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Implementation of Recommended LRFD Guidelines (NCHRP 12-49) for Seismic Design of Highway Bridges in New Jersey

FHWA-NJ-2004-019

December 2004

BACKGROUND

The San Fernando Earthquake of February 9, 1971 was a turning point in the development and subsequent implementation of seismic design codes for highway bridges. Following the San Fernando Earthquake many research and development projects were initiated. Among these was a major study sponsored by FHWA to develop seismic design guidelines for highway bridges, which was conducted by the Applied Technology Council (ATC) and published as ATC-06 [1]. In 1991, the American Association of Highway and Transportation Officials (AASHTO) adopted the guidelines as a standard specifications (also known as Division I-A). During the 1990s changes (mostly terminology) were made to Division I-A specifications and they were adopted into AASHTO LRFD. Thus, existing seismic codes are mostly based on research conducted in the 1970s after the San Fernando Earthquake. During the past two decades there have been several major earthquakes with significant impact on seismic performance of highway



Damage to bridges
during past
earthquakes.

bridges. In addition to reinforcing lessons learned from the San Fernando Earthquake, these earthquakes provided many other lessons to be considered in the seismic analysis and design of highway bridges. These earthquakes highlighted:

- Importance of site conditions,
- The need to consider near fault ground motion,
- Importance of connection details, and reliability of multi-column bent performance,
- **The possibility of occurrence of rare events (an important lesson for low seismicity region such as New Jersey),**
- The likelihood of premature failure of more recent bearings,
- The fling-step phenomenon (large unidirectional velocity pulses in the fault-normal direction), and fault rupture crossing the bridge site, and
- Development of advanced analytical tools.

To reflect the experience gained during these earthquakes, in 1998 a project was sponsored by AASHTO and conducted through the National Cooperative Highway Research Program (NCHRP), known as NCHRP Project 12-49, and entitled “Comprehensive Specifications for the Seismic Design of Bridges.” The final document addresses the state-of-the-art aspects of highway bridge seismic design, including the latest approaches for representing the seismic hazard, design and performance criteria, improved analysis methods, steel and concrete superstructure and substructure design and detailing, and foundation design. The proposed provisions are now being used in trial designs and also as an option in actual designs around the country, and are being considered (albeit now probably in a modified form) for adoption by AASHTO as *“Revised LRFD Design Specifications (Seismic Provisions).”*

NCHRP 12-49

Comprehensive Specification for the
Seismic Design of Bridges

Revised LRFD Design Specifications
(Seismic Provisions)

TRANSPORTATION RESEARCH BOARD
NAS-NRC
PRIVILEGED DOCUMENT

This report, not released for publication, is furnished only for review to members or participants in the work of the National Cooperative Highway Research Program. It is to be regarded as fully privileged, and dissemination of the information included herein must be approved by the NCHRP.

THIRD DRAFT OF SPECIFICATIONS
AND COMMENTARY

March 2, 2001

The objective of this study was to evaluate the NCHRP 12-49 guidelines and to assess its impact on the seismic design of highway bridges in the State of New Jersey.

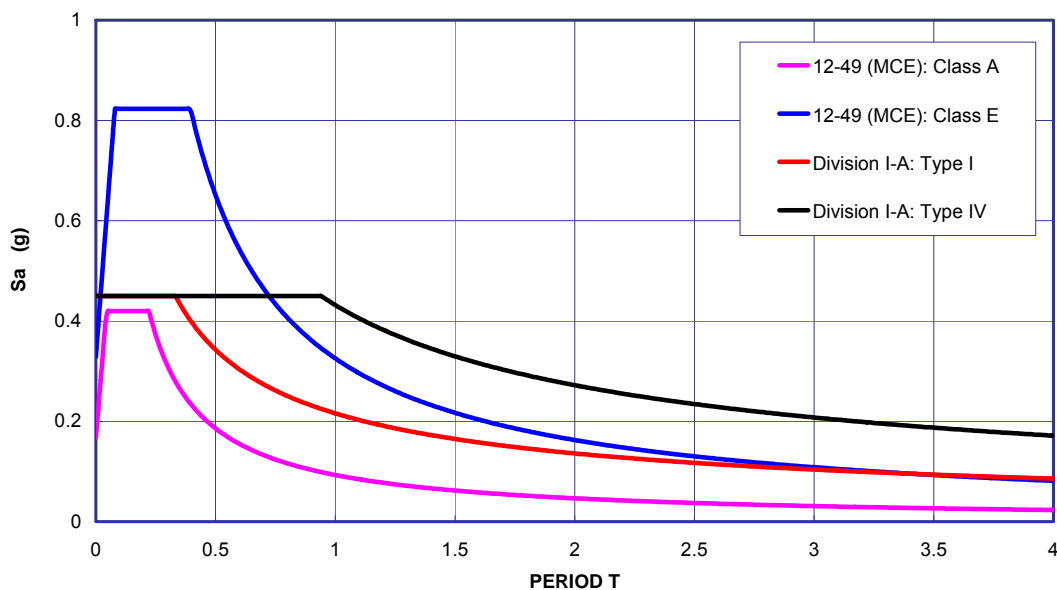
RESEARCH APPROACH

From a list of NJ bridges with more than 3-spans and built recently (since 1997), five bridges distributed throughout the state were selected to classify the sites using available data and determine the corresponding design response spectra using both the existing and proposed new codes. These bridges are:

- Union Avenue over Passaic River (Bergen County),
- NJ Rt. 15 over NYS Western Rail (Sussex County),
- NJ Rt. 35 over Navesink River (Monmouth County),
- US Rt. 206 over Raritan River (Somerset County), and
- Ocean Drive over Middle Thorofare (Cape May County).

Newark (Essex County, NJ) was also used as a location for additional seismic design spectrum and force determinations.

The following figure shows the response spectra for the range of site conditions based on NCHRP 12-49 (i.e., site classes A and E) and those for Division I-A (soil type I and IV) for Newark, NJ¹. Note that the spectrum corresponding to NCHRP 12-49 corresponds to upper level event (MCE), which is 3% PE in 75 years or approximately 2,500 years return period. Division I-A has only one event with about 500 years return period. For competent soils the spectral accelerations are smaller based for the proposed new code (i.e., Class A/pink vs. Type I/red). For soft soil sites, the spectral accelerations based on NCHRP 12-49 (Class E/blue curve) are higher than those based on existing code (Type IV/black) only for low period (high frequency) systems. In this case, for systems with periods longer than 0.7 second the spectral accelerations are lower based on the proposed new code. This is an important point to be considered in the design process. Note that Division I-A spectrum is capped at a fixed value regardless of site condition. There is no scientific and/or empirical explanation on the derivation of this short-period cap, and site-specific results indicate that Division I-A can underestimate design spectral values by a factor of 1.5 or more.



¹ Trends and patterns discussed are general, and in the sake of brevity results of additional examples are not presented.

Of course the response spectrum by itself does not determine the level of seismic forces. Dynamic and nonlinear response characteristics of the bridge should also be considered. Therefore, a better comparison of the two seismic specifications is made by comparing the seismic forces. This is represented by dividing the design response spectra by the appropriate response modification factor (considering low period modifier) and the Φ factor (or strength reduction factor per each specs).

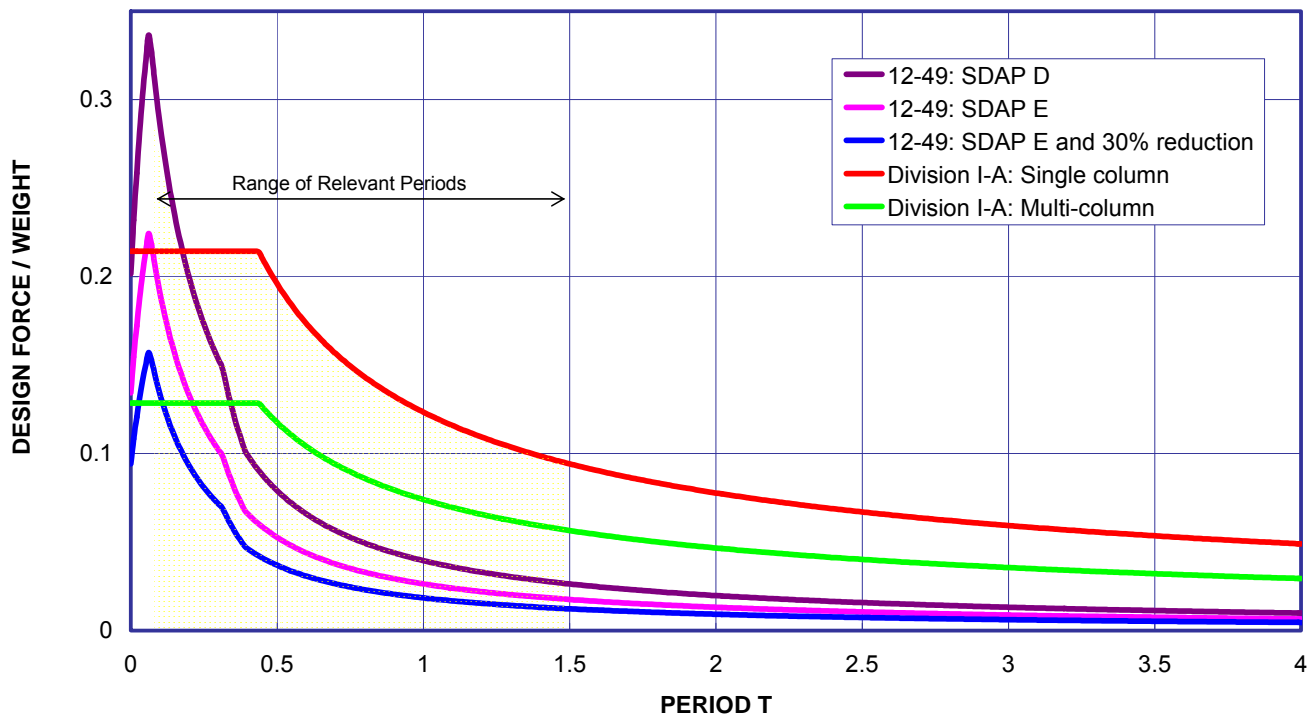
The following figure shows relative values of seismic forces. Assumptions used in developing the Division I-A seismic force spectrum are: Type II soil, importance category is non-critical non-essential (i.e., "Other") corresponding to response modification factors of 5 (multi-column) and 3 (single column), and response reduction factor, Φ , of 0.7 is assumed. Assumptions used in obtaining the corresponding NCHRP 12-49 seismic force spectrum are: Class C soil, life safety performance, upper level event (MCE or 2500 years return period), base response modification factor of 6 (SDAP E), reduction of 30 percent assuming displacement capacity verified, and response reduction factor of unity ($\Phi = 1$). Because of the low period modifier, under NCHRP 12-49 the actual response modification factor depends on the period and can be as low as unity for short-period systems, thus, the reason for the significant change in the shape of the seismic force spectrum for NCHRP 12-49 compared to spectral acceleration spectrum.

Furthermore, seismic force spectra under the proposed NCHRP 12-49 for two additional situations, where the design method does not use advance analysis or the design is less aggressive are also plotted. These are: i) a case where under SADP E no additional 30 percent reduction is made and, ii) a case where similar to current approach modal analysis (SDAP D) is assumed to be used (i.e., no pushover analysis performed). The curves for these two cases are labeled "12-49: SDAP E" and "12-49: SDAP D", respectively. Under SDAP D the response modification factor is 4 compared to 6 for SDAP E. These NCHRP 12-49 spectra, which are the same for single and multi-column bents are compared to Division I-A spectra for single and multi-column bents.

As it can be seen from comparison of these curves, even when the less advance analysis method is employed the NCHRP 12-49 seismic forces are much smaller than Division I-A for the relevant period range (shaded area in Figure 9). In the higher end of this region (e.g., $T = 1$ second) the seismic forces using SDAP D is almost half of Division I-A for multi-column bents and about one-third for single column bents. Seismic forces based on proposed NCHRP are even smaller when a more advance analysis approach is employed. For example, for a system with 1-second fundamental period the seismic forces for SDAP E (with 30 percent reduction) are one-sixth and one-fourth of Division I-A forces for single and multi-column bents, respectively.

It must be emphasized that the observations discussed in this report are not unique to this site and **applies to the entire state of NJ**. Indeed the trend is the same for all over US. To this end, it is expected that for **eastern and central US states seismic forces based on NCHRP 12-49 are in general comparable and often lower than those based on Division I-A**. Therefore, as it is shown in the original report any move to lower the seismic hazard by reducing the return period may have a serious implication with regard to future events. The Kobe earthquake demonstrated that

rare events do indeed happen. Future seismic design provisions must take lessons learned during past two decades into account, as the NCHRP 12-49 has done.



RECOMMENDATIONS

- Seismic design forces based on the proposed NCHRP 12-49 code are not necessarily higher than the existing code. Most designs (if not all) for the state of NJ can actually have lower seismic forces compared to the existing code.
- NCHRP provisions provide simplified analysis and design procedure that can apply to a large number of bridges in NJ.
- The cost implication of seismic design requirements for a wider region is minimal to none due to the addition of no analysis design concepts and simplified but more accurate procedures.
- Proposed provisions are nationally applicable and provide uniform hazard across the nation by using recent USGS maps.
- Adopt NCHRP 12-49 in its present form and encourage AASHTO to do the same.
- Consider making comparative designs based on NCHRP 12-49 and Division I-A a part of the bridge project scope in the state of NJ.
- Oppose changes in hazard definition that results in a lower return period (e.g., 1,500 year or lower) since such a move can have serious adverse effect on seismic safety of bridges.
- Encourage seismic provisions, such as NCHRP 12-49 that take advantage of advances in analytical procedures and rewards designs that are based on the state-of-the-knowledge.

- Collect dynamic soil properties as a part of future bridge construction. Gains in more efficient and better designs well justify minimal associated costs.
- Encourage relaxing site-specific analysis limit(s) to promote further collaboration among geology, seismology, geotechnical engineering, and structural engineering to better define seismic hazards and model soil-structure interaction.

Rather than revising NCHRP 12-49 by reducing return period and/or removing incentives for use of the state-of-the-art analysis procedures, the following topics are recommended for future research and development:

- Consideration to dual benefit multi-hazard problems such as response of highway bridges to vertical motion and blast load. Possible research topics for immediate considerations are effect of blast and vertical seismic loads on bridge superstructure, development of protective systems for both sub- and superstructure, and impacts of upward motions on pre-tensioned and post-tensioned bridges.
- Perform a sensitivity study on interdependency of bridge dynamic characteristics (period) and site conditions (hazard level) to more exactly quantify its impact on seismic demands for various bridges.
- Develop design tools to facilitate and streamline the application of new analysis and design concepts under NCHRP 12-49.

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A final report is available online at <http://www.state.nj.us/transportation/research/research.html>

If you would like a copy of the full report, please FAX the NJDOT, Division of Research and Technology, Technology Transfer Group at (609) 530-3722 or send an e-mail to Research.Division@dot.state.nj.us and ask for:

Report Title: Cause and Control of Transverse Cracking in Concrete Bridge Decks

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