware

The manufacturer shall provide 5 devices (3 devices of the same size and rating) for testing in the sizes and ranges indicated in Tables 3.1 or 3.2 . Furthermore, the manufacturer will define lateral/axial design displacements based on constraints outlined in the following Tables.

Table 3.1 Isolator Requirements[1]				
Design Compressive Load (±10%) (DCL)	**Number of Devices**	**Test Article Number**	**Lateral Design Disp. (DD)**	**Minimum Movement Rating[6] (MR)**
150 kips	1	1	DD[3]	2.0 in.
500 kips	3[2]	2, 3, 4	DD[3]	3.0 in.
750 kips[5]	1	5	DD[3]	4.0 in.

Table 3.2 Energy Dissipator Requirements				
Design Rating (±10%) (DR)	**Number of Devices**	**Test Article Number**	**Axial Design Disp. (DD)**	**Movement Rating[6] (MR)**
50 kips	1	1	<12.0 in.[4]	2.0 in.
150 kips	3[2]	2, 3, 4	<12.0 in.[4]	3.0 in.
240 kips[5]	1	5	12.0 in.	4.0 in.

(1) If sufficient damping (>3% at DD) is not provided by the isolator, a damping device shall be incorporated into the design and tested concurrently as a system.

(2) Three identical devices shall be provided. If one test article cannot operate in the entire targeted temperature range (-40F to 120F) specified in test T2.7 the manufacture may choose to fabricate Test Articles 2 & 3 of different materials permitting operation in the total temperature range of interest. Test Article 2 may be designed to operate, for example, in a temperature range of -40F to 80F, whereas Test Article 3 may be designed to operate between for example, 10F to 120F, thus covering the entire temperature range. However, other than material differences, Test Articles 2 & 3 must be identical. If one test article can operate in the entire temperature range, Test Articles 2, 3, and 4 are identical.

(3) The manufacturer may define DD for specific or potential applications, but the target value is DD > ± 3 x MR. (e.g., if MR=2.0 inches, then DD > ±6.0 inches). Note: Higher or lower values may be specified by the manufacturer for potential applications.

(4) The manufacturer shall specify appropriate values up to ±12.0 inches

(5) If the manufacturer normally does not make a component this large, a smaller device may be submitted with HITEC Panel approval.

(6) The movement rating is peak-peak displacement. (e.g., 2.0 in.= ±1.0 in.)

The manufacturer supplied test articles shall be designed to conform to the following limitations of the test equipment.

(1) Max. Compressive Load = 800,000 pounds
(2) Displacement = ±15 inches
(3) Max. Lateral Dynamic Load = ±240,000 pounds
(4) Max. Height = 36 inches
(5) Max. Base Envelope = 48 inches x 48 inches
(6) Max. Velocity = ±50 inches/second

Adapters are to be provided by the manufacturer that enable the test articles to attach directly to the test machine (including multiple component devices, e.g., isolators incorporating energy dissipators). Adapter requirements will be provided to the manufacturers by the testing organization. An adequate supply of components or structural parts designed to fail during test shall also be supplied to the testing organization for replacement as needed. These parts must be interchangeable without having to remove the device from the rig. If repairs cannot be made in the rig, testing will continue with the damaged test article or terminated if further testing will not provide useful information.

4.0 Test Plan

4.1 Material Characterization

The manufacturer shall provide the Test Performer with a Certification of Compliance listing all materials in the device. The certificate shall certify that the devices conform to the design and material requirements, and were manufactured in accordance with their quality control program. The certification shall be supported by a copy of the results of all tests performed on the devices and device materials. Tests shall be certified correct by the testing laboratory personnel who conducted the test and interpreted the test results. ASTM equivalent testing methods are acceptable if supported by a complete description of the Standard used (such as JIS). The manufacturer shall provide representative samples of materials as directed.

The devices shall be designed and fabricated as shown on the working drawings supplied by the manufacturer, and all allowable tolerances will be shown on working drawings. Furthermore, a list of names and addresses of companies or subcontractors that manufacturer the test devices will also accompany the working drawings.

Test data shall be supplied to assure that materials conform to test requirements outlined in Appendix A. However, alternative test methods may be proposed by the manufacturer if a complete description accompanies the submitted test data.

4.2 Component Characterization

Component characterization testing quantifies performance data and provides useful information to the bridge design engineer. Since a wide variety of component designs have been submitted for consideration several test scenarios have been developed to satisfy individual test needs. There are three component groups that are assigned to one of four performance test categories:

(1) Weight-Bearing Parallel-Shear Devices These devices include elastomeric bearings, friction sliders and interspersed plate viscous dampers. The key features are that they are vertical load bearing and contain two horizontal top and bottom mounting surfaces that move laterally in essentially parallel motion with minimal change in vertical spacing.

(2) Weight-Bearing Spherical Devices These devices include singular or plate mounted groups of captured, roller-between-surface devices or sliding friction surfaces on uplift contours. The key features are that they are load bearing and contain two horizontal top and bottom mounting surfaces and that lateral motion is accompanied by a change in vertical spacing.

(3) Non-Weight-Bearing Axial Devices These devices consist of both friction and hydraulic components designed to dissipate energy.

Isolator and energy dissipating devices are assigned to one of four test categories based on their performance characteristics. Each category will be subject to a different series of tests that are required to characterize the device. The four performance categories include:

Weight-Bearing Parallel Shear Devices

Category I - Elastomeric Devices
Category II - Slider and Roller Devices

Weight-Bearing Spherical Devices

Category III - Spherical Slider Devices

Non-Weight-Bearing Axial Devices

Category IV - Energy Dissipators

Category I

A flexible vertical load supporting device with energy dissipating capabilities that lengthens the period of lateral vibration of the system sufficiently to reduce the force response and then tends to return the system to its original position when the load is removed.

Category II

A vertical load supporting device that utilizes rolling or sliding elements and that may require an auxiliary device to satisfy minimum damping requirements. The device lengthens the period of vibration of the system sufficiently to reduce the force response and has energy dissipating capabilities. The device may or may not be self-centering and therefore may or may not return to its original position when the load is removed.

Category III

A vertical load supporting device utilizing rollers or sliding elements that relies on gravity to assist in returning it to its original position when the lateral load is removed. The device lengthens the period of vibration of the system sufficiently to reduce the force response, and may or may not have energy dissipating capabilities.

Category IV

A device that uses either mechanical friction or hydraulic fluid to dissipate energy. The device may or may not be self-centering and therefore may or may not return to its original position when the load is removed.

Table 4.1 is provided to assist in selecting the appropriate test category.

Table 4.1 Category Selection Criteria

PROPERTIES	Category I Elastomeric Isolators	Category II Rollers and Sliders	Category III Spherical Devices	Category IV Damping Devices
Frequency De-coupling	Yes	Yes	Yes	No
Energy Dissipation	Yes	Yes/No	Yes/No	Yes
Restoring Capability	Yes	Yes/No	Yes/No	Yes/No
Vertical Movement	Yes	No	Yes	No

The required tests and their sequencing are summarized for each type of device in the following Tables.

Table 4.3 Category I - Elastomeric Devices

Test Article 1	**T2.1**	**T2.3**	**T2.2**	**T2.8**	**T2.9**	
Test Article 2	**T2.1**	**T2.3**	**T2.2**	**T2.7**	**T2.8**	**T2.9**
Test Article 3	**T2.1**	**T2.3**	**T2.2**	**T2.7**[(1)]	**T2.8**	**T2.9**
Test Article 4	**T2.1**	**T2.3**	**T2.5**	**T2.6**	**T2.3**	**T2.9**
Test Article 5	**T2.1**	**T2.3**	**T2.2**	**T2.8**	**T2.9**	

Table 4.4 Category II - Slider & Roller Devices						
Test Article 1	**T2.1**	**T2.3**	**T2.2**	**T2.8**	**T2.9**	
Test Article 2	**T2.1**	**T2.3**	**T2.2**	**T2.7**	**T2.8**	**T2.9**
Test Article 3	**T2.1**	**T2.3**	**T2.2**	**T2.7(1)**	**T2.8**	**T2.9**
Test Article 4	**T2.1**	**T2.3**	**T2.5**	**T2.6**	**T2.3**	**T2.9**
Test Article 5	**T2.1**	**T2.3**	**T2.2**	**T2.8**	**T2.9**	

Table 4.5 Category III - Spherical Slider Devices						
Test Article 1	**T2.1**	**T2.3**	**T2.2**	**T2.8**	**T2.9**	
Test Article 2	**T2.1**	**T2.3**	**T2.2**	**T2.7**	**T2.8**	**T2.9**
Test Article 3	**T2.1**	**T2.3**	**T2.2**	**T2.7(1)**	**T2.8**	**T2.9**
Test Article 4	**T2.1**	**T2.3**	**T2.5**	**T2.6**	**T2.3**	**T2.9**
Test Article 5	**T2.1**	**T2.3**	**T2.2**	**T2.8**	**T2.9**	

Table 4.6 Category IV - Damping Devices						
Test Article 1	**T2.1**	**T2.4**	**T2.8**	**T2.9**		
Test Article 2	**T2.1**	**T2.4**	**T2.7**	**T2.8**	**T2.9**	
Test Article 3	**T2.1**	**T2.4**	**T2.7(1)**	**T2.8**	**T2.9**	
Test Article 4	**T2.1**	**T2.4**	**T2.5**	**T2.6**	**T2.4**	**T2.9**
Test Article 5	**T2.1**	**T2.4**	**T2.8**	**T2.9**		

(1) Test T2.7 is performed only if Test Article 3 is fabricated from different materials than Test Article 2.

Component Characterization Test Philosophy

Three identical devices are tested to limit the maximum number of loading cycles applied to individual devices, and to provide information on the repeatability and consistency of performance. Furthermore, the proposed sequence of testing enables the analyst to quantify the effects of individual parameters such as temperature, fatigue and wear, and environmental degradation. One larger and one smaller device are also included to provide data on a range of sizes.

Performance characteristics of the test articles are determined at harmonic frequencies of 0.05 Hz (pseudo-static), 0.2 Hz, 0.5 Hz, 1.0 Hz and 2.0 Hz (corresponding to 20.0 sec., 5.0 sec., 2.0 sec., 1.0 sec., and 0.5 sec. periods) because these frequencies bound the natural frequencies of isolated and un-isolated bridge structures.

Load-deflection characteristics of devices with components or materials that yield or respond inelastically typically take several loading cycles to become repeatable, commonly referred to as shaking-down. This number of cycles will be determined and noted. In addition, some devices may use components that are designed to fail/yield during operation; these components may be replaced between tests to allow for continued testing, otherwise testing will be continued with a damaged component or terminated if useful data cannot be obtained.

Test loads not specifically designed to evaluate frequency effects will be applied at 0.5 Hz (corresponding to a 2.0 second period) because this frequency is typical of isolated structures.

Fatigue and wear loads shall be applied at 0.1 Hz (corresponding to a 10. second period) or other frequency deemed acceptable to the manufacturer to prevent heat buildup and to minimize the time required to perform the tests. However, the speed of application shall not be less than 4.5 inches/minute.

Component Test Descriptions

T2.1 Performance Benchmark (All Categories)

Purpose: To experimentally verify the initial stiffness and damping/friction of the device, and the number of cycles of loading required to stabilize response. This number of cycles is referred to as NSD -- number of shake-down cycles.

Procedure: The loads will be applied as follows:

For Category I, II and Category III devices 10 fully-reversed loading cycles at the design displacement (DD) are applied to the test device at 0.5 Hz (corresponding to a 2.0 second period). The design compressive load (DCL) is also applied.

For Category IV devices 10 fully-reversed loading cycles at the design displacement (DD) are applied at 0.5 Hz (corresponding to a 2.0 second period). However, if the design velocity is exceeded, the displacement shall be reduced so that the maximum velocity does not exceed the design velocity (DV).

The intercept and peak values will be reported for each cycle.

NOTE: If the device does not stabilize, the manufacturer will be notified that no further testing will be undertaken.

F(2)= Peak load for second cycle
F(10)= Peak load for tenth cycle

Shake-down occurs if $.7 < F(2)/F(10) < 1.3$

[The data will be used to determine shake down characteristics of the test article and confirm that minimum damping requirements are satisfied for the devices or combination of devices tested.]

T2.2 Load-Deflection Characterization (Categories I, II and III)

Purpose: To determine load-deflection performance characteristics.

Procedure: Load-deflection and damping/friction characteristics are determined as follows. Circular devices are tested in one arbitrarily selected primary direction of operation and at 90 degrees to this direction. Bi-symmetric devices (square or rectangular) will be tested in the primary direction of operation, at 90 degrees to the primary direction, and in a diagonal direction through a point of the bearing surface that is farthest from its centroid (e.g., @ 45° to the primary loading direction for a square cross-section.). The tests consist of three cycles of fully-reversed design displacement (DD) applied at 0.5 Hz (corresponding to 2.0 second period) for all devices. Three tests are performed in the primary direction of operation;

one at 40% DCL, one at 70% DCL, and one at 100% DCL. Tests in the other directions, when required, are performed with DCL. If the device is uni-directional it is tested only in that direction.

[The data will be used to quantify performance characteristics (stiffness and damping) of weight-bearing devices under load.]

T2.3 Frequency Dependant Characteristics (Categories I, II, & III)

Purpose: To determine static and dynamic performance characteristics in the primary direction of operation.

Procedure: With the design compressive load (DCL) applied, three fully-reversed cycles of the design displacement (DD) are applied at 0.05 Hz, 0.2 Hz, and 1.0 Hz, and 50% of DD at 2.0 Hz (corresponding to 20.0 sec., 5.0 sec., 2.0 sec., 1.0 sec., and 0.5 sec. periods).

[The data will be used to quantify performance characteristics (stiffness and damping) of weight-bearing devices under dynamic loading conditions.]

T2.4 Frequency Dependent Characteristics (Category IV)

Purpose: To determine dynamic performance characteristics and verify the constitutive laws.

Procedure: Three fully-reversed cycles of the maximum displacement, are applied at each of the following harmonic frequencies; 0.05 Hz, 0.2 Hz, 0.5 Hz, 1.0 Hz, and 2.0 Hz (corresponding to 20.0 sec., 5.0 sec., 2.0 sec., 1.0 sec., and 0.5 sec. periods). Displacement ranges may have to be limited to ensure the maximum velocity of the device or test equipment is not exceeded.

[The data will be used to quantify the performance of energy dissipating devices at various frequencies and velocities, confirm analytical predictions of the form $F=CV^n$, and verify manufacturer's drop test data (if performed).]

T2.5 Fatigue and Wear (All Categories)

Purpose: To simulate many small displacements due to temperature and live load fluctuations other than earthquake for evaluating possible deterioration in earthquake performance due to resulting debonding, wear, or fatigue.

Procedure: The device is subjected to a minimum of 10,000 cycles of simulated displacement representing the "movement rating" (MR) of the device specified by the manufacturer and applied at 0.1 Hz (corresponding to a 10. second period) or other frequency deemed acceptable to the manufacturer. However, the speed of application shall not be less than 4.5 inches/minute. If the component is designed to be used as a isolation device and provides vertical support (i.e., a load bearing isolator), the full design compressive load DCL is applied.

[The data will be used to quantify damage or degradation arising from the application of high-frequency, small-displacement loadings.]

T2.6 Environmental Aging (All Categories)

Purpose: To verify performance of the device in a salt spray environment such as may be encountered over a long period of time under an open bridge deck joint which is subject to salting.

Procedure: The device shall be exposed in a salt spray chamber for 1000 hours in accordance with the requirements of ASTM B 117.

[The accelerated aging will examine the degradation of the device resulting from key environmental factors.]

T2.7 Dynamic Performance Characteristics at Temperature Extremes (All Categories)

Purpose: To assess the effects of temperature on component performance.

Procedure: With the full design compressive load DCL applied (for load bearing isolators), three fully-reversed cycles of the design displacement DD are applied at 0.5 Hz (corresponding to a 2.0 second period) at the upper and lower temperature extremes specified by the manufacturer. The temperature range of interest for this National Program is from -40F to 120F. [However, if specific devices cannot perform at these temperature extremes, manufacturer specified temperature limits will be used.] T2.7 will be performed on Test Article 3 only if different materials are used for fabricating Test Article 2 pursuant to Tables 3.1 and 3.2.

[The data will quantify changes in performance (stiffness, damping, friction, etc.) that occur from changes in ambient temperature conditions.]

T2.8 Durability Test (All Categories)

Purpose: To assess component durability resulting from a moderate number of strong motion cycles.

Procedure: Twenty (20) fully-reversed cycles at 100% maximum design displacement DD or 100% maximum design velocity DV (for Category IV devices) are applied at 0.5 Hz (corresponding to a 2.0 second period). The full design compressive load DCL is simultaneously applied to the weight-bearing isolators.

[The data will be used to assess performance degradation, quantify useable margins, and provide insight into the suitability of the device for applications where a large number of high-level aftershocks can be expected.]

T2.9 Displacement Stability Test to Failure (All Categories)

Purpose: To determine failure loads and margins of safety.

Procedure: With the DCL applied, the component is loaded laterally at 0.5 Hz (corresponding to a 2.0 second period) with increasing displacement amplitude until "failure" occurs. Each cycle will increase the displacement amplitude by 1.1 times the preceding cycle, e.g, $(1.1)^0$xDD, $(1.1)^1$xDD, $(1.1)^2$xDD, $(1.1)^3$xDD ..... $(1.1)^n$xDD for the nth cycle. For some devices this may be actual failure whereas for other devices it may be a programmed physical stop or ultimate restraint beyond which the device cannot operate. If failure does not occur before the cyclic limits of the test machine (±15. inches) are reached, the device will be subjected to a slow rate monotonic loading to 22. inches (the test machine limit).

[The data will be used to quantify safety margins and provide insight into the stability of the device under high loading states. Failure of an elastomeric device is defined as when 1) the elastomeric material visually/audibly tears or delaminates, or a damping feature cracks or breaks and the lateral shear stiffness degrades significantly, or 2) additional lateral deflection reduces the lateral shear load. Failure of a spherical sliding or pure sliding device occurs when 1) gross structural

damage is visible, 2) the rolling or sliding element does not function properly, 3) the rolling/sliding element reaches a physical stop, or 4) a significant change in performance is observed. Failure of a hydraulic energy dissipator occurs when 1) a major hydraulic leak is observed, 2) the piston assembly hits a physical stop, or 3) a significant change in performance is observed. Failure of a friction energy dissipator occurs when 1) there is a sudden unexpected increase/decrease in stiffness or 2) a significant change in performance occurs.]

5.0 Reporting Requirements

The Test Performer (ETEC) will develop a standard report format to present the key test data. The format will include detailed descriptions of the test set-up, test articles and test procedures, and test data in the appropriate time or frequency domain formats. All significant testing will be video tape recorded as part of the final report. Table 5.1 summarizes the data reporting requirements.

Table 5.1 Reporting Requirements

Test No.	Reported Data												
	A	B	C	D	E	F	G	H	I	J	K	L	M
T2.1	X			X	X			X	X	X	X		X
T2.2	X			X	X			X	X				X
T2.3	X			X	X			X	X	X	X		X
T2.4	X	X		X	X	X	X	X	X				
T2.5			X					X	X				
T2.6	No Performance Testing - A brief Report will be prepared												
T2.7	X	X		X	X	X	X	X	X			X	X
T2.8	X	X				X	X	X	X				X
T2.9	X								X				

A	Lateral* Force vs Lateral* Displacement
B	Lateral* Force vs Lateral* Velocity (calculated)
C	Lateral* Force vs Time
D	Dissipated Energy (Calculated)
E	Stiffness (Calculated)
F	Dissipated Energy vs Frequency (Calculated)
G	Stiffness vs Frequency (Calculated)
H	Lateral* Displacement vs Time
I	Vertical Displacement vs Time
J	Compressive Force vs Time
K	Compressive Force vs Lateral* Displacement
L	Temperature vs Time
M	Vertical Displacement vs Lateral* Displacement

*** Axial for energy dissipators**

Appendix A ETEC

The isolator and energy dissipator component characterization tests will be conducted in the existing bearing test rig illustrated in Figure 1 and shown in Figure 2. This is a special test fixture that was specifically developed for dynamic testing of seismic bearings for nuclear power plants. The test fixture is currently configured to apply up to 800 kips of steady vertical loading in combination with 240 kips of dynamic horizontal load. The fully reversing horizontal cyclic displacements can be as high as ± 15 inches within actuator velocity and load limits. An offset single stroke amplitude limit of 22 inches is available for restoring force and stability tests.

The horizontal displacements are applied to the test articles by a servo controlled hydraulic actuator via a carriage assembly. The vertical loads are applied to the test articles by eight hydraulic actuators through the Vertical Load Application Structure (VLAS). The vertical load hydraulic system will be upgraded with additional accumulator volume to reduce the amount of vertical load variation with VLAS vertical position. The currently targeted upgrade value is less than 5% vertical hydraulic load change with ½ inch change in vertical position.

The carriage assembly is supported by ten low friction Tychoway roller bearings divided into two rows spaced sixty inches apart. The roller bearings travel on hardened steel tracks. The assembly is guided laterally by four Camrol bearings engaging guide rails. Three non-hardened steel tracks extend beyond the test zone to allow the carriage assembly to be moved to an open area for the installation and removal of test articles.

Not shown is a new temperature chamber that will be mounted close to the test fixture and used to pre-cool or pre-heat test articles for testing at temperatures between -40 F and 120 F. Thermal shrouds will be draped around the VLAS to provide a semi-closed zone of forced air cooling/heating during test article transfer and mounting. Thermocouples on the test articles will be monitored and moderate overcooling and overheating will be combined with the test article thermal inertia to provide control of the test starting temperatures. Obviously, the heat generated during the testing will shift these starting temperatures upward. To monitor internal temperatures of elastomeric isolators the manufacturer shall install internal thermocouples at the time of fabrication.

The current bearing test fixture design and operational limits are summarized in Table 6.1 and Figure 3.

The facility's current command system will be upgraded to a PC-driven system with more flexible software to improve the processing of time histories and reduce overall costs.

Table 6.1 Bearing Test Fixture Specification

Specification	Structural Design Limits	Current Operating Limits
STATIC		
Maximum Vertical Load	750 tons	400 tons(1)
Maximum Horizontal Load	170 tons	150 tons(1)
DYNAMIC CYCLING		
Maximum Vertical Load	400 tons	400 tons(2)
Maximum Horizontal Load	120 tons	120 tons(2)
Maximum Cycling Displacement	±15 inches	±15 inches(3)
STABILITY TESTING		
Maximum Vertical Load	400 tons	400 tons(2)
Maximum Horizontal Load	150 tons	150 tons(2)
Maximum Displacement from Center Line (In Pull Direction)	22 inches	22 inches(3)

Notes:

(1) Load Cell Range/Actuator Limited
(2) Structural Limit
(3) Design Envelope

Accommodation of Test Articles

The wide variety of test articles in the program requires different fixturing to adapt to the differences in type and scale. From a testing perspective, there are basically three component types among the current set of candidates;

(1) **Weight-bearing parallel-shear devices** These devices include elastomeric bearings, friction sliders and interspersed plate viscous energy dissipators. The key features are that they are load bearing and contain two horizontal top and bottom mounting surfaces that move laterally in essentially parallel motion with minimal change in vertical spacing.

(2) **Weight-bearing spherical devices** These devices include singular or plate-mounted groups of captured, roller-between-surface devices or sliding friction surfaces on uplift contours. The key features are that they are load bearing and contain two horizontal top and bottom mounting surfaces and that lateral motion is accompanied by a change in vertical spacing.

(3) **Non-weight-bearing axial devices** Currently, these devices are either hydraulic or friction energy dissipators. The key feature is they are telescoping tubular devices.

The weight-bearing devices will be tested in the existing test fixture using the space between the carriage and VLAS to mount the devices with appropriate adapters. The vertical motions of the spherical sliding devices will require fixture modifications discussed in a later section of this report. The non-weight bearing axial devices will also be tested in the existing fixture as depicted in Figure 4. In this test setup, a special reaction post is attached to the existing frame that permits in-place use of the bearing test fixture's dynamic actuator.

Fixturing and Adapters

Manufacturers will be requested to provide test hardware with adapters that permit mounting to the same test fixturing. Recognizing there are some major dimensional differences in the vendor hardware, several test arrangements would be made available in order to minimize the required size of the manufacturers' adapters. With respect to the weight-bearing devices, Figure 5 illustrates the basic test article accommodation envelop without makeup adapters. The VLAS can be moved ±3 inches from the position shown with an effective nominal opening of 39 inches. Figure 6 shows two makeup adapters that are available that reduce the effective opening to near 21 inches (Adapter C) and near 25 inches (Adapter A).

The horizontal mounting areas are limited by the rectangular bases of the top adapters. The horizontal mounting area for the basic configuration shown in Figure 5

is about 62 in. by 82 in., for Adapter C it's about 36 in. by 39 in., and for Adapter A it's about 54 in. by 54 in. The longer dimension corresponds to the direction of carriage motion. The bolt hole patterns for all of the adapters will be repetitive, but it is a detail yet to be worked out. Specific adapter requirements will be provided to the manufacturer at the start of the Program.

With respect to the axial energy dissipating devices, it is proposed a single standard pin/clevis detail be specified for the different devices. The maximum allowable length of the telescoping device is TBD inches and the maximum allowable diameter is TBD inches. Specific pin/clevis requirements will be specified at the start of the Program.

As pointed out in the bearing test fixture background discussions, the stroke of the horizontal actuator is nominally ± 15 inches, the maximum horizontal actuator dynamic load is ± 240 kips and the maximum vertical (weight) load is 800 kips. Isolators and hydraulic energy dissipators should be sized appropriately to fit within the prescribed limits of the test system. Although Table 6.1 indicates there is room for increased test fixture capabilities, there is no current plan to make these changes. The assumption used in estimating costs is that the manufacturer will provide test articles that fall within the test fixture dimensional and load limits.

Spherical Slider Testing

As previously discussed, the bearing test fixture has been configured to produce up to 800 kips of vertical downward force at the present time. The 800 kips force is implemented by eight symmetrically positioned hydraulic actuators with a combined net piston area of approximately 300 in^2. These actuators are fed by a very well regulated but somewhat static hydraulic system. When testing a spherical slider isolator, it is expected that the VLAS will be displaced no more than 1.5 inch upward (e.g., a circular profile device with 3 seconds period will displace vertically 1.3 inches under the maximum bearing test fixture stroke of ±15 inches). The vertical displacements are transferred into the eight actuators which results in a discharge of up to 450 in^3 of hydraulic fluid. The present hydraulic system will not readily accept this amount of back-flow and the VLAS will hydraulically resist the vertical displacement.

To accommodate the need for vertical travel, methods of softening the hydraulic system have been evaluated. One method would be to add close coupled gas filled bladder accumulators to the VLAS hydraulic system. For example, if four 10 gallon accumulators were installed with a 50% gas volume, approximately 4600 in^3 would be available for the actuator back flow. The resulting compression of the initial gas

volume would result in an approximately 10% increase in static pressure, which translates into a proportional increase in VLAS vertical loading. It is apparent that integrating properly sized gas filled bladder accumulators into the VLAS hydraulic system would allow suitable VLAS displacement with acceptable variations in vertical load application. In addition to adding capacitance to the hydraulic system, methods to improve hydraulic supply regulation will also be evaluated.

The other spherical slider test issue is the vertical inertial load. In the field, the vertical accelerations will lead to vertical variations in isolator/bearing loads. However, in the bearing test fixture, most of the simulated weight load is achieved by vertical hydraulic preloading, not top weight, which will not vary significantly when the VLAS hydraulic system is upgraded. Therefore, the vertical load variations will not be fully simulated in the motion-controlled component tests.

Instrumentation

The proposed instrumentation for the component testing is given in Table 6.2 and depicted in Figure 7.

Table 6.2 Component Test Instrumentation - 18 Channels

5 Position Transducers;	
4 Vertical;	Each corner of VLAS
1 Horizontal;	Carriage**
1 Accelerometer on Carriage**	
9 Axial Load Cells	
8 Vertical;	Each of VLAS actuators
1 Horizontal;	Actuator**
2 Thermocouples	
Elastomers;	Side and (fabricated inside) midbody
Sliders;	Top/Bottom back drilled
Spherical;	2 places
Dissipators;	1 place

** Used for telescoping devices

7.0 Suitability of Proposed Test Conductor

ETEC is a U.S. Department of Energy (DOE) test and development center that has 30 years of experience designing, building and operating unique large-scale facilities for testing a wide range of components and equipment, and considerable experience in shock and vibration testing of large-scale components, and isolator and energy dissipating systems. ETEC is well suited for this important HITEC program.

As a DOE test center, ETEC offers the following to its government and commercial customers.

Independent Testing
Protection of Proprietary Interests
Quality Assurance Program
Procedurized Test Environment
Trained and Certified Personnel
Instrument Traceability

ETEC provides completely unbiased and independent testing services for competing customers without compromising quality, efficiency or conflict of interest rules. All ETEC employees are required to sign an agreement to protect proprietary interests of all customers. Additionally, an affidavit is distributed annually to all employees to verify that there have been no changes in their conflict of interest status.

The cost to the customer for performing work at ETEC is based on time and materials, and therefore if funds are not completely used, remaining monies are returned to the customer. In addition, resources that remain following the test can be stored at the site awaiting further use. The customer is therefore assured future access to the resources.

Figure 8 illustrates the methodology employed for key test programs such as the HITEC Qualification Program. The procedure ensures that all safety, environmental, and technical issues are properly addressed. Furthermore, ETEC's procedures ensure that all personnel are appropriately trained and certified as shown in Figure 9.

Experience in Design, Start-up and Operation of Unique, Large-Scale Test Facilities

ETEC's primary mission is applied engineering development of emerging technologies. ETEC performs test facility design, manages construction, and manages and conducts system and component development test programs. The majority of ETEC personnel are graduate engineers with backgrounds in analysis,

design, operation and control of test systems. Engineering disciplines include heat transfer and fluid dynamics, stress and structural dynamics, electronics and electrical power, instrumentation and controls, data acquisition, physical chemistry and reaction kinetics, metallurgy, materials and computer science. ETEC can readily draw upon the human resources of the neighboring Rocketdyne Division which has over 7,000 employees, and the Rockwell Science Center which has over 400 employees.

Existing Facilities Suited for Proposed Tests

ETEC's isolator bearing test rig and seismic test are ideally suited for performing the proposed tests. Although facility modifications may be necessary to accommodate the HITEC test needs, the majority of existing equipment will have direct application for the proposed tests and consequently minimize test costs. The resources include an apparatus for applying compressive and lateral loads, high pressure gas storage and hydraulic accumulators for operating the system, computer hardware and software for controlling load application, and suitable electric power and instrumentation hookups. Furthermore, ETEC's extensive experience operating and modifying these facilities will facilitate execution of the proposed test program.

Chemistry, Metallurgical, and Instrument Standards Laboratory Support on Site

ETEC laboratories provide analytical services and specialized technical consultation for all on-site test facilities and activities. The chemistry laboratory is fully equipped to identify and characterize unknown materials. Gas chromatography, spectroscopy, and X-ray diffraction and fluorescence are some of the analytical methods employed. The Metallography Laboratory has a full complement of cutters, polishing wheels and precision optical instruments for sample preparation, mounting and microstructure characterization including a computer-aided scanning electron microscope. Furthermore, other laboratories at the site can provide radiological analyses and radiation surveys, or sophisticated equipment to meet other customer needs. The Instrumentation and Standards Laboratory maintains over 7,000 instruments using on-site service, calibration and repair capabilities. Working and transfer standards permit traceability of instrumented test data to national standards maintained at the National Institute of Standards and Technology (NIST), formerly known as the National Bureau of Standards (NBS). Certificates of calibration will be provided for all test equipment to verify their accuracy. Calibration of equipment shall have been performed within the last six months prior to testing.

Appendix A

Material & Fabrication Requirements

HIGHWAY BRIDGE SEISMIC ISOLATOR AND DAMPING DEVICES- Devices shall be designed and fabricated as shown on the working drawings supplied by the manufacturer and as provided in the following specifications.

Alternative methods and materials may be supplied by the manufacturer, if supported by complete description and test data.

GENERAL (Categories I through IV).--

Metal parts shall conform to the following:

Metallic Materials - Steel	
Material	**Specification**
Steel bars, plates and shapes	ASTM Designation: A 709, grade 36, 50, or 50W A 575, A 576 (AISI or M Grades 1016 through 1030 except Grade 1017) A 570, A 572 A 572 Grade 50
Steel fasteners for general applications:	
Bolts and studs which include threaded rods and non-headed anchor bolts	ASTM Designation: A 307; F 568 Class 4.6 A 108 AASHTO Designation: M 314, Grade 36 or 55
Nuts	ASTM Designation: A 563 including Appendix X1; A 563M including Appendix X1

Metallic Materials - Steel	
Material	**Specification**
Washers and other parts for general applications	Commercial quality
High strength steel fasteners:	
Bolts for structural steel joints	ASTM Designation: A 325; A 325M
Bolts and studs which include threaded rods and non-headed anchor bolts, for general applications	ASTM Designation: A 449; F 568, Class 9.8 (M1.6-M14), Class 8.8 (M16-M72), Class 8.8.3 (M16-M36)
Nuts	ASTM Designation: A 563 including Appendix X1; A 563M including Appendix X1
Washers	ASTM Designation: F 436; F 436M
Stainless steel bars and plates	ASTM Designation: A 240, Type 304 or 316
Stainless steel fasteners for general applications:	Alloys 304, 316
Bolts, screws, nuts, and studs which include threaded rods and non-headed anchor bolts	ASTM Designation: F 593; F 738M
Washers	ASTM Designation: A 240; ANSI B 18.22M
Carbon-steel castings	ASTM Designation: A 27/A 27M, Grade 65-35 [450-240], Class 1
Malleable iron castings	ASTM Designation: A 47, Grade 32510; A 47M, Grade 22010
Gray iron castings	ASTM Designation: A 48, Class 30B
Ductile iron castings	ASTM Designation: A 536, Grade 65-45-12
Cast iron pipe	Commercial quality standard soil

Metallic Materials - Steel	
Material	**Specification**
Steel pipe	ASTM A 53 Type E or S
Steel Sheet Metal	A 570
Steel Forgings	ASTM designation: A 668 Class C(Carbon), Class G(Alloy)
H.D. Galvanized Coatings	ASTM A 123, A 153

Non Ferrous Materials	
Material	**Specification**
PTFE or Equivalent	ASTM D 1457
Elastomers and Seals	ASTM D 4014
Bronze Castings	ASTM B 22
Copper Alloy	ASTM B 100

Welding shall conform to the requirements in AWS D1.1. Welding of stainless steel parts shall be performed using modern commercial shop practice with stainless steel electrodes.

The external seals or external elastomers in any device shall show no cracks when tested for ozone resistance at 20 percent strain, 100 hrs. at $104^{o} \pm 3.6^{o}$ F. in accordance with ASTM Designation: D 1149 (except 50 ± 5 parts per 100,000,000).

Devices shall be permanently marked on 2 of 4 sides. The markings shall consist of production lot number, date of fabrication, design load, and sample number.

Devices shall be assembled at the factory and suitable temporary assembly ties shall be provided so that the entire assembly is shipped as a unit and remains intact when uncrated and installed. Should it become necessary to disassemble the test device during testing, component pieces shall be match marked to ensure they can be restored to their original place and oriented as manufactured.

The manufacturer shall provide the testing Contractor with a Certificate of Compliance listing all materials in the device. The certificate shall certify that the devices conform to the design and material requirements, and were manufactured in accordance with the approved quality control program. The certification shall be supported by a copy of the results of all tests performed on the devices and device materials.

Tests results shall be certified correct and signed by the testing laboratory personnel who conducted the test and interpreted the test results.

ELASTOMERIC DESIGNS, (Category I).--

The devices with alternate layers of rubber and steel plates vulcanized together shall conform to the provisions for steel-laminated elastomeric bearings in ASTM Designation D 4014.

The elastomer in the elastomeric bearing shall be specified by the manufacturer. Elastomeric bearings with a lead core shall have a core consisting of a minimum of 99 percent pure lead.

Galvanizing of steel laminates will not be required.

The steel laminates shall be covered at the sides of the bearing with a minimum thickness of 0.5-inch of the same elastomer as specified for the elastomeric bearing.

SLIDING ELEMENT IN SLIDER AND ROLLER DESIGNS (Category II) AND SLIDER ON CURVED SURFACE DESIGNS (Category III).--

The devices with sliding element shall conform to the details shown on the working drawings, and the following:

The bearing material which slides on the metal surfaces may be polytetrafluoroethylene (PTFE) surfacing or other material specified by the manufacturer. All alternative materials shall be identified as to their generic properties, including their physical test properties.

The sliding element shall be protected from exposure to conditions which may affect the friction coefficient of the sliding element.

The PTFE bearing surface using a fabric shall be filled or unfilled PTFE fabric made from virgin PTFE oriented multifilament and other fibers. The resin in the filaments shall be virgin PTFE material (not reprocessed) meeting the requirements of ASTM Designation: D 1457.

The PTFE bearing surface using a sheet shall be made from unfilled PTFE resin and shall conform to the following requirements:

The PTFE resin shall be virgin material (not reprocessed) meeting the requirements of ASTM Designation: D 1457. Specific gravity shall be from 2.13 to 2.19. Melting point shall be 623° F ($\pm 2^{o}$ F.).

The unfilled PTFE sheets shall be recessed into a steel backing plate a minimum of 1/2 the PTFE thickness.

The PTFE sheet shall be adhesive bonded in the recess of steel plate under controlled factory conditions. The adhesive material shall be an epoxy resin conforming to the requirements of Federal Specification: MMM-A-134.

Contact surfaces of PTFE sheet and steel plate to be bonded shall be uniformly roughened to a minimum roughness height value of 250 micro-inches.

The side of the PTFE sheet to be bonded shall be factory treated by the sodium naphthalene or sodium ammonia process, after the contact surface is roughened.

Stainless steel surfaces shall be a weld overlay on structural steel plate, or at the Contractor's option, solid or sheet stainless steel with a minimum thickness of 0.060 inch.

When a weld overlay is used for stainless steel surfacing, the overlay shall be a minimum of 3/32 inch thick after welding, grinding and polishing and shall be produced using Type 309L electrodes.

When sheets are used for stainless steel surfacing, the sheets shall be attached by perimeter welding. At the Contractor's option, the stainless steel plate shall be bonded to the steel sole plate under pressure using epoxy resin adhesive and then mechanically connected with 18-8 stainless steel cap screws. The cap screws shall be placed outside the area of contact with the PTFE surface at each corner and at 4 inch maximum spacing along the edges. After completion of the weld operation, the stainless steel surface shall be smooth and free from waves.

The mating surface of the stainless steel plate in contact with the PTFE surfacing shall have a surface finish determined according to ANSI Standard B46.1. The sliding element of the devices shall have a coefficient of initial static friction as specified by the manufacturer.

Stainless steel surfaces shall not be painted.

Glossary

AASHTO. American Association of State Highway and Transportation Officials
AISI. American Iron and Steel Institute
ASTM. American Society for Testing and Materials
AWS. American Welding Society
Damping. The ability to dissipate energy.
Damping Device. A device that is designed to dissipate energy.
Design Displacement (DD). The maximum lateral displacement of seismic isolators and the maximum displacement of energy dissipators under seismic loading.
Design Compressive Load (DCL). The maximum design vertical load (dead load, live load, overturning, etc.)
Design Lateral Load (DLL). The maximum lateral load expected under seismic loading. (Except Energy Dissipators)
Design Rating (DR). The maximum axial load expected under seismic loading. (Energy Dissipators Only)
Design Velocity (DV). The maximum velocity expected under seismic loading. (Except Isolators)
Energy Dissipator. A device that is used to dissipate energy by friction or viscous flow.
HITEC. Highway Innovative Technology Evaluation Center
Isolator. A device that is used to isolate a structure from the ground motion produced by an earthquake.
Motion-Controlled. Specified motion that an isolator or energy dissipator is forced to follow.
Movement Rating (MR). The small displacement range (lateral) of the device due to temperature and live load fluctuations (excluding earthquakes).
Number of Shake-down cycles (NSD). Number of fully-reversed motion-controlled cycles required for an isolator or energy dissipator to repeat its performance
Spherical Slider Isolator. An device consisting of one surface that either rolls or slides on another spherical surface designed to return to its unloaded position when lateral loads are removed.
Slider Isolator. A device that utilizes rollers or sliding surfaces to isolate a structure from ground motion produced by an earthquake.