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STANDARDS FOR THE TESTING AND EVALUATION OF SEISMIC ISOLATION SYSTEMS

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ABSTRACT

Draft guidelines for the testing and evaluation of seismic isolation systems have recently been developed at the National Institute of Standards and Technology (NIST). These guidelines are organized into three sections: pre-qualification, prototype, and quality control testing. The guidelines are broadly applicable, since they are independent of the type of isolation system and superstructure. The guidelines will serve as a resource document for industry, and as a basis for developing future standards for testing of isolation systems. This paper gives an overview of the NIST draft guidelines, emphasizing the philosophy behind the development of the guidelines. A brief summary of the contents of the guidelines is also presented.

1.0 INTRODUCTION

A national, consensus based standard for the testing and evaluation of seismic isolation systems currently does not exist. Consequently, tests required by the building codes are open to subjective interpretation, the performance of different systems is not easily compared, and suppliers of isolation systems are faced with unique test requirements on each and every new job. These impediments will only slow the acceptance of this promising new technology.

A comprehensive set of draft guidelines for the testing and evaluation of seismic isolation systems has recently been developed by the Building and Fire Research Laboratory (BFRL) of the National Institute of Standards and Technology (NIST). The *final* guidelines will serve as a resource document for individuals and agencies involved in the design and construction of isolated structures. The guidelines will also serve as a basis for developing a national test standard.

The NIST guidelines are broadly applicable. Except as described later, the guidelines are not specific to a particular type of isolation system or superstructure. The guidelines can be used in projects that involve buildings, bridges, nuclear plants and equipment, and elastomeric, sliding or hybrid isolation systems. A broadly based guideline has several advantages over system specific procedures. First, the potential of the technology can be maximized by all sub-disciplines. Second, broadly based guidelines will minimize the likelihood of each sub-discipline developing unique standards for their own application, which would only slow further progress. And finally, the guidelines do not favor one isolation system over another. Therefore, the guidelines should encourage competition between various systems, resulting in production of the highest quality systems.

Representatives from industry, the research community and government have been given the opportunity to review the draft guidelines and suggest modifications. A national workshop was also held to provide a forum for review and discussion of the draft guidelines. The final guidelines will be based on the draft guidelines, with appropriate modifications made to reflect the quasi-consensus changes recommended by the base isolation community. These outreach efforts are expected to strengthen acceptance of the guidelines, and encourage their use and support.

This paper gives an overview of the NIST draft guidelines, and the plans for future work related to the guidelines. A brief overview of the draft guidelines is presented in the next section, followed by a discussion of the industry review and feedback, and the outline for future work.

2.0 OVERVIEW OF THE DRAFT GUIDELINES

The draft guidelines cover three broad categories of testing: pre-qualification, prototype and quality control. These are defined as follows:

Pre-qualification Tests need not be project specific. They are conducted to establish the fundamental characteristics of an isolation system, and to determine the extent to which the properties of the system are dependent on load and environmental factors.

Prototype Tests are project specific. They are conducted to verify the design properties of the isolation system prior to construction.

Quality Control Tests are also project specific. They are conducted to verify the quality and consistency of the manufacturing process, and to measure the as-built properties of the isolation system prior to installation. Quality control tests include production tests on the materials and component, as well as tests on completed isolation units.

Prototype tests and quality control tests are currently required by the 1994 Uniform Building Code (UBC) (*Uniform*, 1994), and the 1991 AASHTO *Guide Specification for Seismic Isolation Design* (*Guide*, 1991), although the exact nature of the tests and interpretation of the test results are not clearly spelled out. Pre-qualification tests are not formally required by either of these codes; however, in practice tests similar to the pre-qualification series are usually conducted as a new isolation system is developed. Appropriate prototype and quality control tests can only be conducted after a proper series of pre-qualification tests have been conducted.

The draft guidelines are organized into three separate reports. One report covers pre-qualification and prototype testing (Shenton, 1994a), and the others address quality control testing for elastomeric systems (Shenton , 1994b) and quality control testing for sliding isolation systems (Shenton, 1994c). The guidelines for quality control testing are classified according to the type of isolation system because of the production tests. These tests must be system specific, since they depend on the materials being used and the unique details of the design.

2.1 Pre-qualification Tests

Pre-qualification tests are exploratory in nature, they are designed to "get to know" the system. For example, one pre-qualification test is designed to determine the effect of temperature on the effective stiffness and energy dissipation capacity of the device. Another is designed to determine the effect of frequency of cyclic loading. The series also establishes characteristics of the static load carrying capacity of the device. As the name implies, the pre-qualification series is intended to provide preliminary information and data about the isolation system. The results of the tests could be submitted by a vendor in their pre-bid package, so that the end user can judge whether the system is suitable for their particular application or not. It should be noted that there are presently no known plans to develop a formal national pre-qualification or certification program for seismic isolation systems.

The pre-qualification series include not only initial tests to determine basic system properties, but also a complete series of prototype and quality control tests. These tests are outlined in the subsections that follow. Tests specific to the pre-qualification series are shown in Table 1. Note that the tests in Table 1 are grouped into two sub-categories: Preliminary Characterization (I), and Ultimate and Reserve Capacity (II). The procedures in category I determine the effect of load and environmental factors on the system performance. The procedures in category II establish the ultimate or reserve capacity of a device for various load conditions. The pre-qualification series is to be conducted only once, for a system of a given design, material and construction. The series would only be repeated if there were major design changes to the device.

Table 1. Schedule of Pre-qualification Tests[1]

Category	Test	Purpose
I	I.1	Establish dependence on virgin loading
	I.2	Establish dependence on frequency of load
	I.3	Establish dependence on load cycle history
	I.4	Establish dependence on load cycling
	I.5	Establish dependence on vertical load
	I.6	Establish dependence on load direction
	I.7	Establish dependence on load plane rotation
	I.8	Establish dependence on bilateral load
	I.9	Establish dependence on temperature
	I.10	Establish dependence on creep
	I.11	Establish dependence on aging
II	II.1	Ultimate compression under zero lateral load
	II.2	Compression in displaced position
	II.3	Ultimate tension under zero lateral load
	II.4	Tension in displaced position
	II.5	Lateral load and displacement capacity under design vertical load

[1]Pre-qualification shall also include a complete series of prototype tests and quality control tests.

2.2 Prototype Tests

The prototype series is divided into two categories: Seismic Loads (III) and Non-Seismic Loads (IV). This is shown in Table 2. Note that prototype testing includes a full series of quality control tests, as described in the next subsection.

The principal design properties of the isolation system, effective stiffness and energy dissipation capacity (i.e., damping), are measured in prototype test III.1. These properties are essential to the design of the superstructure. The effective stiffness and energy dissipation capacity of the system determine the magnitude of the force that is transmitted to the superstructure, and control the displacement across the isolation interface. Two other seismic load tests are conducted, one to measure the isolation system degradation (stiffness and energy dissipation) under cyclic loading (III.2), and one to check for stability at maximum seismic displacement (III.3). Test III.2 is significant with regard to the long term performance and durability of the isolation system. Test III.3 checks that the system can maintain its vertical load carrying capacity while in the maximum displaced position.

The extent of testing required in the prototype series, in particular under test III.1, will depend on the outcome of the pre-qualification series. For example, if a system is found to be dependent on the frequency of loading, the test matrix in III.1 is augmented to include tests to measure the stiffness and energy dissipation for a range of frequencies.

First and foremost, the performance of an isolation system must be stable and predictable under *non-seismic* load conditions, which are imposed over most of the design life of the isolation system. This is addressed with the category IV tests in the prototype series. Non-seismic load tests are included for wind load, thermal displacement, thermal cycling and braking/centrifugal force. The first is most important to large structures, such as buildings, that are exposed to wind load. The latter three are intended principally for bridge applications. There are certainly other non-seismic load conditions that are important to other applications. In such cases the guidelines could be supplemented to include additional non-seismic load tests that are unique to a particular application. Obviously, only those non-seismic load tests deemed to be relevant to a particular application need to be conducted.

There is an exception in the guidelines that exempts prototype tests under certain conditions. It has been included with the intent of minimizing or eliminating duplicate testing of identical units. The exception states that the results of prototype tests previously conducted can be substituted, provided the tests were conducted on a device or unit of essentially the same design, material and construction, the largest overall dimension of the unit is within 10% of the same dimension of the unit previously tested, and all other critical dimensions are within 15% of the same dimensions of the unit previously tested.

Table 2. Schedule of Prototype Tests[1]

Category	Test	Purpose
III	III.1	Effective Stiffness and Energy Dissipation Capacity
	III.2	System Degradation Under Cyclic Loading
	III.3	Stability at Maximum Lateral Displacement
IV	IV.1	Wind Load
	IV.2	Thermal Displacement
	IV.3	Stability with Thermal Cycling
	IV.4	Braking/Centrifugal Force

[1]Prototype Testing shall also include a complete series of quality control tests.

2.3 Quality Control Tests

As mentioned above, the quality control series is divided into production tests and completed unit tests. Tests conducted on the materials or component parts that go into making a unit are considered production tests. Completed units tests are tests conducted on the assembled isolator unit.

The production tests for elastomeric systems are designed to establish the properties, and consistency of those properties, of the elastomer that is used in fabricating the device. The production tests currently specified in the guidelines include tests for hardness, tensile strength and elongation at break, bond strength, compression set, low temperature properties, high temperature aging, and ozone resistance. These are similar to the material tests that have been used in the past for fabricating non-seismic elastomeric bridge bearings. The completed unit tests for elastomeric systems are presented in Table 3. These are the final tests conducted on the unit before it is installed. The purpose of the sustained compression test is to verify the integrity of the elastomer and steel bond. This is a very time consuming test, lasting generally between twelve and fifteen hours. Research is needed to develop a more efficient method of testing the elastomer/steel bond. One suggested alternative is a shear test with zero compression load.

Table 3. Schedule of Completed Unit Quality Control Tests for Elastomeric Systems

Test	Purpose
1	Effective Stiffness and Energy Dissipation Capacity
2	Sustained Compression
3	Compression Stiffness

Production tests for sliding systems are designed to ensure the quality of the sliding interface. These include tests for surface roughness, trueness of surface, interface material properties, backing material properties, bearing pad attachment and sliding interface attachment. The completed unit tests for sliding systems are shown in Table 4. The sustained compression test in this case is to be conducted only for systems that are susceptible to creep.

Table 4. Schedule of Completed Unit Quality Control Tests for Sliding Systems

Test	Purpose
1	Effective Stiffness and Energy Dissipation Capacity
2	Sustained Compression

Quality control tests, in particular the completed unit tests, can be costly and time consuming. The extent of testing to be recommended in the final guidelines has generated some debate within the base isolation community. Some would place more emphasis on completed unit tests, requiring each and every unit that is manufactured be tested. In this case, few if any production tests would be required. The justification for this approach is that, regardless of how the unit was manufactured, the proof of the performance of the device is the completed unit test. Others would require a rigorous production test program, and fewer completed unit tests. In this case only a certain percentage of units manufactured would be tested, unless some of these failed, in which case all units manufactured would be tested. There are advantages and disadvantages to both of these approaches, with regard to how they may affect the future and growth of this technology. On the one hand, a heavy emphasis on completed unit tests may stifle growth, because of the burden and time required for testing, which would dissuade owners from considering isolation. One the other hand, an isolated structure has yet to be subjected to a major event. A failure of an isolated structure, due to marginal quality control testing, could be devastating to the future of this technology.

2.4 General Requirements and a Typical Test Description

The general requirements for testing are outlined in a separate chapter in the report on pre-qualification and prototype testing (Shenton 1994a). The general requirements cover such things as qualifications of the test facility, and instrumentation; calibration of the test facility and instrumentation; data acquisition; analysis of the recorded data; and reporting of results.

To illustrate typical test requirements, a sample test description is presented in figure 1. All of the test descriptions are presented in a similar format. The standard format includes several subsections: Test Designation, Purpose, Sequence, Procedure, Criteria and Special Requirements. The substance of the test is outlined under the Sequence, Procedure and Criteria subsections. The load, frequency of load, number of cycles, etc. are given under Sequence. A step by step description of how the test should be conducted is given under Procedure. Finally, performance criteria have been established for each test and are presented in the Criteria subsection. The results of the test are to be evaluated against the performance criteria: units that do not meet or exceed the criteria may not perform satisfactorily in service. Establishing the numeric values for the performance criteria is the most difficult task in developing the guidelines. For this reason, many have been simply expressed in terms of a variable in the draft guidelines. One of the major tasks to be undertaken in drafting the final guidelines will be to specify the numeric value for the performance criteria. The feedback received from industry will be extremely useful in this effort.

INDUSTRY REVIEW AND FEEDBACK

The draft guidelines were developed in collaboration with an oversight committee of five experts from the field of seismic isolation. Once the draft guidelines were completed, the next step in development was to obtain feedback from a broader base of practitioners, manufacturers, and researchers in the base isolation community. This was accomplished through mail reviews and workshop discussions, as described below.

The draft guidelines were published in March 1994, and more than 200 copies were distributed to industry representatives and researchers. Comments were solicited and have been received from approximately 40 individuals. Many constructive suggestions have been made, and these will be considered in developing the final guidelines.

In addition to soliciting comments on the guidelines by mail, a workshop was held on July 25, 1994 to provide an interactive forum for review and comment on the draft guidelines. Approximately 35 invited participants from industry and the research community attended. The draft guidelines were discussed among the participants in small groups and plenary sessions, and comments and suggested changes were recorded. The results of the workshop were summarized in notes, which will be incorporated in development of the final guidelines.

The draft guidelines are currently being revised to reflect the feedback obtained from the mail reviews and workshop, and the final guidelines should be published as NIST technical reports in July of 1994.

FUTURE ACTIVITIES

NIST has submitted a proposal to the American Society of Civil Engineers (ASCE) suggesting that ASCE develop a national, consensus based standard for testing seismic isolation systems. It was proposed that the NIST guidelines be used as a starting point for development of the consensus standard. ASCE would appear to be the organization best suited to develope a national, consensus based standard, since seismic isolation technology is distributed among various civil engineering sub-disciplines, and seismic isolation has applications in a wide variety of civil type structures.

As a follow up to the development of the NIST guidelines for testing base isolation systems, an experimental program is being planned at NIST. The purpose of test program is to evaluate the testing procedures proposed in the guidelines. In the first phase of the test program the effect of scaling on the ultimate load carrying capacity of isolation bearings in compression will be examined. The work will then be extended to study the ultimate capacity in combined compression and shear.

SUMMARY

The development of guidelines for the testing and evaluation of seismic base isolation systems has been described. Draft guidelines have been developed at NIST, and have undergone an extensive review by the base isolation community. Feedback from the review is currently being incorporated into the draft guidelines, which will then be published as final guidelines. The rationale behind the guidelines has been outlined, and an overview of the structure and content of the guidelines has been presented.

It has been proposed that the final guidelines be used as a model document in the development of a national consensus standard for testing base isolation systems. Future activities at NIST include an experimental program aimed at evaluating the proposed test procedures.

REFERENCES

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Shenton, H.W., III, 1994b, "Draft Guidelines for Quality Control Testing of Elastomeric Seismic Isolation Systems," NISTIR 5345, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland, 28 pages.

Shenton, H.W., III, 1994c, "Draft Guidelines for Quality Control Testing of Sliding Seismic Isolation Systems," NISTIR 5371, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland, 28 pages.

Uniform Building Code, 1994, International Conference of Building Officials, Whittier, California.

Guide Specifications for Seismic Isolation Design, 1991, American Association of State Highway and Transportation Officials, Washington, D.C.

Test Designation: I.5

Purpose: Establish dependence on vertical load.

Sequence: Three fully reversed cycles to peak displacements of ±D. Tests shall be conducted for vertical loads corresponding to P_L, P_D, P_U. The frequency of loading shall be not less than f_L or 0.004 cyc/sec.

Procedure: Place the specimen in the test machine and secure to the supports and loading plate. Apply the full vertical load to the specimen and allow the load to stabilize. Apply the cyclic lateral load to the specimen for the required 3 fully reversed cycles of the test. Remove the vertical load. The test shall be run continuously without pause between cycles. The test shall be conducted at the vertical loads specified in the order P_L, P_D, and P_U. Sufficient time shall be allowed between tests at the different vertical loads to dissipate any heat developed during the previous test.

Criteria: The System, Unit or Component response is considered to be independent of vertical load if:

(1.) the Average Effective Stiffnesses measured at vertical loads corresponding to P_L and P_U are within ±α% of the Average Effective Stiffness measured at the vertical load corresponding to P_D, i.e.,

$$\frac{|K_H^P - K_H|}{K_H} \leq 0.01\alpha$$

where K_H is the reference Average Effective Stiffness measured at a vertical load corresponding to P_D, and K_H^P denotes the Average Effective Stiffness measured at vertical loads corresponding to P_L and P_U.

(2.) the Average Energy Dissipation measured at vertical loads corresponding to P_L and P_U are within ±β% of the Average Energy Dissipation measured at the vertical load corresponding to P_D, i.e.,

$$\frac{|E_H^P - E_H|}{E_H} \leq 0.01\beta$$

where $E_H$is the reference Average Energy Dissipation measured at a vertical load corresponding to P_D, and E_H^P denotes the Average Energy Dissipation measured at vertical loads corresponding to P_L and P_U.

Special Requirements: None

Figure 1. Typical Test Description (Test for Dependence on Vertical Load)