Specifications for the Seismic Design of New Highway Bridges

by Ian Buckle

Abstract

The current seismic design criteria and procedures in the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges were developed in the late 1970s following the 1971 San Fernando earthquake in California. Although these provisions were notable for their innovation at the time, experience with their use over the intervening years and the performance of bridges during recent damaging earthquakes in California (and elsewhere) led to the decision by AASHTO to have the specifications reviewed and modified as appropriate. NCEER was awarded a contract for this purpose by the National Academy of Sciences on behalf of the Transportation Research Board and AASHTO. This review is now complete and a revised set of specifications has been prepared which include new or modified provisions for soil effects, site-specific spectra, important bridges, temporary structures, seat widths for skewed bridges, analysis methods, and minimum requirements for bridges in low and moderate seismic zones.

Collaboration

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Objectives and Approach

The objective of this project was to review and update the seismic design provisions in Division I-A of the Standard Specifications for Highway Bridges used by the American Association of State Highway and Transportation Officials (AASHTO) for the design of bridges in the United States. This review was to reflect experience gained by users of the present specification and the results of recent research and earthquake reconnaissance exercises. As a result, surveys were made of designer experience, world trends in seismic codes for bridges and the performance of bridges in recent damaging earthquakes. Advantage was also taken of a parallel exercise being conducted for the California Department of Transportation by the Applied Technology Council under project ATC-32. An eight-member review panel was appointed by the National Cooperative Highway Research Program. This panel was actively involved in commenting and contributing to the revised specifications and acting as liaison to the various State Departments of Transportation.

This research task was begun as part of NCEER's Bridge Project and later completed under the Highway Project. The task number is NCHRP 20-7/45.

Introduction

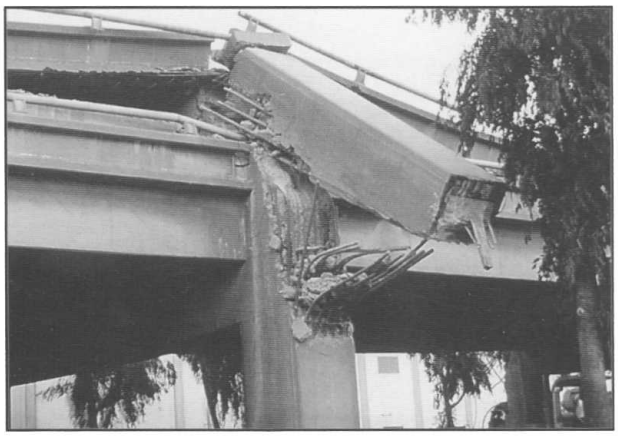
The 1971 San Fernando earthquake was a major turning point in the development of seismic design criteria for bridges in the United States. Prior to 1971, the American Association of State Highway and Transportation Officials (AASHTO) specifications for the seismic design of bridges were based, in part, on the lateral forces requirements for buildings, which were developed by the Structural Engineers Association of California. In 1973, the California Department of Transportation (Caltrans) introduced new seismic design criteria for bridges, which included the relationship of the site to active faults, the seismic response of the soils at the site, and the dynamic response characteristics of the bridge. In 1975, AASHTO adopted Interim seismic design specifications which were a slightly modified version of the 1973 Caltrans provisions, and made them applicable to all regions of the United States.

In addition to these code changes, the 1971 San Fernando earthquake stimulated research activity on seismic problems related to bridges. In light of the findings from this research, the Federal Highway Administration (FHWA) awarded a contract to the Applied Technology Council (ATC) in 1978 to:

- Evaluate current criteria (1978) used for seismic design of highway bridges;
- Review recent seismic research findings for design applicability and use in new specifications;
- Develop new and improved seismic design guidelines for highway bridges applicable to all regions of the United States; and
- Evaluate the impact of these guidelines and modify them, as appropriate.

The guidelines developed under this ATC project (known as ATC-6) were a major contribution to the state-of-the-art in the early 1980s (ATC

1981). For example, they were the first set of design criteria to specifically address seismic displacements in bridges and call for minimum seat widths at all girder support locations. These recommendations were initially adopted by AASHTO as a Guide Specification in 1983 (AASHTO 1983) and later incorporated as seismic provisions into the AASHTO Standard Specifications for Highway Bridges, as Division I-A, in 1991 (AASHTO 1992).



■ Figure 1

The collapse of the Cypress Street Viaduct in Oakland during the Loma Prieta earthquake of October 1989 was a major factor in the AASHTO decision to review the seismic design requirements in the Standard Specifications for Highway Bridges.

The collapse of several major bridges during the Loma Prieta earthquake near San Francisco in October 1989 (figure 1) followed by spectacular damage to bridges during earthquakes in Costa Rica (1990, 1991) and the Philippines (1991) were major factors in the AASHTO decision to review the then current seismic design requirements for all bridges in the United States. The National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board was asked by AASHTO to initiate NCHRP Project 20-7, Task 45, "Revisions to the AASHTO (Guide) Specification for Seismic Design of Highway Bridges," in order to perform this review and prepare necessary revisions, if appropriate. The contract to perform this review was awarded to NCEER by the National Academy of Sciences on behalf of the Transportation Research Board in 1991. It was completed in June 1994 (NCEER 1994).

Research Plan

Working with a technical panel appointed by the NCHRP, a list of potential issues for consideration and review was developed and prioritized. The focus of the project, however, was on incorporating readily available research results and engineering practice into the updated specification.

The project was conducted in several stages, as follows:

- A number of standards, specifications, and research results were reviewed, including the 1992 AASHTO Standard Specifications (Division I-A), current Caltrans seismic design procedures and emerging criteria from the ATC-32 project (Review of Caltrans Specifications), seismic design criteria contained in the NCHRP Project 12-33 LRFD bridge specifications effort (subsequently completed and adopted by AASHTO as the LRFD Bridge Design Specifications), and bridge performance during recent earthquakes.

- A survey of designer experience with the Division I-A specifications was conducted and an evaluation of design philosophy was performed.

- Analytical studies were conducted by NCEER and the project subconsultants.

- Several draft revisions in various formats of increasing complexity were prepared and sent for review to AASHTO and other practicing engineers. On the basis of the review comments, a final version of the revised specifications was prepared and submitted to AASHTO for approval and adoption in June 1994.

Accomplishments

As noted earlier, several versions and drafts were prepared for review by the NCHRP technical panel and AASHTO. Version 1 of the draft specifications consisted of format change revisions only, to improve readability and clarity of intent. Version 2.0 included technical revisions so as to correct ambiguities, omissions, and errors that were contained in the 1992 Division I-A. Version 2.1 was prepared to include provisions for temporary bridges (which had previously been omitted from the AASHTO specifications), and Version 2.2 included new analysis provisions, along with clarifications for the specification provisions concerned with seismic hazard, site specific spectra, and pile foundations.

A major change in formatting was accomplished by grouping all provisions for each of the four seismic performance categories (SPC's) into separate sections in the specification (see table 1). Previously, requirements for a particular SPC were distributed throughout the specification and interwoven with the requirements for the other SPC's. This rearrangement should improve the use of the specification, as the requirements are now presented in a more logical and easier to find manner.

Table 1

Table of Contents for Proposed Specification for Seismic Design of Highway Bridges

Section	**1**	**Introduction**
	1.1	Purpose and Philosophy
	1.2	Background
	1.3	Basic Concepts
	1.4	Project Organization
	1.5	Quality Assurance Requirements
	1.6	Flow Charts
Section	**2**	**Symbols and Definitions**
Section	**3**	**General Requirements**
	3.1	Applicability of Specifications
	3.2	Acceleration Coefficient
	3.3	Importance Classification
	3.4	Seismic Performance Categories
	3.5	Site Effects
	3.6	Elastic Seismic Response Coefficient
	3.7	Response Modification Factors
	3.8	Determination of Elastic Forces and Displacements
	3.9	Combination of Orthogonal Seismic Forces
	3.10	Minimum Seatwidth Requirements
	3.11	Design Requirements for Single Span Bridges
	3.12	Requirements for Temporary Bridges and Staged Construction
Section	**4**	**Analysis Requirements**
	4.1	General
	4.2	Selection of Analysis Method
	4.3	Uniform Load Method - Procedure 1
	4.4	Single Mode Spectral analysis Method - Procedure 2
	4.5	Multimode Spectral Analysis Method - Procedure 3
	4.6	Time History Method - Procedure 4

■ Table 1
Table of contents for proposed specification for seismic design of highway bridges.

A standard format has also been provided for provisions within a given SPC. It will be seen from table 1 that the format used now contains six subsections in each SPC-based section, as noted below:

1 General
2 Design forces
3 Design displacements
4 Foundation and abutment design requirements
5 Structural steel design requirements
6 Reinforced concrete design requirements

A number of technical changes have also been made to the specifications, including the following:

Table 1 (continued)

Section	**5**	**Design Requirements for Bridges in Seismic Performance Category A**
	5.1	General
	5.2	Design Forces for Seismic Performance Category A
	5.3	Design Displacements for Seismic Performance Category A
	5.4	Foundation and Abutment Design Requirements for Seismic Performance Category A
	5.5	Structural Steel Design Requirements for Seismic Performance Category A
	5.6	Reinforced Concrete Design Requirements for Seismic Performance Category A
Section	**6**	**Design Requirements for Bridges in Seismic Performance Category B**
	6.1	General
	6.2	Design Forces for Seismic Performance Category B
	6.3	Design Displacements for Seismic Performance Category B
	6.4	Foundation and Abutment Design Requirements for Seismic Performance Category B
	6.5	Structural Steel Design Requirements for Seismic Performance Category B
	6.6	Reinforced Concrete Design Requirements for Seismic Performance Category B
Section	**7**	**Design Requirements for Bridges in Seismic Performance Categories C and D**
	7.1	General
	7.2	Design Forces for Seismic Performance Categories C and D
	7.3	Design Displacements for Seismic Performance Categories C and D
	7.4	Foundation and Abutment Design Requirements for Seismic Performance Categories C and D
	7.5	Structural Steel Design Requirements for Seismic Performance Categories C and D
	7.6	Reinforced Concrete Design Requirements for Seismic Performance Categories C and D

■ Provisions have now been added for "temporary" bridges, so that they are constructed with at least a minimum level of seismic safety. In addition, the definition for temporary has been set as five years or less (i.e., any bridge expected to carry traffic for more than five years must be designed to the same level of seismic safety as a permanent bridge).

■ In lieu of using a seismic response coefficient as determined by the specifications, a five percent-damped, site-specific response spectrum may be used provided that the spectrum accounts for both the local seismology and site soil conditions.

■ Two additional analysis procedures have been added to the specifications: the uniform load method (which was included in earlier editions of the specifications but removed several years ago) and the time-history method. This now provides the design engineer with the choice of four analysis procedures, depending on the type and geometry of the bridge being considered.

■ A fourth soil profile type has been added for soft "bay-type" muds and a soil site coefficient of 2.0 has been assigned. This was in response to the concerns raised by the collapses of structures founded in soft bay muds during the Loma Prieta earthquake in 1989.

■ The specifications now recommend that special studies be performed not only for bridges being constructed on sites close to active faults, but also for locations susceptible to long duration earthquakes, and for "important" bridges.

■ The definition of a "regular" bridge has been augmented and clarified, to ensure that the appropriate analysis method is used in the design of the bridge. In addition, special requirements have been added for the analysis of curved bridges and for important or critical structures.

■ For bridges in SPC A, minimum connection force and seat width requirements have been clarified. New seat width provisions have been added for skewed bridges (in part, as a result of the poor

performance of highly skewed bridges during recent damaging earthquakes in California). These new requirements for skewed bridges have also been added to the provisions for bridges in SPC B, C, and D.

The new specification provisions (NCEER 1994) were presented to AASHTO in June 1994, and are currently in the process of being approved and adopted. It is expected that the specifications will be published by AASHTO in the spring of 1995, fully replacing the current Division I-A specifications.

Summary

The present seismic design provisions in the AASHTO Standard Specifications for Highway Bridges were reviewed under this project Although the existing provisions were notable for their innovation at the time of their development (1978-1981), recent experience with damaging earthquakes in California and elsewhere suggested that a review of these requirements was timely. As a consequence, revised specifications have been prepared which include new or modified provisions for soil effects, site-specific spectra, important bridges, temporary structures, seat widths for skewed bridges, analysis methods, and minimum requirements for bridges in low and moderate seismic zones.

The revised specification was submitted to AASHTO in June 1994 and is now well advanced through the review and adoption process. Publication of the new specification is expected in the Spring of 1995

It is recognized that AASHTO specifications are not static, and it is expected that additional improvements in the design process will continue to be made on a fairly regular basis. For example, it is expected that future revisions to the AASHTO specifications will include refinements to the performance criteria and expanded definitions for the importance categories, the incorporation of site amplification factors that are also a function of earthquake magnitude, the redefinition of R-factors to account for importance and redundancy, the rationalization of the ϕ-factors and the development of design procedures for moderate seismic zones (e.g , SPC B) which are less conservative but still straight forward to apply. In fact, many of these issues are currently being addressed in research sponsored by either Caltrans, under project ATC-32, or the FHWA, through the NCEER Highway Project

Technical References

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