OVERVIEW OF THE 2007 LRFD GUIDE SPECIFICATIONS FOR SEISMIC DESIGN OF BRIDGES

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Abstract

A new, long awaited, AASHTO LRFD Guide Specification for Seismic Design of Highway Bridges has been developed under the guidance and support of the AASHTO T-3 Committee on Seismic Design. This paper will give a brief history and background on the development of the Guide Specifications to meet the expectations of the T-3 Committee. The Guide Specifications were developed specifically for ordinary, girder and slab type bridges, using a Displacement Based Approach with design factors calibrated to prevent collapse and reflect both the inherent reserve capacity to deform under imposed seismic loads and to accommodate relative displacements at the supports and articulated connections. This presentation will focus on the selection of the seismic hazard and give a brief overview of the new specification.

Introduction and Background

The work that led to the recent adoption of the AASHTO LRFD Guide Specification for Seismic Design of Highway Bridges began with the development of the of the AASHTO LRFD Bridge Design Specifications over a decade ago (1). Recent major earthquakes that have occurred in the Western United States, Japan, Taiwan and Turkey have increased public awareness of the losses that occur as a result of earthquakes serving as a constant reminder to the engineering profession that modern day design specifications are needed.

The NCHRP Project 12-49 "Recommended LRFD Guidelines for the seismic Design of Highway Bridges," Part 1: Specifications were prepared as part of the overall NCHRP Project "Comprehensive Specifications for the Seismic Design of Bridges" (2). The Guidelines were completed and submitted to the AASHTO T-3 Committee on Seismic Design of Bridges and the State Bridge Engineers for their review. Following an evaluation by several states, the T-3 Committee and State Bridge Engineers did not accept the Guidelines as written and recommended that some changes be made to comply with their requirements. The evaluation included trial designs from the states of: New Jersey, Washington, Arkansas, Oregon, South Carolina, Tennessee and Nevada. Additionally, with the elapse in time, since the NCHRP Project 12-49 was completed, other new developments had surfaced, which were then considered as updates to be included in the follow-up NCHRP 20-07/193

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Recommended Guidelines for Seismic Design of Bridges (3). This second NCHRP effort coupled with the assistance and support of MCEER/FHWA and the AASHTO T-3 Committee for Seismic Design resulted in the AASHTO adoption of this second NCHRP project as the AASHTO Guide Specifications for Seismic Design of Bridges at the 2007.

The overall effort leading to the final adoption included several tasks which were recommended by AASHTO T-3 Committee. Initially Task F3-4 which was funded by MCEER/FHWA was initiated to assist the AASHTO T-3 Committee in finding a consensus among state bridge engineers on what should be adopted as seismic guidelines for the LRFD design of bridges (4). The scope of this task was to produce a "road map" for development of the LRFD Guide Specifications. The screening and retention of appropriate material targeted for use in the development of the new LRFD Guidelines was conducted considering the following:

a) Recent research

b) Practical and easy-to-use guidelines

c) Cost effective use of public funds

d) Reasonable tolerance of risk

e) Review of comments by the T-3 Committee

The objective of Task F3-4 was to propose a road map that draws special consideration to the issues needing improvement or modification as highlighted by the AASHTO's T-3 Committee. These issues were identified as follows:

1. Selection of Return Period and Design Spectrum for a Single Hazard Level, which is more consistent with the hazards used in bridge design addressing a No Collapse Criteria for bridges.

2. Maintain the Range of Applicability for the No Analysis zones.

Achieving consensus on these issues was considered a major milestone in the road towards the adoption of seismic guidelines for the LRFD design of bridges.

Recommended Approach to Addressing Seismic Hazard

The AASHTO Guide Specifications for LRFD Seismic Bridge Design is documented in the NCHRP 20-07/Task 193 Task 6 Report (5). Task 6 contains a section addressing seismic hazard in accordance to the road map established in the above mentioned Task F3-4. The recommended approach to addressing the seismic hazard is based on the following positions:

- Recommendations would be primarily for design against the effects the ground shaking hazard

- Selection of a return period for design less than 2500 years
- Inclusion of the USGS 2002 Update of the National Seismic Hazard Maps (6)
- Effects of near field and fault rupture to be addressed separately
- Displacement based approach with both design spectral acceleration and corresponding displacement spectra provided
- Hazard maps under the control of AASHTO with each state having the option to modify or update their own State Hazard using the most recent seismological studies consistent with the established risk

Background on Seismic Hazard

The current state-of-practice in addressing the seismic hazard for the design of bridges in the U.S. has evolved from just conforming to AASHTO Division 1-A requirements to adopting higher standards that take into account the possible effects of larger earthquakes in the Eastern United States and the impacts of major earthquakes that occurred recently in the Western United States, Japan, Taiwan and Turkey (7). This change in the seismic hazard practice can be best illustrated in looking at the following sources:

- NEHRP 1997 Seismic Hazard Practice
- Caltrans Seismic Hazard Practice
- NYCDOT and NYSDOT Seismic Hazard Practice
- NCHRP 12-49 Seismic Hazard Practice
- SCDOT Seismic Hazard Practice
- Site Specific Hazard Analyses Conducted for Critical Bridges

The NCHRP 20-07/Task 193 Task 6 Report documents the background on seismic hazard drawn from the above mentioned resources.

Proposed Seismic Hazard for Design of Normal Bridges

In reviewing the seismic hazard practice in different regions as described previously, it became apparent that some important aspects of this practice need to be taken into consideration when developing new guidelines. These aspects were pivotal in reaching the objective of producing guidelines that would be adopted by AASHTO.

These aspects include:

1) Consideration for lower return period for Design based on the Maximum Considered Earthquake (MCE) maps published in 1996 with USGS 2002 Update shall be considered a minimum standard. Modification or increase in the hazard intensity based on Seismological Studies needs to be included as an option for states and agencies seeking a higher degree of hazard identification to a specific region or bridge.

2) The reduction in the design intensity can be implicitly achieved by considering applying a reduction/modifier factor for design spectrum derived from USGS MCE maps. An alternative to this approach would be embarking on developing new maps based on a modified new definition of the MCE for Bridge Design.

3) Consideration of applying a reduction factor on the hazard intensity for existing bridges or bridges located in rural areas.

4) Selection of a lower return period for Design is made such that Collapse Prevention is not compromised when considering historical large earthquakes. This reduction can be achieved by taking advantage of sources of conservatism not explicitly taken into account in current design procedures. These sources of conservatism are becoming obvious based on recent findings from both observations of earthquake damage and experimental data. Some of these sources are shown in Table 1 below.

TABLE 1: IDENTIFIED SOURCES OF CONSERVATISM

Source of Conservatism	**Safety Factor**
Computational vs. Experimental Displacement Capacity of Components	1.3
Effective Damping	1.2 to 1.5
Dynamic Effect (i.e., strain rate effect)	1.2
Pushover Techniques Governed by First Plastic Hinge to Reach Ultimate Capacity	1.2 to 1.5
Out of Phase Displacement at Hinge Seat	Addressed in Task 6 Report

The conservatism is directly coupled to the seismic reliability of the structural system under consideration. The current state-of-practice favors continuous superstructures for the majority of bridges with an objective of minimizing expansion joints to increase serviceability, reduce maintenance, and increase life cycle of the bridge. This selection has a favorable impact on the earthquake redundancy of the bridge system. Considering a single performance level of “No Collapse”, the seismic redundancy of the bridge system is enhanced with the increase of the number of plastic hinges that must yield and then fail in order to produce the impending collapse of the structure. This enhanced redundancy translates into a delayed failure (i.e. collapse) provided sufficient seat width exists in the bridge system. Therefore two distinctly different aspects of the design process need to be provided:

a) An appropriate method to design adequate seat width(s) considering out of phase motions.

b) An appropriate method to design the ductile substructure components without undue conservatism.

These two aspects are embedded with different levels of conservatism that need to be calibrated against the single level of seismic hazard considered in the design process.

The first aspect is highly influenced by variation in the periods of the frames on both sides of a joint as well as the damping generated by the ductile behavior of plastic hinges. This aspect is addressed in terms of recommendations or limits on periods ratio for frames on both sides of an expansion joint.

The second aspect is addressed using a static push-over analysis. As shown in Figure 1, the collapse displacement is usually reached when the P-Δ line intersects the load-displacement curve of the structure, because at this point, any increment in displacement produces an increment in the P-Δ effect due to gravity loads that cannot be resisted by the lateral resistant system. It is important to mention that for structures with relatively small gravity loads, a much larger reduction in component strength can be tolerated without reaching structural collapse. This is relevant to bridge columns carrying relatively low axial loads. In essence, the continuity of the superstructure and low axial loads in columns make a typical bridge more resilient against collapse in a seismic event.

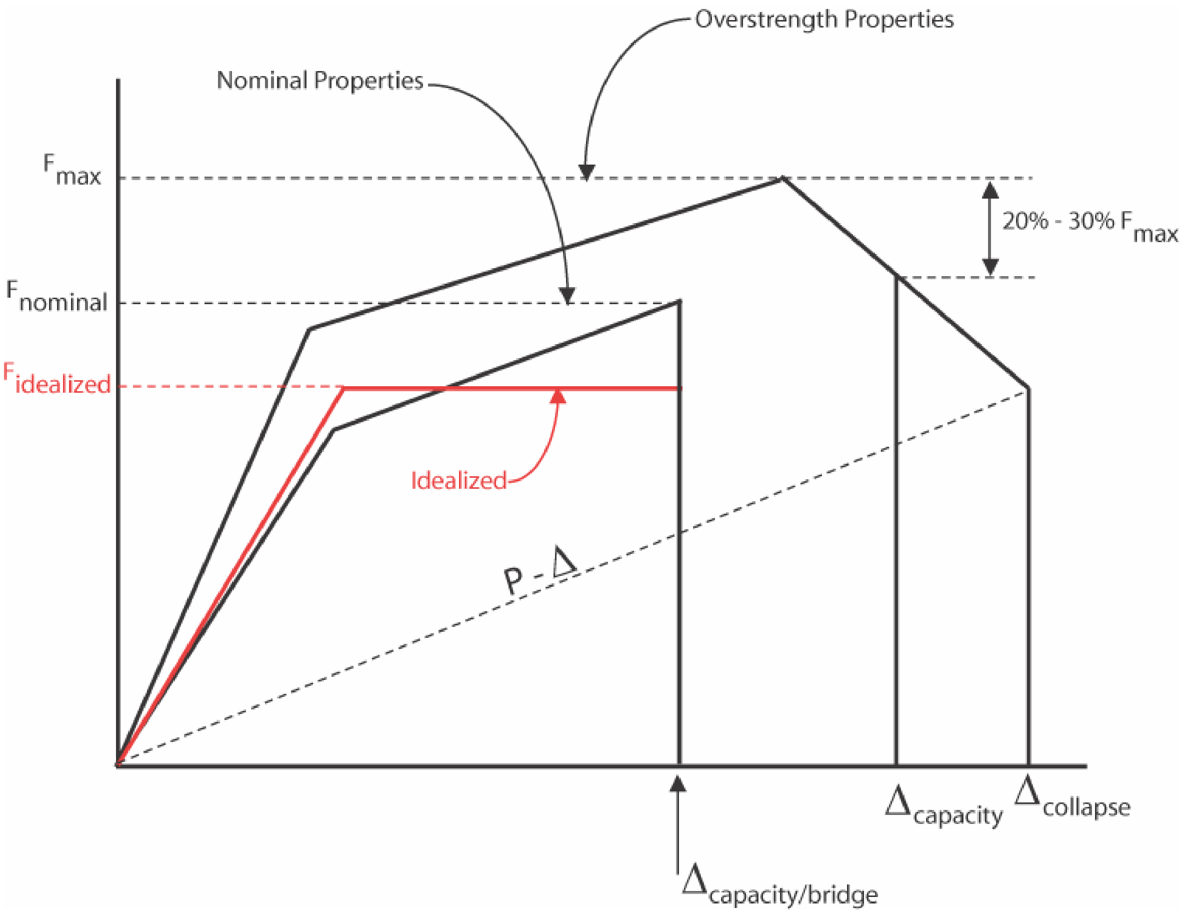

FIGURE 1: IDEALIZED LOAD – DEFLECTION CURVE OF A BRIDGE

During seismic excitation the structure or any of its components can fail under a smaller displacement than the displacement $\Delta_{collapse}$ illustrated in Figure 1. This failure is mainly attributed to nonsymmetric cumulative plastic displacement that is highly dependent on the characteristics of the earthquake ground motions. The reliable displacement capacity is typically associated with the displacement corresponding to a limited decrease in strength of 20% to 30% maximum, obtained under monotonically increasing deformation. As shown in Figure 1, the displacement capacity $\Delta_{capacity}$ can only be established given the descending slope following the point of maximum lateral resistance F_{max}. Recognizing the complexity of determining $\Delta_{capacity}$, the $\Delta_{capacity/bridge}$ is used as a conservative and simple measure assuming nominal properties.

In summary, the two aspects described above should be considered in the practice to justify a reduction in the design hazard and ensure the development of a simplified methodology that addresses the different sources of conservatism included in the current state of the practice.

In order to assess the feasibility of a reduction in hazard from the 2% in 50 years hazard level adopted by NCHRP 12-49, a Probabilistic/Deterministic comparison is conducted on 20 sites using the one-second spectral acceleration for the Deterministic Seismic Hazard Analysis (DSHA), and the Probabilistic Seismic Hazard Analysis (PSHA). Figure 2 shows the PSHA/DSHA comparison for the one-second acceleration and the PSHA/DSHA ratio at each of the selected sites.

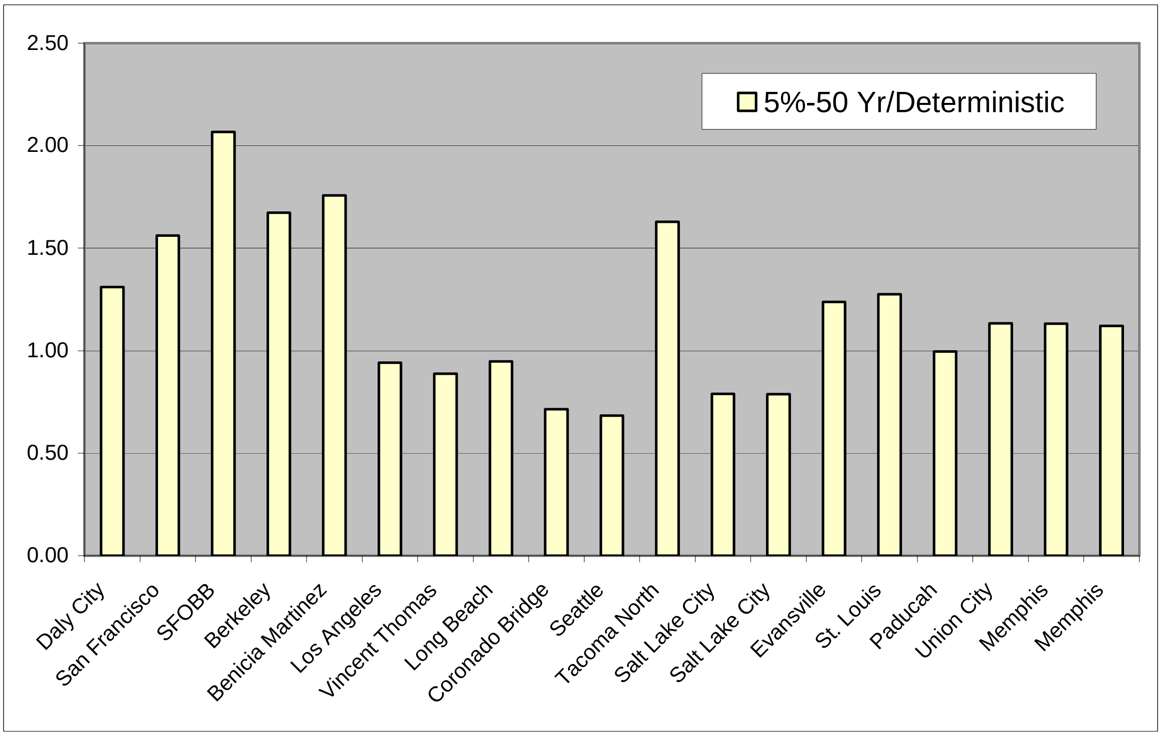

FIGURE 2: PROBABILISTIC TO DETERMINISTIC RATIO AT SELECTED SITES

Based on this comparison, the following recommendations were proposed:

1. Adopt the 7% in 75 years hazard level for development of a design spectrum.

2. Ensure sufficient conservatism (1.5 safety factor) for minimum seat width requirement. This conservatism is needed to use the reserve capacity of the hinging mechanism of the bridge system. This conservatism is calibrated in the specifications to address unseating vulnerability.

3. Partition Seismic Design Categories (SDCs) into four categories and proceed with the development of analytical bounds using the 7% in 75 years hazard level.

<u>Recommendation 1, Development of AASHTO Seismic Hazard by USGS :</u>

Following the recommendations of the Task 6 Report discussed above, the AASHTO T-3 Committee entered into an agreement with USGS to prepare two types of products for use by AASHTO. The first product was a set of paper maps of selected seismic design parameters for a 7% probability of exceedance in 75 years (equivalent to 5% in 50 Years recommended by the Task 6 Report). The second product was a ground motion software tool to simplify determination of the seismic design parameters for the bridge designers.

The LRFD Guide Specifications use spectral response acceleration with a 7% probability of exceedance in 75 years as the basis of the seismic design requirements. As part of the National Earthquake Hazards Reduction Program, the U.S. Geological Survey's National Seismic Hazards Mapping Project prepares seismic hazard maps of different ground motion parameters with different probabilities of exceedance. However maps were not prepared for the probability level required for use by these guidelines. These maps were prepared by the U.S. Geological Survey under a separate Technical Assistance Agreement with the American Association of State Highway and Transportation Officials (AASHTO), Inc. for use by AASHTO and in particular the Highway Subcommittee on Bridges and Structures.

The set of paper maps covered the fifty states of the U.S. and Puerto Rico. Some regional maps were also included in order to improve resolution of contours. Maps of the conterminous 48 states were based on USGS data used to prepare maps for a 2002 update. Alaska was based on USGS data used to prepare a map for a 2006 update. Hawaii was based on USGS data used to prepare 1998 maps. Puerto Rico was based on USGS data used to prepare 2003 maps.

The maps included in the map package were prepared in consultation with the Subcommittee on Bridges and Structures. The package included a series of maps that provide:

- the peak horizontal ground acceleration coefficient, PGA
- a short period (0.2 sec) value of spectral acceleration coefficient, Ss
- a longer period (1.0 sec) value of spectral acceleration coefficient, S1

The maps are for spectral accelerations for a reference Site Class B.

The ground motion software tool was packaged on a CD-ROM for installation on a PC using a Windows-based operating system (6). The software includes features allowing the user to calculate the mapped spectral response accelerations as described below:

- PGA, Ss, and S1: Determination of the parameters PGA, Ss, and S1 by latitude-longitude or zip code from the USGS data.
- Design values of PGA, Ss, and S1: Modification of PGA, Ss, and S1 by the site factors to obtain design values. These are calculated using the mapped parameters and the site coefficients for a specified site class.

In addition to calculation of the basic parameters, the CD allows the user to obtain the following additional information for a specified site:

- Calculation of a response spectrum: The user can calculate response spectra for spectral response accelerations and spectral displacements using design values of PGA, Ss, and S1. In addition to the numerical data the tools include graphic displays of the data. Both graphics and data can be saved to files.

- Maps: The CD also include the 7% in 75 year maps in PDF format. A map viewer is included that allows the user to click on a map name from a list and display the map.

Recommendation 2, Development of Specifications for No-Collapse :

Life safety for the design event shall be taken to imply that the bridge has a low probability of collapse but, may suffer significant damage and significant disruption to service is possible. Partial or complete replacement may be required.

Significant damage shall be taken to include permanent offsets and damage consisting of:

- cracking,
- reinforcement yielding,
- major spalling of concrete
- extensive yielding and local buckling of steel columns,
- global and local buckling of steel braces, and
- cracking in the bridge deck slab at shear studs.

These conditions may require closure to repair the damages. Partial or complete replacement of columns may be required in some cases. For sites with lateral flow due to liquefaction, significant inelastic deformation may be permitted in the piles. Partial or complete replacement of the columns and piles may be necessary if significant lateral flow occurs. If replacement of columns or other components is to be avoided, the design strategy producing minimal or moderate damage such as seismic isolation or the control and reparability design concept should be assessed. Significant disruption to service shall be taken to include limited access (reduced lanes, light emergency traffic) on the bridge. Shoring may be required.

Considering the above mentioned performance criteria, the displacement approach is solely adopted based on satisfying displacement capacity against displacement demand. As a measure of damage in the bridge structure, the local member ductility demand, $_D$, shall satisfy:

- $\mu_D \leq 5$ For single column bents
- $\mu_D \leq 6$ For multiple column bents

The state engineers' panel considered these values achievable practically without the risk of stretching the limits of columns observed in experimental testing.

For SDC A,B,C the seat requirements of the current LRFD specifications are maintained after confirming their adequacy for the upgraded hazard level. For SDC D, hinge seat or support length, N, shall be available to accommodate the relative longitudinal earthquake displacement demand at the supports or at the hinge within a span between two frames and shall be determined as:

$$N = \left(4 + 1.65\Delta_{eq}\right)(1 + 0.00025\, S^2) \geq 24$$

where:

Δ_{eq} = seismic displacement demand of the long period frame on one side of the expansion joint (in.).

S = angle of skew of support measured from a line normal to span (°)

The above equation ensures a 1.5 minimum safety factor for seat width considering that this mitigation is economical and needed to develop other reserve capacity in the overall bridge system.

<u>Recommendation 3, Selection of Seismic Design Category (SDC):</u>

Each bridge shall be assigned to one of four Seismic Design Categories (SDC), A through D, based on the one second period design spectral acceleration for the design earthquake (S_{D1} refer to Article 3.4.1) as shown in Table 2

TABLE 2: PARTITION FOR SEISMIC DESIGN CATEGORIES A, B, C AND D.

Value of $S_{D1} = F_v S_1$	**SDC**
$S_{D1} < 0.15$	**A**
$0.15 \leq S_{D1} < 0.30$	**B**
$0.30 \leq S_{D1} < 0.50$	**C**
$0.50 \leq S_{D1}$	**D**

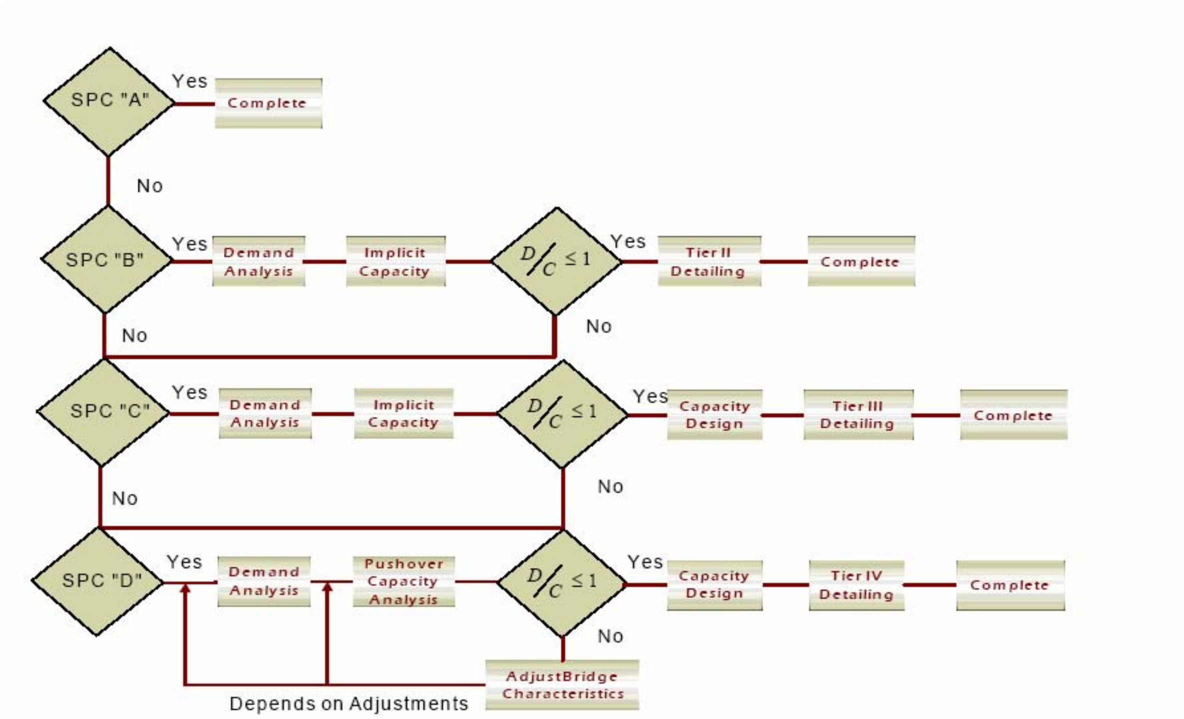

FIGURE 3: SEISMIC DESIGN CATEGORY (SDC) CORE FLOWCHART.

The five requirements for each of the proposed Seismic Design Categories shall be taken as shown in Figure 3.

Conclusion

A new, long awaited, AASHTO LRFD Guide Specification for Seismic Design of Highway Bridges has been developed under the guidance and support of the AASHTO T-3 Committee on Seismic Design and several participating member and volunteer states. The Guide Specification and new seismic hazard for a 1000 year return period were adopted unanimously by AASHTO at the yearly meeting on July 12, 2007.

The Guide Specifications were developed specifically for ordinary, girder and slab type bridges, using a Displacement Based Approach with design factors calibrated to prevent collapse and reflect both the inherent reserve capacity to deform under imposed seismic loads and to accommodate relative displacements at the supports and articulated connections. A new seismic hazard map was developed by USGS for 7% probability of exceedance in 75 years (i.e. approximately a 1000 year return period) specifically for AASHTO and is now under the control of AASHTO. The selected hazard for design was made considering large historical earthquakes, without compromising collapse prevention, using calibrated design factors. Uniform hazard design spectra are constructed using the Three Point Method with the new AASHTO/USGS Maps for the PGA, 0.2 second, and 1.0 second horizontal ground accelerations and corresponding HEHRP Site Class Spectral Acceleration Coefficients.

As seen from the approach taken to address the appropriate hazard level for the new LRFD Guidelines, the performance criteria associated with typical bridges needed to be considered in order to select an appropriate return period that meets the objective of the stakeholders recognizing that the LRFD Guidelines are minimum requirements that can be upgraded regionally or on specific essential or critical bridges.

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