Development of National Guidelines for Seismic Performance Testing

by

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ABSTRACT

In order to make the bridge experiments more efficient in terms of providing reliable and comparable information, Federal Highway Administration has conducted a systematic study on bridge testing methods. The most common procedures and issues are identified. Proper methods on specimen construction, loading procedure, as well as measurements and data format will be established to provide experimental researchers an easy reference that makes test results comparable to results from other tests.

KEYWORDS: Bridge performance testing; earthquakes; guidelines; performance-based approach; performance testing; Seismic testing

1.0 INTRODUCTION

Experimental studying on bridges and components of bridges is an essential need for the improvements on design and construction techniques. As the seismic design concept for bridges gradually turns to performance-based approach, the need for a large amount of comparable tests results increases. In order to make the bridge experiments more efficient in terms of providing reliable and comparable information, the Federal Highway Administration (FHWA) has launched a systematic study on the techniques and procedures of conducting experimental bridge ests. The objective of the study is to develop the National Guidelines for Experimental Tests on Highway Structures.

A literature review covering a wide range of bridge tests were performed. Information of the major experimental research institutes was collected. Some laboratory administrative personnel were or will be interviewed to include their practical experiences. These materials will be summarized and a proposed experimental guidelines will be produced. These results will be made available for experts to review and comment.

2.0 BENEFITS FROM THE GUIDELINES

Each experimental study has its own purpose and unique setup to serve this purpose. The results from experiments always contain more information than they were designed to provide. A large part of the information is often either ignored or not comparable with other tests due to incompatible format and testing conditions. If widely adopted experiment guidelines exist, the part of an experiment that is not essential to its purpose can be conducted in the standard manner. Commonly demanded information will not be ignored. The result can be used for theoretical derivation or empirical model calibration with a solid confidence that the data were obtained from an experiment compliant to a reliable procedure. In the mean time, the tester receives additional credits and publicities because the experimental results appear in more consequent studies.

This guidelines is not similar to some of the existing testing standard such as those in ASTM

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testing manual. Due to the explorative origin of the tests regulated by this guidelines, making changes to the procedure in accordance to the need of the specific test does not immediately disqualify the results. The intention is to provide assistance rather than restriction to the experimental community.

3.0 COMMON METHODS AND PURPOSES FOR BRIDGE COLUMN TESTS

Dynamic structural tests are commonly divided into 3 categories. They are quasi-static tests, pseudodynamic tests, and shake table tests (Kausel, 1998; Dimig et al, 1999). Dynamic tests on bridges are carried out for either discovering element properties that were not clear to engineers or verifying the theoretical predictions. The most common goals for dynamic bridge tests are:

(1) To determine strength and ductility under strong earthquake (capacity)
(2) To determine displacement and force demand
(3) To determine effectiveness of retrofit
(4) To observe failure patterns such as cracking, buckling, etc.
(5) To observe the performance of new design or retrofit methodologies
(6) To develop and verify analytical or empirical models
(7) To inspect existing bridges

Different goal results in different test requirements and test methods. The issues being addressed in this guidelines are those shared by a number of different tests.

4.0 GUIDELINES

There are three major issues in a bridge test: specimen, loading, and data handling. The specimen is a full or reduced replica of the interested part of a real or imaginary bridge. It needs to be designed to best reflect the bridge characteristics. The loading procedure is usually a simulation of load history occurs in a real event. For random-type input such as earthquake and wind, some load histories that are different from the real load but possess certain realistic characteristics are used (e.g. cyclic load). The results of the tests need to be recorded and stored with adequate conditioning and format.

4.1 Model construction

4.1.1 Prototype

For general bridge studies, which may target a group of bridges, the bridge parameters, such as size, shape, designed loads, and detailing, may not be available from the original design agencies. One approach is to conduct a statistical investigation (Lowes and Moehle, 1995, Abo-Shadi et al, 2000) to determine the most representative parameters for the group of bridges. The other approach is to simply use a most common value regardless what group of bridges the test is designed for. The proper guideline provisions to these two scenarios are described below:

(1) The National Bridge Inventory (NBI) Database is a complete collection of bridge external dimensions, functions, locations, ages, etc. This information can be converted to that required by the testers (Lampe and Azizinamini, 2000). This can largely reduce the time spent on preliminary investigation and increase the representativeness of the selected parameters.
(2) When the tester only needs a general bridge model, a set of most common parameters can be provided. For example, a height of 20 ft (6 m), span of 65 ft (20 m), and width of 40 ft (12 m) can be provided. The dead load and live load can be derived from the dimensions given above. For more convenience when only one bent is involved, a dead load of 800 kip (360 ton) and a live load of 200 kip (90 ton) can be provided. The sum of dead load and live load determines the axial load of the column and the dead load alone determines the lateral loads.

4.1.2 Scale

A dimensionless analysis is used to find the proper scaling of each parameter (Moncarz, 1981; Bertero, 1984). In the quasi-static bridge column tests, all time-dependent parameters that relate to velocity and acceleration are ignored. The axial load and lateral load from the superstructure are reduced to an external force applied vertically and horizontally to the top of the column. The material properties, such as elastic modulus, yielding stress, and specific weight, are kept to the same as the prototype (scale factor=1). The parameter that needs to be changed as will is the geometrical dimensions. The resultant scaling factors for quasi-static tests are listed in the 1st column of Table I.

Time and time-dependent variables need to be considered in the scaling for fast tests such as shake table tests. Because of the involvement of the gravitational acceleration (cannot be changed in large structural tests), the scaling is diverted into two courses:

(1) Gravity is insignificant:
The vertical load is either unimportant to the test or is applied externally. The self weight of the entire specimen is negligible to the purpose of the test. Supplementary vertical load (if necessary) is applied through force actuators. The input and response acceleration is allowed to be scaled without changing specific weight. The proper scaling is shown in the 2nd column of Table I.

(2) Gravity is essential:
If the gravity force from the self weight is one of the important factor in the test, the horizontal acceleration needs to be kept the same scale as the gravitational acceleration (unity) because the vertical (gravity) force and horizontal (inertia) force come from the same mass. Due to the difficulty of changing specific weight in specified proportion, the scaling of specific weight is substitute by auxiliary masses. The auxiliary mass needs to be attached to the heaviest places, which is usually the superstructures, without introducing additional stiffness. The proper scaling and auxiliary mass are listed in the 3rd column of Table I.

It has been noticed that the construction materials have different mechanical properties at different size. The mechanical properties such as elastic modulus and yielding or ultimate stress are not only difficult to change by any specific scale but also difficult to maintain constant when size is changed. There are multiple reasons that make the mechanical properties size-dependent, such as different manufacturing process and failure mechanism. Special care should be taken to ensure this does not alter the test result unexpectedly.

4.2 Load histories

The cyclic loading procedure is usually considered to be a good simulation tool for earthquakes when more realistic options, i.e. true dynamic tests, are not feasible. Since it is an approximation of earthquake load, there can be numerous approaches. Most tests done to bridge columns have adopted a progressive pattern cyclic loading procedure (Figure 1). This procedure involves some pilot cycles in the elastic range that provides more accurate estimation for yielding displacement, followed by plastic cycles that contain 2-3 cycles at each deformation level and increase in multiples of yielding displacement. It is believed that two or three cycles for each displacement level is a balance between demonstration of strength degradation and avoidance of undesired early fatigue fracture (Lowes and Moehle, 1995). This procedure was evolved from the standard steel element cyclic procedures (ECCS, 1986; Stone and Cheok, 1989; ATC-24, 1992). This procedure provides a general test condition for earthquake loads.

When specific earthquake record is to be tested on the specimen, a preliminary analysis is required to estimate structural response, and consequently the displacement history of the specimen (El-Bahy et al, 1999).

The shake table test is a real dynamic test. As being more realistic, it is important to be careful controlling the test environment. The loading records need to be properly filtered and scaled. Elastic tests should be conducted prior to full-scale nonlinear tests. Modal parameters are retrieved in the elastic tests in order to well categorize the model. One or more of the hammer test, harmonic input test, and random vibration test can be used for this purpose.

Pseudodynamic tests represent the balance of actuality and test facility limit. In the slow pseudodynamic tests, the inertia force and viscous damping force are calculated in a computer that controls the loading procedure. The design of the real part and imaginary part as well as the scaling follows the specimen construction part of this guidelines.

4.3 Measurements and data acquisition

The technologies used in measurement systems evolve quickly. New issues emerge while old issues are resolved. It is not easy to setup general guidelines for all tests. However, well-configured measurement and acquisition systems share some similar principles. It is important to layout the principles to be followed.

A few fundamental values, such as lateral load, lateral displacement, and curvature, should be required by the guidelines. Some physical detail that may affect the resultant accuracy should be specified. For example, the range of the curvature measurement (with respect to section size) needs to be sufficient to cover the plastic hinge zone and part of the elastic zone. Any potential slippage surface needs to be monitored on both sides.

The data acquisition systems have all become digital nowadays. Analog filtering is crucial for such systems. For slow static tests, the system can stop at each designated load step and allow the measurements recorded. Analog filters can be conditionally absent if several readings are made and averaged to eliminate the fluctuation from high-pitch electronic or physical noise. For high-speed tests, the analog low-pass filtering range needs to cover the highest frequency of the interested vibration component. The sampling rate should be higher than twice of the filter cut-off frequency.

The study on data format, storage, and transmission is currently one of the major efforts from many experimental institutes lead by the National Science Foundation (NSF). The progress will be closely observed and integrated with this guidelines.

5.0 SUMMARY

Most bridge column tests are either for research purpose or for specific construction or retrofit project. The uniqueness of these tests makes it difficult to set up general guidelines for all. However, as a leading agency in the highway industry, the FHWA will persevere in the effort of laying out the national testing guidelines for bridges due to the anticipated tremendous benefits to the researchers and designers in this country. The first appearance of the product is expected to take place in a short time. This project will not be able to provide premium result without the contributions from bridge testing experts. All suggestions and discussions are highly appreciated.

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TABLE I SCALING FACTORS FOR DIFFERENT TESTS

Variable	Slow test	Dynamic test	
		Gravity insignificant	Gravity essential
Geometric size l	S_L	S_L	S_L
Time t	N/A	S_L	$S_L^{0.5}$
Stress σ	1	1	1
Strain ε	1	1	1
Elastic modulus E	1	1	1
Yielding stress σ_y	1	1	1
Density ρ	N/A	1	1
Force P	S_L^2	S_L^2	S_L^2
Bending moment M	S_L^3	S_L^3	S_L^3
Rotation angle (Δ/L) θ	1	1	1
Curvature ϕ	S_L^{-1}	S_L^{-1}	S_L^{-1}
Displacement U	S_L	S_L	S_L
Acceleration	N/A	S_L^{-1}	1
Auxiliary mass	N/A	0	S_L^2-S_L^3
External damping	N/A	S_L^2	$S_L^{1.5}$
External stiffness	S_L	S_L	S_L

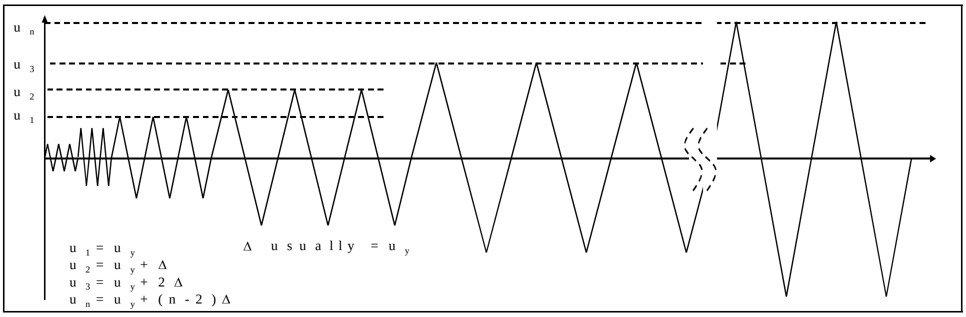

Figure 1 The progressive cyclic load history