National Institute of BUILDING SCIENCES

Building Seismic Safety Council

Development of the 2020 NEHRP Provisions

ASCE/SEI 7-16 Adoption Report

November 30, 2017

An Authoritative Source of Innovative Solutions for the Built Environment

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Prepared by the

National Institute of Building Sciences

Building Seismic Safety Council

For

Department of Homeland Security

Federal Emergency Management Agency (FEMA)

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PREFACE

The Building Seismic Safety Council (BSSC) has entered its 39th year and its 10th cycle of developing *National Earthquake Hazards Reduction Program* (*NEHRP*) *Recommended Seismic Provisions for New Buildings and Other Structures* (commonly referred as "the Provisions") that are then used as a key national code resource to update model codes and national standards for buildings against seismic risk. We have not experienced a major earthquake in this country since 1994, but rest assured, one is in our future. When it occurs, because we have built buildings in the last 40 years to better resist seismic events, there will not be the level of destruction and loss of life that we see in earthquakes around the world where there is insufficient or no seismic construction. Yes, there will be damage and some loss of life, but not to the level seen elsewhere, thanks to our seismic codes and standards, where they are adopted and enforced. We will recover faster, and then make our communities stronger and more resilient to earthquakes than before.

As described in the introduction in this document, conceived and sponsored by the NEHRP of Federal Emergency Management Agency (FEMA), the BSSC develops the Provisions in a deliberative process that involves seismic code experts, engineers and industry representatives, who address and come to agreement on the engineering, safety, constructability and economic issues that are extant in the development of all building codes and standards. BSSC works hand-in-hand with the American Society of Civil Engineers (ASCE) Seismic Subcommittee to transfer the Provisions with minimum modifications into the standards language found in ASCE/SEI 7 *Standard on Minimum Design Loads for Buildings and Other Structures*. This has been a successful process that could be replicated for other hazard- and safety-related parts of building codes. The section that follows the introduction provides a description of how the Provisions development process begins with the adoption by ballot of the latest edition of ASCE /SEI7 (ASCE/SEI 7-16) as the base document for modification in the next edition of the Provisions for 2020.

If you are a member of the disaster community, please take a look at the introduction and description of the ballot to get an idea of how the BSSC process works. For engineers, please go on and read the section on the changes between the 2015 Provisions and ASCE 7-16 to better understand the technical content of the Provisions and changes that were made in the transition into the seismic chapters of ASCE 7-16.

The BSSC has now embarked on another five-year cycle for development of what will be the 2020 edition of the Provisions. As in past cycles, seismic engineers and industry representatives again will approach this process enthusiastically. This is how we make our communities safer, and how we make life better.

Philip Schneider, AIA
Executive Director
Building Seismic Safety Council

EXECUTIVE SUMMARY

The *National Earthquake Hazards Reduction Program* (*NEHRP*) *Recommended Seismic Provisions for New Buildings and Other Structures* (Provisions) is a knowledge-based state-of-the-art seismic code resource document, which provides a platform for translation of new research results and consensus in engineering practice for use in updating national design standards and building codes. The NEHRP Provisions are developed by the Provisions Update Committee of the Building Seismic Safety Council (BSSC), which is sponsored by the Federal Emergency Management Agency (FEMA). Many significant technical changes related to seismic design are initiated and vetted within BSSC and included in the NEHRP Provisions affect the seismic related chapters within ASCE/SEI 7 *Standard on Minimum Design Loads for Buildings and Other Structures* and Associated Criteria.

This report, prepared at the outset of the 2020 NEHRP Provisions development cycle, presents some important background on the NEHRP Provisions development process and summarizes the results of the first ballot in the 2020 development cycle to adopt ASCE/SEI 7-16 as the primary reference document for the Provisions. As a practice initiated with the 2009 edition of the Provisions, after adopting ASCE/SEI 7, the BSSC makes substantive recommendations for modification and improvement to the standard based on recent research and improvements in knowledge. In the 2015 NEHRP Provisions the BSSC developed significant modifications to ASCE/SEI 7-10, which were then adopted in ASCE/SEI 7-16. For the 2020 Provisions the BSSC has adopted ASCE/SEI 7-16 as the reference with the intent to make changes that will be reflected in ASCE/SEI 7-22. This report also summarizes some of the important changes made by the 2015 NEHRP Provisions that were adopted by ASCE/SEI 7-16 and a few changes that were further modified in the ASCE/SEI 7-16.

1. Introduction to Development of NEHRP Provisions

In 2015, Federal Emergency Management Agency (FEMA)'s National Earthquake Hazards Reduction Program awarded the a contract to the Building Seismic Safety Council (BSSC) of National Institute of Building Sciences (NIBS) to develop the 2020 *National Earthquake Hazards Reduction Program* (*NEHRP*) *Recommended Seismic Provisions for New Buildings and Other Structures* (Provisions). The NEHRP Provisions is a knowledge-based state-of-the-art seismic code resource document, which provides a platform for translation of new research results and consensus engineering practice for use in updating national design standards and building codes. Since the establishment of NEHRP in 1977, FEMA, as one of the four NEHRP agencies, has contracted with BSSC, to develop and publish nine editions of NEHRP Provisions, in 1985, 1988, 1991, 1994, 1997, 2000, 2003, 2009, and 2015 in three to five year cycles. The 2020 Provisions will mark the 10th publication.

Authorized by the U.S. Congress, the National Institute of Building Sciences provides an authoritative source and a unique opportunity for open and candid discussion among private and public sectors within the built environment. BSSC provides an active national forum for all entities interested in the seismic provisions development process. BSSC not only assembles technically sound building seismic provisions that are vetted by hundreds of subject-matter experts, but casts them as consensus resources that account for technical, social, economic, and regulatory issues that affords wide acceptance and implementation by building code organizations, states, local communities, and federal agencies. The entities that are involved with BSSC and the Provisions development process are presented in Figure 1.

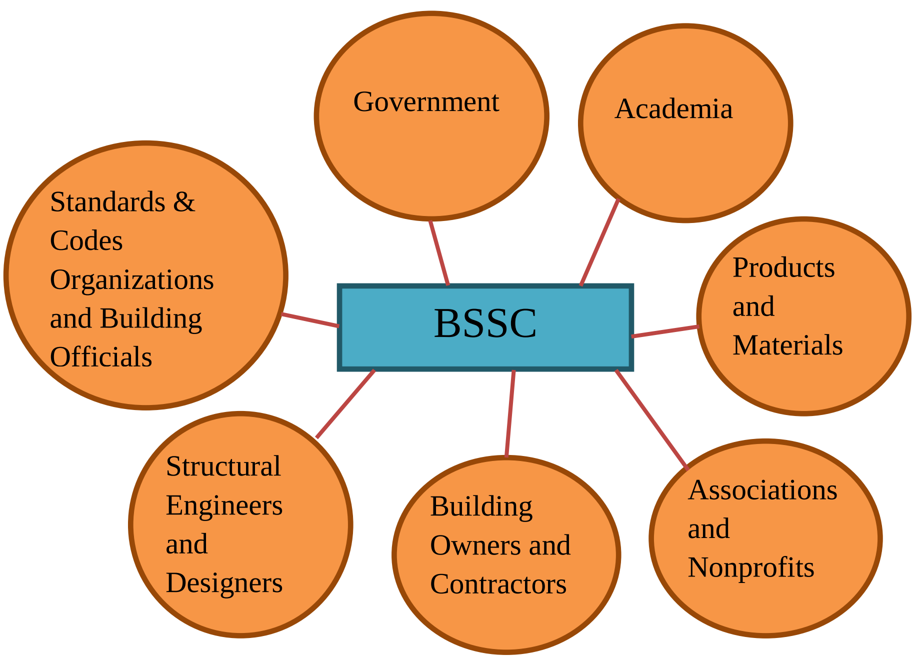

Fig. 1. Entities Involved with the Building Seismic Safety Council

The Provisions are developed by a volunteer Provisions Update Committee (PUC) of national subject matter experts approved by the BSSC Board of Direction. The PUC includes technical experts representing the breadth of seismic design disciplines, the former PUC chair from the previous cycle, and the chair of the ASCE 7 Seismic Subcommittee. Representatives from FEMA, US Geological Survey (USGS), and National Institute of Standards and Technology (NIST) serve as liaisons to PUC. The PUC selects relevant topics that are based on *Recommended Issues and Research Needs*, a report that identified remaining issues in previous cycle, and other inputs, such as new USGS seismic hazard models, NIST applied research and NSF and industry sponsored research. Topics are then assigned to volunteer Issue Teams, which include both PUC members and others with expertise in the issues being considered.

The BSSC conducts a deliberative process that allows academic, technical and detailed comment on proposals and resolution of conflicts in seismic design guidance. As a first step, Issue Teams prepare proposals for technical changes through consensus, which are then balloted, and in some cases re-balloted according to a Board approved set of procedures, by the PUC, followed by an industry ballot by the BSSC Member Organizations (MOs) representing the broader seismic community. The BSSC Board of Direction balances and referees the MOs to ensure that concerned commercial interests are involved in changes affecting seismic engineering. The BSSC Board of Direction further reviews all ballots to ensure that voting procedures approved at the outset of the cycle are observed. The organization chart of Provisions development is demonstrated below.

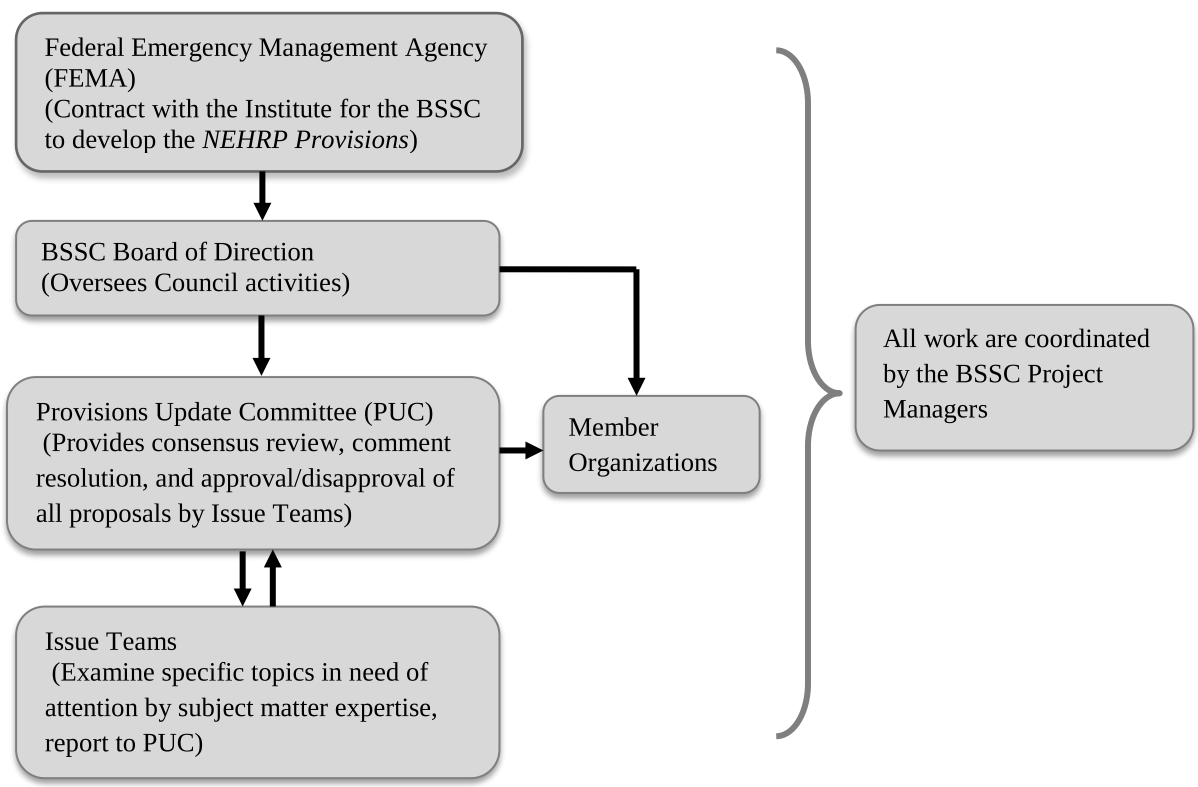

Fig. 2 BSSC Structure for Developing the NEHRP Provisions

Provisions development involves another support and advisory committee that operates under the BSSC. Every 10 years, FEMA, the BSSC and USGS collaborate to re-examine the rules and the basis for developing seismic design values maps. Under the BSSC, a joint committee called Project 17 was convened to address issues of seismic design map values during the 2020 cycle. Previous cycles had Project 07 and Project 97. The prior work of this committee has resulted in major changes to the rules of seismic design value maps and design procedures. For example, Project 97 adopted a seismic design basis for ordinary structures that sought avoidance of collapse for a major foreseeable earthquake event, termed Maximum Considered Earthquake (MCE); targeted MCE with a uniform hazard having 2475 year return period (with exception in regions proximate to major active faults where MCE is limited by deterministic caps); developed design procedures using a standard acceleration response spectrum; and, introduced the concept of the Seismic Design Categories (SDCs). Project 07 migrated from a uniform hazard with a 2,475 year return period to uniform risk of 1% in 50 year collapse risk. Project 17, at the time of this writing, is addressing issues through five work groups (WG): (1) Acceptable Risk WG to address selection of an appropriate risk basis for the design value maps; (2) Multi-Period Spectral Parameters WG to correct the representation of spectral shape for soft soil site with motions dominated by large magnitude earthquakes; (3) Precision and Uncertainty WG with the intent of stabilizing the mapped values of motion over time to minimize changes to practice; (4) Seismic Design Category WG with the goal of minimizing the ground motion fluctuation impact to design requirements; and (5) Deterministic Caps WG to develop specification of the deterministic ground motion upper bound on which seismic hazards at sites close to major active faults are capped. Any change proposals for modifying the seismic design value maps and design procedures will be balloted by the PUC and Member Organizations before they are implemented by USGS for inclusion in the Provisions.

2. NEHRP Provisions to the Model Building Codes and Standards

Until the 2009 edition, the NEHRP Provisions were code-language documents that were broadly adopted by regional model building codes and national standards, such as the Uniform Building Code (UBC), ASCE 7, and the Structural Engineers Association of California (SEAOC) Blue Book. Notably, the 2000 and 2003 editions of the International Building Code adopted the 1997 and 2000 NEHRP *Provisions* directly into Chapter 16 of the code, together with modifications to the materials standards, adopted in Chapters 17 through 22 of the code. In 2006, the International Code Council (ICC) decided to refer to industry standards for most technical structural engineering criteria. Instead of transcribing the NEHRP Provisions in their entirety, ICC transcribed only that portion of the *Provisions* associated with determining design ground motion parameters, together with the associated maps, and referred to the ASCE 7 Standard, which was adopted by reference for the balance of the seismic design criteria. [1]

Starting with the 2009 edition, in recognition of the fact that the codes and standards arena operates differently than it did during previous editions of the Provisions, the PUC began adopting the ASCE 7 Standard as the base document of the provisions by reference, and focused on substantive technical and conceptual modification and improvement of the standard based on recent research and improvements in knowledge. This practice has continued as shown by the following table.

Table 1. ASCE/SEI 7 Adoptions by NEHRP Provisions

Provisions Edition	Reference Standard Adopted for Provisions Development	Standard Affected by Provisions Development
2009	**ASCE/SEI 7-05**	**ASCE/SEI 7-10**
2015	**ASCE/SEI 7-10**	**ASCE/SEI 7-16**
2020	**ASCE/SEI 7-16**	**ASCE/SEI 7-21**

In this manner, the NEHRP Provisions became a technical resource and proving ground for new requirements and consensus engineering practices that are offered for use by the ASCE Standard and the International Building Code. The 2009 and 2015 NEHRP Provisions include (and the 2020 Provisions will include): Part I Provisions for recommended new changes and modifications to the adopted ASCE/SEI 7; Part II with the full ASCE 7 commentary that includes changes based on Part I; and, Part III for resource papers covering new concepts and methods for trial use and other supporting materials for design professionals.

Many significant technical changes related to seismic design were initiated and vetted within PUC and BSSC, which were then codified, balloted and standardized by the ASCE Seismic Subcommittee (SSC) and the ASCE Main Committee to develop the next version of ASCE *Minimum Design Loads for Buildings and Other Structures* and Associated Criteria. This linkage between the two documents has been in place for over a decade and the NEHRP Provisions affects all seismic related chapters (chapters 1, 11 through 22) within ASCE 7 Standard. A graphical summary of this process from start to finish can be seen in Figure 3.

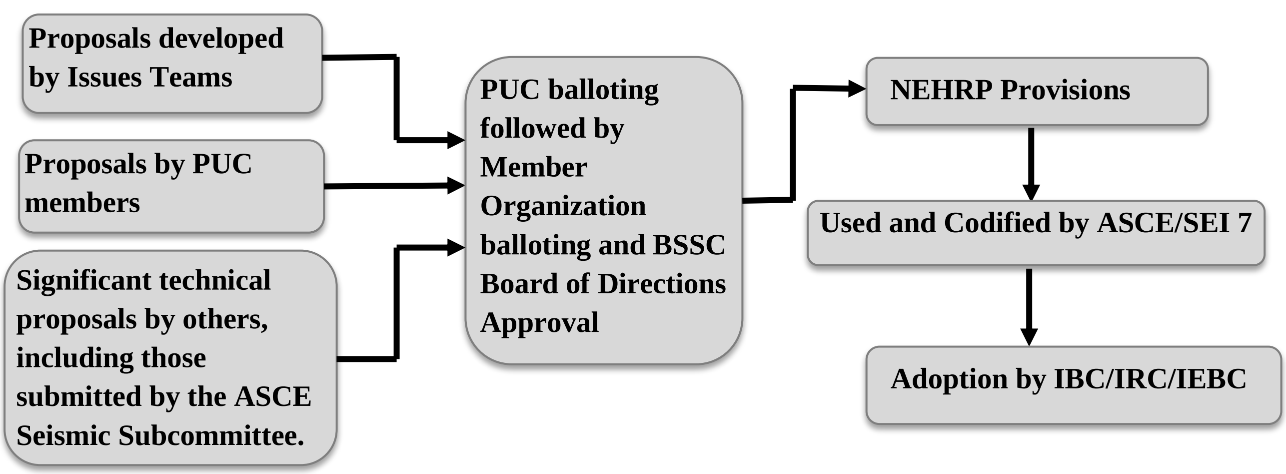

Fig. 3 Process for Developing the NEHRP Provisions and Transitioning to National Standards and Model Building Codes

3. Adoption of ASCE/SEI 7-16 for Developing the 2020 NEHRP Provisions

3.1 General Balloting Procedure

As mentioned above, BSSC adopted ASCE/SEI 7-16 standard as the reference for developing the 2020 NEHRP Provisions for consideration to be adopted in next edition of ASCE/SEI 7 standard. This adoption was accomplished as the first ballot for development of the 2020 NEHRP Provisions in a two- step process, first a ballot by PUC members, then a ballot by the member organizations of BSSC. The BSSC staff conducted the ballots using the newly developed online balloting process that incorporates the BSSC Board of Direction accepted procedures:

> Electronic ballots shall provide four alternatives "Yes," "Yes with Reservations," "No," and "Not Voting." "Yes with Reservations" and "No" votes must be accompanied by an explanation for the vote. A "No" vote must be accompanied by specific suggestions to convert the negative to affirmative. If no comments are provided when required, the vote on that ballot item will not be tallied.
>
> On an electronic ballot, a two thirds (2/3) affirmative ("Yes" and "Yes with Reservations") vote of the "Yes," "Yes with Reservations," and "No" votes received shall be sufficient to record a favorable vote provided at least one half (1/2) of the eligible committee members ballots . . . are returned. If a 50 percent response is not obtained by the closing date, the ballot period may be extended at the discretion of the PUC Chair, and all those eligible to vote will be notified of such an extension.

The PUC met to resolve comments within the ballot according the general procedures which are:

> Following balloting, each comment received on each proposal shall be classified as one of the following:
>
> a. Persuasive (relevant and of such substance as to require incorporation into the proposal),
> b. Nonpersuasive,
> c. Nonresponsive (not consistent with the intent or subject matter of the proposal), or
> d. Editorial/Persuasive (editorial in nature and revisions to be made).
>
> Each proposal proponent or IT shall categorize the ballot comments received on the proposal as indicated above and shall present the categorization to the PUC with recommendations as follows:
>
> a. For comments categorized as "Persuasive," the proposal proponent or IT may recommend to the PUC either that the proposal be substantively revised to respond to the comment and subsequently reballoted or that the issues raised by the comment require further study during the next update.

b. For comments categorized as “Nonpersuasive” or “Nonresponsive,” the proposal proponent or IT will explain the reasoning behind that decision.
c. For comments categorized as “Editorial,” the proposal proponent or IT will identify the specific changes to be made.
d. Substantive technical changes that are conceptually simple may be approved based on a vote of the PUC. Revisions that are complex shall be re-balloted.

The PUC shall vote on each recommended resolution of each “No” (Negative) vote in accordance with the procedures above. All Negatives must be resolved through PUC vote for the proposal to be passed by the PUC. A PUC vote is not required for resolution of comments made in a “Yes with Reservations” vote except where the comment suggests a substantive technical change to the proposal.

If a proposal fails an electronic ballot, it shall not be reconsidered at a PUC meeting without significant revision and a second PUC electronic ballot, unless the PUC votes to proceed with resolution of comments. At a proponent’s request and at the Chair’s discretion, a failed proposal may be discussed for the purpose of providing guidance to the proponent for potential resubmittal.

Then the BSSC Board of Direction will meet to determine that the procedures were appropriately followed and to accept the ballot conducted by the PUC to go for MO balloting. The ballot items accepted by MOs, resolved by the PUC necessary, and approved by BSSC Board will be included in the 2020 NEHRP Provisions.

The PUC and MO first ballots are described in the next two sections.

3.2 Provisions Update Committee (PUC) Ballot

The adoption of ASCE/SEI 7-16 as the basis for 2020 NEHRP Provisions is conducted that ASCE 7-16 is adopted by its entirety rather than chapter by chapter. This allows any major differences between the 2015 Provisions and ASCE 7-16 that PUC wants to retain or further improve to be considered as separate new proposals.

Ballot No. 1: Adoption of ASCE 7-16 as the basis for 2020 NEHRP Provisions

Scope: Review the seismic requirements of ASCE/SEI 7-16 and adopt ASCE/SEI 7-16 as the primary reference standard, with exceptions and modifications, for the 2020 edition of the Provisions.

PUC Online Voting:

- **Period:** July 14, 2017-August 5, 2017
- **Results:** as shown in Table 2 from the Institute online balloting process, sixteen members voted with 14 voting yes and 2 voting yes with reservations. The two “yes with

reservation" votes suggested that an ASCE errata was not incorporated into the first printing of ASCE/SEI 7-16 and should be included for the ballot.

Table 2. PUC Online Voting Results on Adoption of ASCE 7-16 as the Basis for 2020 NEHRP Provisions

Last Name	Vote*	Page #	Line #	Comment	Suggested Change
Bonneville	Y				
Carrato	Y				
Dutta	Y				
Gillengerten	YR	ASCE 7-16 Chapter 13	General	"There is some important errata that was not incorporated into the first printing of the standard. This should be included in the ballot discussion."	"Please review the attached errata, which was submitted to ASCE ."
Hooper	Y				
Lizundia	Y				
Malley	Y				
Manley	Y				
Pekelnicky	Y				
Soules	YR	General – Section 13.1.4 Items 5 and 6	General –Section 13.1.4 Items 5 and 6	"Errata and one approved ballot proposal were left out of Chapter 13 in the first printing of ASCE 7-16."	"The correct wording is shown in the attached files."
Stewart	Y				

*: Y: yes; YR: yes with reservation; N: No; NV: not voting

PUC Meeting, August 29-30, 2017: David Bonneville, the PUC Chair, sent the latest ASCE/SEI 7-16 errata to PUC members before the meeting. The errata was approved by the PUC for inclusion with ASCE/SEI 7-16 to form the basis for 2020 NEHRP *Provisions*. PUC approved the modified ballot 1.

BSSC Board approval, October 24, 2017: The BSSC Board of Direction approved the PUC ballot procedure for Adopting ASCE 7-16 as the basis for 2020 NEHRP Provisions and agreed to proceed to next step, member organization ballot.

3.2 Membership Organization Ballot [results and summary to be included upon MO ballot completion]

- The MO ballot result and PUC resolution of the ballot

- BSSC Board of Direction acceptance of the MO ballot, as resolved as necessary by the PUC, for serving as the reference document for the 2020 NEHRP Provisions

4. Major Differences between 2015 NEHRP Provisions and ASCE/SEI 7-16

The 2015 NEHRP Provisions were developed from 47 proposals submitted, reviewed, and balloted between March 2011 and February 2015. The 2015 NEHRP Provisions recommended many changes to chapters 11 through 22 of ASCE/SEI 7-10: [2]

- Revisions, replacements and additions to Chapters 11, 12, 14, 15, 21 and 22.
- Complete replacement of Chapters 16, 17, 18 and 19.
- A minor modification to Chapter 1.
- The addition of Chapter 24.

For information on specific changes in Part 1 of the Provisions, Table 3 below provides the topics of the approved change proposals along with their relevant section numbers and commentary section numbers of ASCE/SEI 7-10.

Except for Chapter 24, which was not accepted by the ASCE Seismic Subcommittee for inclusion in ASCE 7-16, most of the changes proposed by the 2015 NEHRP Provisions were accepted and used in ASCE/SEI 7-16, which was then adopted by reference by the International Building Codes (IBC) 2018. Some of the changes were modified for code language by Seismic Subcommittee (SSC) of ASCE 7. Important changes in Chapters 11, 12, 16, 19, and 21 are summarized in this section based on presentations made at the August 29-30, 2017 PUC meeting by the proposal proponents from the 2015 cycle. The presentations are included in the Appendix.

Table 3. 2015 NEHRP Provisions Change Proposals and Their Relevant Section Numbers and Commentary Section Numbers of ASCE/SEI 7-10

Topics of change proposals	**Related or new sections of ASCE/SEI 7**	**Related commentary sections**
Intent of the Provisions	Section 1.1 (this applies to the 2015 Provisions only)	2.1
Adoption of ASCE/SEI 7-10 Chapters 11-23, Supplement No. 1 and the Expanded Commentary for the 2015 Provisions	All sections of Chapters 11-23 in ASCE/SEI 7-10 without exception	All sections of C11-C22
Revised site coefficients F_a, F_v, and F_{PGA} for MCE_R spectral response and maximum considered geo-mean peak ground acceleration PGA_M	Sections 11.4.2, 11.4.3, and 11.8.3	C11.4, C11.4.2, C11.4.3 C11.8
Site-specific ground motion procedures for certain structures on site classes D and E	Sections 11.4.7, and 21.4	C11.4.7 C21.4
Limit S_{MS} not less than S_{M1}	Section 11.4.3	C11.4.3
Adoption of FEMA P-695 methodology for qualification of alternative new seismic resistant systems	Section 12.2.1, 12.2.1.1	C12.2.1.1
Adoption of FEMA P-795 methodology for equivalence of substitute components	Section 12.2.1.2	C12.2.1.2
Strength-based design of foundations	Sections 1.2,12.1.5, 12.7, and 12.13.1-7	C12.13.1, 5-7
Requirements for using maximum S_s value in determination of C_s	Sections 12.8.1.3	C12.8.1.3

Topics of change proposals	Related or new sections of ASCE/SEI 7	Related commentary sections
Accidental Torsion	Section 12.8.4.2	C12.8.4.2
Modal analysis procedure in scaling design values of combined response, 3D structural modeling and linear modal response history analysis	Section 12.9.1 Section 12.9.4 Section 12.9.8 Section 12.9.2	C12.9.1 C12.9.3 C12.9.4 C12.9.8 C12.9.2
Requirements for structure foundations on liquefiable sites	Section 12.13.8	C12.13.8
Revision to section 12.14 Simplified Alternative Seismic Design Criteria	Section 12.14.1	C12.14.1
A new alternative diaphragm design procedure and diaphragm design force reduction factor R_s Diaphragm design procedure mandatory for pre-cast concrete diaphragm in SDC D, E and F, optional for other concrete and wood sheathing diaphragms	Sections 11.2, 11.3, 12.3.1.3, 12.10, and 12.10.3 Sections 11.3, 14.2.2.1, and 14.2.4,	C11.2, C11.3, C12.3.1.3, C12.10, and C12.10.3 C14.2.2.1, C14.2.4
Adoption of ASCE/SEI 7-10 Supplement No. 2, deletion of the line item on tanks and vessels supported on other structures or towers in Table 15.4	Section 15.4.1	C15.4.1
Chapter 16 Seismic Response History Procedure	Sections All listed sections of Chapter 16, 11.4.7, and 12.4.2.2	C16, C11.4.7
Chapter 17 Seismic Design Requirements for Seismically Isolated Structures	All listed sections of Chapter 17	C17
Steel ordinary concentrically braced frames (OCBF) used in isolated structures in SDC D, E and F Steel grid frames at base level of isolated structures	Section 17.2.5.4 Section 17.2.4.9	C17.2.5.4
Chapter 18 Seismic Design Requirements for Structures with Damping Systems	All listed sections of Chapter 18	C18
Chapter 19 Soil-Structure Interaction for Seismic Design	All listed sections of Chapter 19	C19
Seismic design ground motion maps for Guam and America Samoa Seismic design ground motion maps based-on the 2014 USGS seismic hazard maps	Chapter 22 Introduction and Figures 22-7, 22-8 and 22-13 Chapter 22 Figures 22-1, 22-2, 22-9, 22-18, 22-19	C22
Chapter 23, Vertical Ground Motions for Seismic Design (retained from 2009 NEHRP Provisions)	All sections of Chapter 23A	C23A
New Chapter 24 Alternative Seismic Design Requirements for SDC B Buildings	All sections of new Chapter 24	All sections of C24

4.1 Major Differences in Ground Motion, Site Specific Procedure

Design ground motion is one of the primary factors used to determine the required seismic resistance (strength) of structures and supported nonstructural components. Design ground motion is defined by an acceleration response spectrum and characterized by the following parameters:

$$S_{DS} = 2/3 \times F_a \times S_s$$
$$S_{D1} = 2/3 \times F_v \times S_1$$

Where S_{DS} and S_{D1} are the design earthquake spectral response acceleration parameters at short period and at 1-second period, respectively. S_s and S_1 are the USGS mapped values of MCE_R spectra accelerations for reference soil conditions. F_a and F_v are coefficients related to Site Class that indicate, respectively, the relative amplification or attenuation effects of site soils on short-period and long-period ground shaking energy.

The 2015 NEHRP Provisions contain updated values for the F_a and F_v coefficients (Tables 11.4-1 and 11.4-2). These coefficients were originally developed in the 1990s based primarily on recorded motions from the 1989 Loma Prieta Earthquake. Studies at the Pacific Earthquake Engineering Research Center considered shaking data from more recent earthquakes and combined this information with models of site nonlinearity to derive new coefficients. In general, the values for F_a and F_v are now somewhere between 80% and 120% of their previously tabulated values. [3] ASCE/SEI 7-16 adopted the new site coefficient values in the 2015 NEHRP Provisions, with the exception that for Site Class E when S_1 is equal to or greater than 0.2 s, ASCE/SEI 7-16 refers to site specific analysis instead of providing values (see Table 4). At the time of this writing, the ASCE 7 Seismic Subcommittee is considering providing these values as found in the 2015 NEHRP Provisions in a supplement of ASCE/SEI 7-16.

Table 4. Long-Period Site Coefficient, F_v, 2015 NEHRP Provisions and ASCE/SEI 7-16

	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at 1-s Period					
Site Class	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 = 0.5$	$S_1 \geq 0.6$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.8	0.8	0.8	0.8	0.8	0.8
C	1.5	1.5	1.5	1.5	1.5	1.4
D	2.4	2.2[1]	2.0[1]	1.9[1]	1.8[1]	1.7[1]
E	4.2	3.3[1] (ASCE 7-16: See Section 11.4.8)	2.8[1] (ASCE 7-16: See Section 11.4.8)	2.4[1] (ASCE 7-16: See Section 11.4.8)	2.2[1] (ASCE 7-16: See Section 11.4.8)	2.0[1] (ASCE 7-16: See Section 11.4.8)
F	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8

Note: [1] Also, see requirements for site-specific ground motions in Section 11.4.8.

In seismic design, the three-domain design spectrum (constant response acceleration, velocity and displacement) is used to define ELF (Equivalent Lateral Force Procedure) (and MRSA - Modal Response Spectrum Procedure) design forces. The three-domain design spectrum is derived from three seismic design maps values: the short period and 1-second period spectral values, S_S and S_1; and the constant displacement transition period, T_L. Late in the 2015 NEHRP Provisions update cycle, it was found that the traditional three-domain design derived from these parameters did not adequately address ground motion demands for sites on soft soils that are dominated by large magnitude events. For such sites, it was found that the spectral demands could be significantly underestimated at periods greater than 1-second, and could be overestimated at short periods.[3,5] Ideally, for such sites, the design spectral shape would be defined by a multi-period spectrum covering a full range of periods. However, due to time constraints, it was not possible to implement such a revision in the last cycle. The 2015 Provisions adopted the new site-specific requirements of Section 11.4.7 in lieu of a more comprehensive approach to add new "spectrum shape adjustment" factors, C_a and C_v, to the equations of Section 11.4 that would define values of SM_S and $SM_{1.}$ More details can be found in the paper written by Kircher[5]. The new site-specific analysis requirements of Section 11.4.7 necessitated changes to the site-specific analysis methods of Chapter 21. While the 2015 NEHRP Provisions included changes in the Section 21.4 requirements for determining values of SD_S and SD_1 from a site-specific design spectrum, but the Provisions missed the changes under section 21.2.2 requirements defining the deterministic lower limit on the MCE_R response spectrum, and Section 21.3 requirements establishing the 80 percent lower-bound limit on site-specific design spectrum. ASCE/SEI 7-16 included the changes in Section 21.4 proposed in the 2015 NEHRP Provisions, and picked up the last-minute changes under Sections 21.2.2 and 21.3.

In the 2020 Provisions cycle, the multi-period spectrum issue is being addressed through Project 17.

4.2 Major Differences in Diaphragm Design

Diaphragms are generally treated as horizontal deep beams or trusses that distribute lateral forces to the vertical elements of a seismic force-resisting system. As deep beams, diaphragms must be designed to resist the resultant shear and bending stresses. Diaphragms are commonly compared to girders, with the roof or floor deck analogous to the girder web in resisting shear, and the boundary elements (chords) analogous to the flanges of the girder in resisting flexural tension and compression. As in girder design, the chord members (flanges) must be sufficiently connected to the body of the diaphragm (web) to prevent separation and to force the diaphragm to work as a single unit.[2] The diaphragm provisions in ASCE/SEI 7-10 (and previous editions) take an elastic design approach for diaphragm elements, basing the forces on a multiple of the floor force calculated using the Equivalent Lateral Force (ELF) procedure. This has historically resulted in generally acceptable seismic diaphragm performance for most building configurations and diaphragm material types. However, during the 2015 cycle, studies had shown that the actual force levels imposed on diaphragms during ground shaking could be significantly higher than those currently prescribed in the code, particularly when diaphragm response is near-elastic. The effects of higher modes than the first mode were found to contribute significantly to diaphragm response, and these findings prompted an investigation into the entire process of diaphragm design.[3]

Based on experimental and analytical data and observations of building performance in past earthquakes, the 2015 Provisions contained new equations that generally yield larger design forces in diaphragm design. Since diaphragms designed with the current procedure are generally well-behaving, though, the capacity side of diaphragm design was also addressed, which is related to material-specific factors that are related to overstrength and deformation capacity. In short, demands were previously underestimated but were also assessed against unrealistically limited elastic capacities. The new procedure, despite its higher calculated demands, yields a similar final design because of the additional consideration of diaphragm ductility. It should be noted that for diaphragms constructed of most materials (wood sheathing, metal deck, etc.), the 2015 NEHRP provisions only provide an improved understanding of seismic diaphragm behavior, but the new procedure is more critical for precast concrete diaphragms. Tests show that, compared to other systems, precast concrete diaphragms have limited ductility; more specifically, the long diaphragm spans that precast diaphragms lend themselves to cause relatively low performance of the system. In essence, the new diaphragm design procedure in the 2015 NEHRP Provisions, which was adopted by ASCE/SEI 7-16 in Section 12.10.3, is being mandated for precast concrete diaphragms in buildings assigned to SDC (Seismic Design Category) C, D, E, or F and are being offered as an alternative to Sections 12.10.1 and 12.10.2 for other precast concrete diaphragms, cast-in-place concrete diaphragms, and wood-sheathed diaphragms supported by wood framing. [2,3,4]

It should be noted that alternative diaphragm design for steel deck diaphragms, for which it is believed that more research is needed and is currently one of the topics under the 2020 NEHRP Provisions cycle, is included as a Part 3 resource paper in 2015 NEHRP Provisions and is not included in ASCE/SEI 7-16. Some other minor adjustments of the design parameters are made in ASCE/SEI 7-16, such as for seismic force for diaphragms, including chords, collectors, and their connections to vertical elements.

In the 2015 NEHRP Provisions**,** C_{p0} is constant up to 80% height of the building, while in ASCE/SEI 7-16, where C_{p0} is not constant up to 80% height of the building, parameter C_{pi} is used. And while there is no lower-bound limit on C_{pn} in the 2015 NEHRP *Provisions,* ASCE/SEI 7-16 has a lower bound limit of $C_{pi.}$

4.3 Major Differences in Non-Linear Response Analysis

Response history analysis (RHA) is a form of dynamic analysis in which the response of a structure to a suite of ground motions is evaluated through numerical integration of the equations of motions. In nonlinear response history analysis, the structure's stiffness matrix is modified throughout the analysis to account for the changes in element stiffness associated with hysteretic behavior and P-delta effects. When nonlinear response history analysis is performed, the R , C_d , and Ω_0 coefficients considered in linear procedures are not applied because the nonlinear analysis directly accounts for the effects represented by these coefficients.[2]

Nonlinear response history analysis is permitted to be performed as part of the design of any structure and is specifically required to be performed for the design of certain structures incorporating seismic base isolation or energy dissipation systems. Nonlinear response history analysis is also frequently used for the design of structures that use alternative structural systems, or do not fully comply with the prescriptive requirements of the standard in one or more ways.[2]

Before this edition, ASCE 7 specified that nonlinear response history analyses be performed using ground motions scaled to the design earthquake level, and that design acceptance checks be performed to ensure that mean element actions do not exceed two-thirds of the deformations at which loss of gravity-load-carrying capacity would occur.[2] The PUC judged that these requirements lacked specificity in many areas, leading to inconsistencies in interpretation. In 2015 NEHRP Provisions, a complete reformulation of these requirements was undertaken to require analysis at the Risk-Targeted Maximum Considered Earthquake (MCE_R) level, and to be more consistent with the target reliabilities indicated in Section 1.3.1.3.[3]

The procedure in the 2015 NEHRP Provisions is intended to provide buildings with equivalent or better seismic performance compared to designs using the ASCE Chapter 12 procedures. It includes a code-level evaluation of the building using either the Equivalent Lateral Force (ELF) Procedure or the Modal Response Spectrum Analysis (MRSA) Procedure for the purpose of assuring that the structure designed using the RHA provisions will be equivalent in terms of strength (though not necessarily displacement). The nonlinear analysis is then performed to demonstrate that the structure has predictable and stable response under MCE_R level ground shaking and to determine forces for force-controlled components. Service-level evaluation (to address for example Risk Category IV buildings) is not required because ground motion for such analysis is not provided by Chapters 11 and 12.[2.3]

Prior to the 2015 NEHRP Provisions, ASCE 7 specified that nonlinear response history analyses be performed using ground motions scaled to the design earthquake level. In the 2015 NEHRP Provisions, the level of ground motion is defined by target response spectra that might be derived from either the MCE_R spectrum determined in accordance with Chapter 11 or Chapter 21, which conservatively envelopes the results of seismic hazard analysis for each period, or a Conditional Mean Spectrum, in which the spectrum is calculated based on a spectral acceleration at an appropriate period and the mean of spectral acceleration values at other periods. This conditional calculation ensures that the resulting spectrum is reasonably likely to occur and that ground motions selected to match the spectrum have an appropriate spectral shape consistent with naturally occurring ground motions at the site of interest. The procedure requires eleven ground motions (versus minimum of three ground motions in ASCE/SEI 7-10) representing near-field (if appropriate) and far field sites. The procedure specifies the lower bound (0.2T) and upper bound (generally 2.0T) period range for ground motions to be scaled to so that they are representative of the site specific MCE_R spectrum. [2.3]

Modeling requirements in the 2015 NEHRP Provisions are given with the intent of reasonably capturing the spatial and temporal distributions of inelasticity. Three-dimensional analysis is required for the final analysis and requirements are specified for realistically addressing gravity loading, P-delta effects and diaphragm modeling to cover the range of expected stiffness. Inherent torsion is addressed through the modeling requirements in a manner similar to that given in Chapter 12 and accidental torsion is not required to be explicitly modeled (a rigorously debated issue), though the commentary provides recommendations for addressing buildings likely to perform in a highly torsional manner. [2.3]

Acceptance criteria are expressed in terms of global response in which unacceptable performance is defined based on possible collapse, story drift, non-convergence, deformation-controlled response and force-based demands for brittle components; and, element-level response, considering both deformation and force-controlled actions. A big focus of the chapter in the 2015 NEHRP Provisions is to develop acceptance criteria more clearly tied to risk targeted goals as those used in Chapter 12.[2.3]

Design review is required for all structures designed in accordance with the RHA procedure. The review is required to be performed by one or more professionals with expertise in ground motion selection and scaling, analytical modeling and structural system behavior. [2.3]

While ASCE/SEI 7-16 adopted almost all changes and made some language more specific and more standard-like, there is one major difference under Section 16. 3 Modeling and Analysis for Torsion: the 2015 Provisions leave this to the linear design step, but the ASCE/SEI 7-16 allows linear design step if no Type 1a/1b irregularity exists, otherwise requiring mass offsets in the non-linear model. Some other minor tweaks by ASCE/SEI 7-16 include: for near-fault verse far-field ground motions (under section 16.2), the Provisions left this fairly non-prescriptive while ASCE/SEI 7-16 added specificity in Chapter 11 (near-fault is $R < 15$km if $M > 7.0$ and $R < 10$km if $7.0 > M > 6.5$); for orientation of ground motions in far-field, the Provisions applied pairs of records with “random orientation”, while ASCE/SEI 7-16 added a more specific +/- 10% requirement (Section 16.2.4, “each pair of horizontal ground motion components shall be applied to the building at orthogonal orientations such that the average (or mean) of the component response spectrum for the records applied in each direction is within +/- 10% of the mean of the component response spectra of all records applied for the period range specified in Section 16.2.3.1).

4.4 Soil Structure Interaction

In an earthquake, the shaking is transmitted up through the structure from the geologic media underlying and surrounding the foundation. The response of a structure to earthquake shaking is affected by interactions among three linked systems: the structure, the foundation, and the geologic media underlying and surrounding the foundation. In a seismic analysis, it is typically assumed that structures have a fix base at the foundation-soil interface and the forces that are applied to the structure are devised based on parameters representing free-field ground motions. The term “free-field” refers to motions not affected by structural vibrations or the foundation characteristics of the specific structure. The Soil Structure Interaction (SSI) provisions are intended to allow a more complete and accurate analysis of the combined system including structure, foundation and underlying soil/rock[2].

The 2015 NEHRP Provisions provide a complete revision to the ASCE 7-10 Chapter 19 SSI requirements, and allow the designer to account for foundation deformations, inertial effects and kinematic effects. Substantial revisions have been made to Chapter 19 in ASCE 7-16. They include (1) the introduction of formulas for the stiffness and damping of rectangular foundations, (2) revisions to the formulas for the reduction of base shear caused by SSI, (3) reformulation of the effective damping ratio of the SSI system, (4) introduction of an effective period lengthening ratio, which appears in the formula for the effective damping ratio of the SSI system, and which depends on the expected structural ductility demand, and, (5) the introduction of kinematic SSI provisions. Most of these revisions are based on the NIST GCR 12-917-21 (NIST 2012) report of a recent NEHRP research project at Applied Technology Council (ATC) on SSI.

ASCE/SEI 7-16 adopted Chapter 19 of the 2015 NEHRP Provisions with one change: The Provisions permitted more aggressive reductions in kinematic soil structure interaction if SSI analysis is peer reviewed, and ASCE/SEI 7-16 did not allow the peer-review-based reduction.

4.5 Summary of other differences

In recent years, engineers and building officials have become concerned that the seismic design requirements for Seismic Design Category (SDC) B are complex and are difficult to implement. The 2015 NEHRP Provisions contain a new chapter, Chapter 24, that is a simplified, alternate seismic design procedure for structures in Seismic Design Category (SDC) B. A structure in SDC B designed using 2015 Provisions Chapter 24 is essentially equivalent to a design using ASCE 7-10 Chapter 12, but the engineer has the convenience of a much simpler, more transparent, and easy to follow design requirement document to work with. For example, Chapter 24 does not contain the “special” lateral force resisting systems, removes T_L from the calculation for the base shear coefficient, and only contains Chapter 13 requirements for parapet and hazardous materials provisions.[3]

While Chapter 24 will produce the same design as following other chapters in ASCE/SEI 7-10, with concerns that this will further increase the already large volume size of ASCE/SEI 7, it was not included in the ASCE/SEI 7-16. Chapter 24 was subsequently updated to be compatible with the latest ASCE/SEI 7-16 and is published as a standalone FEMA NEHRP technical resource document (FEMA P-1091).

5. Concluding Remarks

This report, prepared during the 2020 NEHRP Provisions development cycle, presents some important background on the NEHRP Provisions development process and summarizes the results of the first ballot in the 2020 development cycle to adopt ASCE/SEI 7-16 as the primary reference document for the Provisions. Parallel to the PUC, Member Organizations, and BSSC Board of Direction approving the adoption of ASCE/SEI 7-16 for the 2020 cycle, the PUC has been and will be working a wide range of topics that will result in proposals to improve the current ASCE/SEI 7-16 standard. The topics being considered include (1) seismic performance objective evaluation; (2) seismic force resisting systems and design coefficients; (3) modification of existing modal response spectrum method; (4) shear wall design; (5) nonstructural components; (6) nonbuilding structures; (7) soil-foundation interaction; (8) base isolation and energy dissipation; (9) diaphragm issues – RWFD (rigid wall flexible diaphragms) and alternative diaphragm design provisions; (10) and seismic design value map related topics and design procedures, which will be initiated from Project 17.

With the NEHRP Provisions as its basis, BSSC has also engaged in a series of outreach efforts to educate the engineers, the disaster community, and the general public, which include live webinars, online training courses, workshops, special BSSC sessions at national conventions, and conference papers and presentations.

The NEHRP Provisions have successfully advanced the seismic design and analysis in the building industry and enhanced public safety against earthquake disasters in the past 40 years. The success of the NEHRP Provisions is due to the continuous support from the National Earthquake Hazards Reduction Program and its four designated agencies (NIST, USGS, NSF and FEMA), especially the Federal Emergency Management Agency (FEMA). More importantly, thanks to the engagement and effort from numerous subject-matter experts under the Provisions Update Committee, Project 17 Committee, organizational members, and many other support committees under BSSC. The list of experts involved in the present cycle, the latest development on the above mentioned topics, and new training and outreach efforts by BSSC can be found on the BSSC website: http://www.nibs.org/?page=bssc.

6. References

(1) Building Seismic Safety Council (BSSC), 2017. *Proceeding of Project 17 Workshop on Seismic Hazard Mapping*, Washington, DC. http://c.ymcdn.com/sites/www.nibs.org/resource/resmgr/bssc2/20170411P17WorkshopProceedin.pdf,

(2) Building Seismic Safety Council (BSSC), 2015. *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*, (FEMA P-1050), prepared for the Federal Emergency Management Agency, Washington, DC

(3) Bonneville, D. and Shuck A, 2014. An Introduction to the 2015 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures, *Proceedings*, 10*th* *U.S. National Conference on Earthquake Engineering*, Anchorage, Alaska.

(4) American Society of Civil Engineers (ASCE), 2016, *Minimum Design Loads for Buildings and Other Structures*, (ASCE/SEI 7-16), ASCE, Reston, Virginia.

(5) Kircher, C. New Site-Specific Ground Motion Requirements of ASCE 7-16, *Proceedings, 2017 SEAOC Convention*, San Diego, CA

7. Appendix – Presentations on Major Differences between ASCE/SEI 7-16 and the 2015 NEHRP Provisions

2015 *Provisions* – ASCE/SEI 7-16 Comparisons: Chapter 12 Diaphragms

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Alternative ASCE 7-16 Force Level for Seismic Design of Diaphragms

Diaphragms, Chords, and Collectors

12.10.1.1 Diaphragm Design Forces. Floor and roof diaphragms shall be designed to resist design seismic forces from the structural analysis, but not less than the following forces:

$$0.2S_{DS}Iw_{px} \le F_{px} = \frac{\sum_{i=x}^{n} F_i}{\sum_{i=x}^{n} w_i} w_{px} \le 0.4S_{DS}Iw_{px}$$

Where

F_{px} = the diaphragm design force
F_i = the design force applied to Level i

w_i = the weight tributary to Level i
w_{px} = the weight tributary to the diaphragm at Level x

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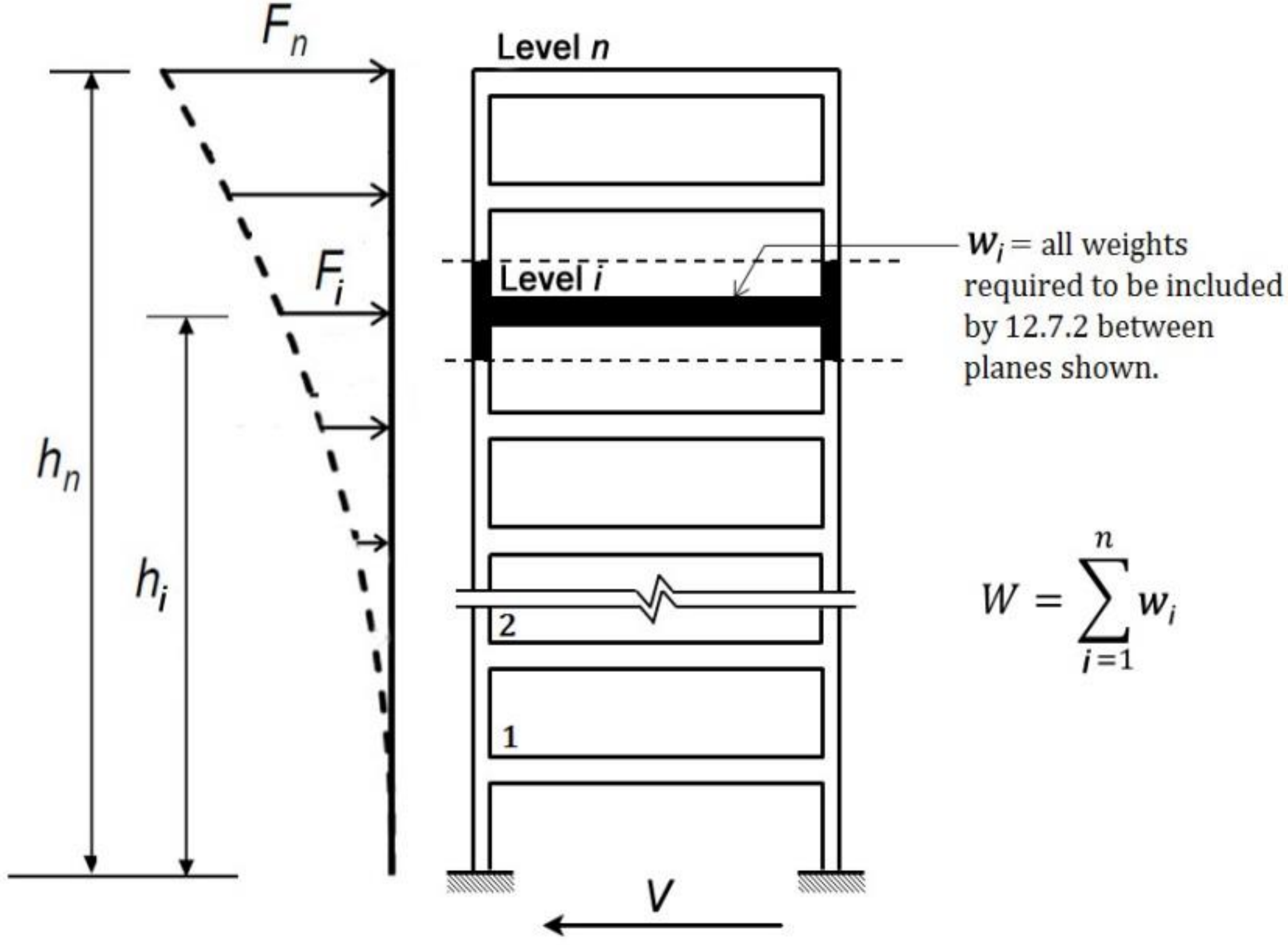
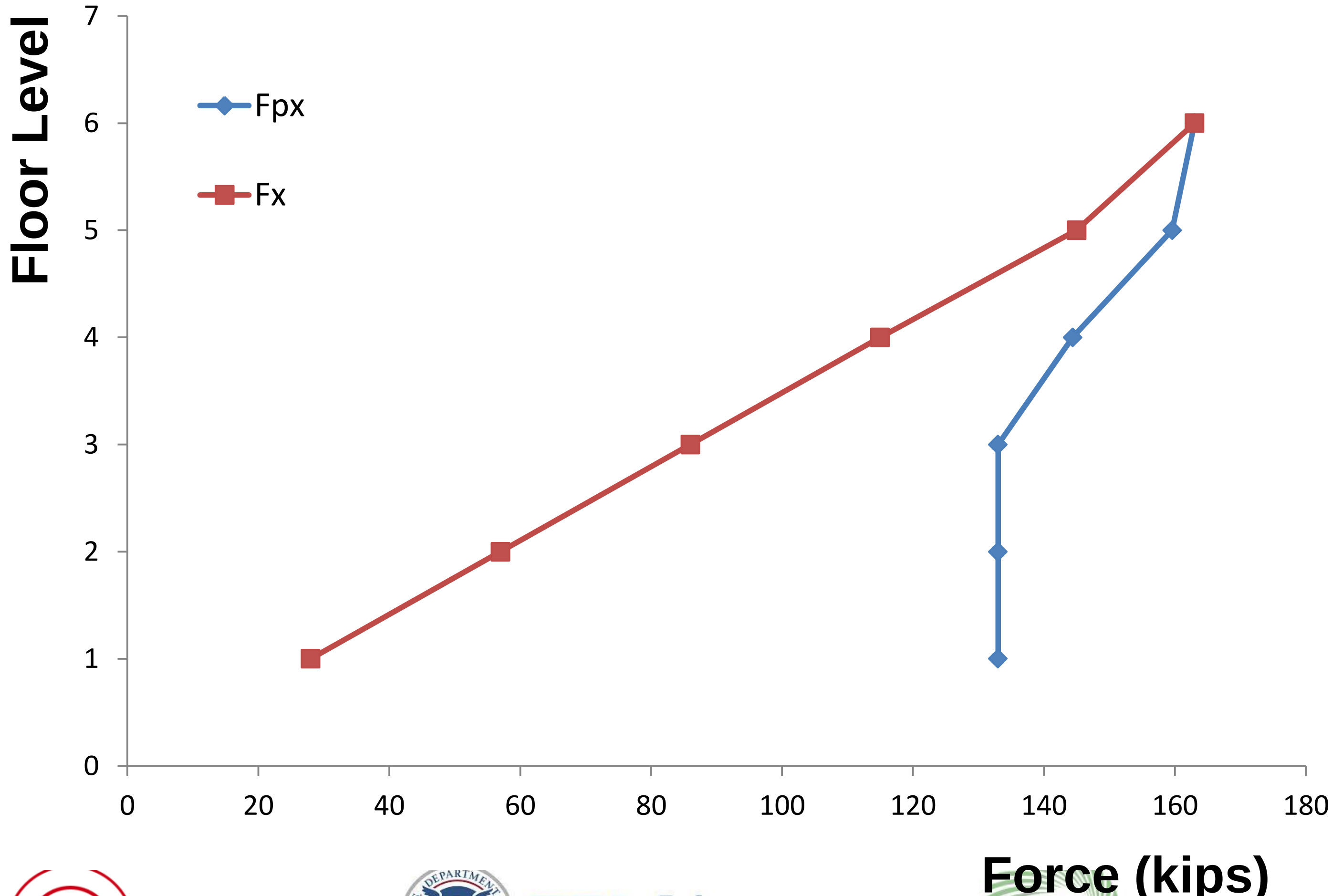
Diaphragms, Chords, and Collectors



Diaphragm Design Forces



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Diaphragm IT Products

- Design Force Level Proposal for Part 1 of the 2015 NEHRP *Provisions* – modifies ASCE 7-10 Section 12.10 Included in ASCE 7-16
- Design Force Level Proposal for Part 3 of the 2015 NEHRP *Provisions* – modifies ASCE 7-10 Section 12.10
- Precast Diaphragm Design Proposal for Part 1 of the 2015 NEHRP Provisions – modifies ASCE 7-10 Section 14.2 Included in ASCE 7-16
- Resource Paper for Part 3 of the 2015 NEHRP *Provisions*

2015 NEHRP Provisions

NEHRP Recommended Seismic Provisions for New Buildings and Other Structures

Volume I: Part 1 Provisions, Part 2 Commentary

FEMA P-1050-1/2015 Edition

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NEHRP Recommended Seismic Provisions for New Buildings and Other Structures

Volume II: Part 3 Resource Papers

FEMA P-1050-2/2015 Edition

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Diaphragm Design

In 2001 Rodriguez et al. noted that inelastic response in multi-story buildings tended to cause an important reduction in floor accelerations contributed by the first mode of response but had a much lesser effect on those contributed by the higher modes of response.

They proposed the *First Mode Reduced* method, in which the roof acceleration could be determined by a square root sum of the squares combination in which the first mode contribution was reduced for inelasticity and the higher modes were left unreduced.

Diaphragm Design

$$F_{px} = C_{px}w_{px}/R_s$$

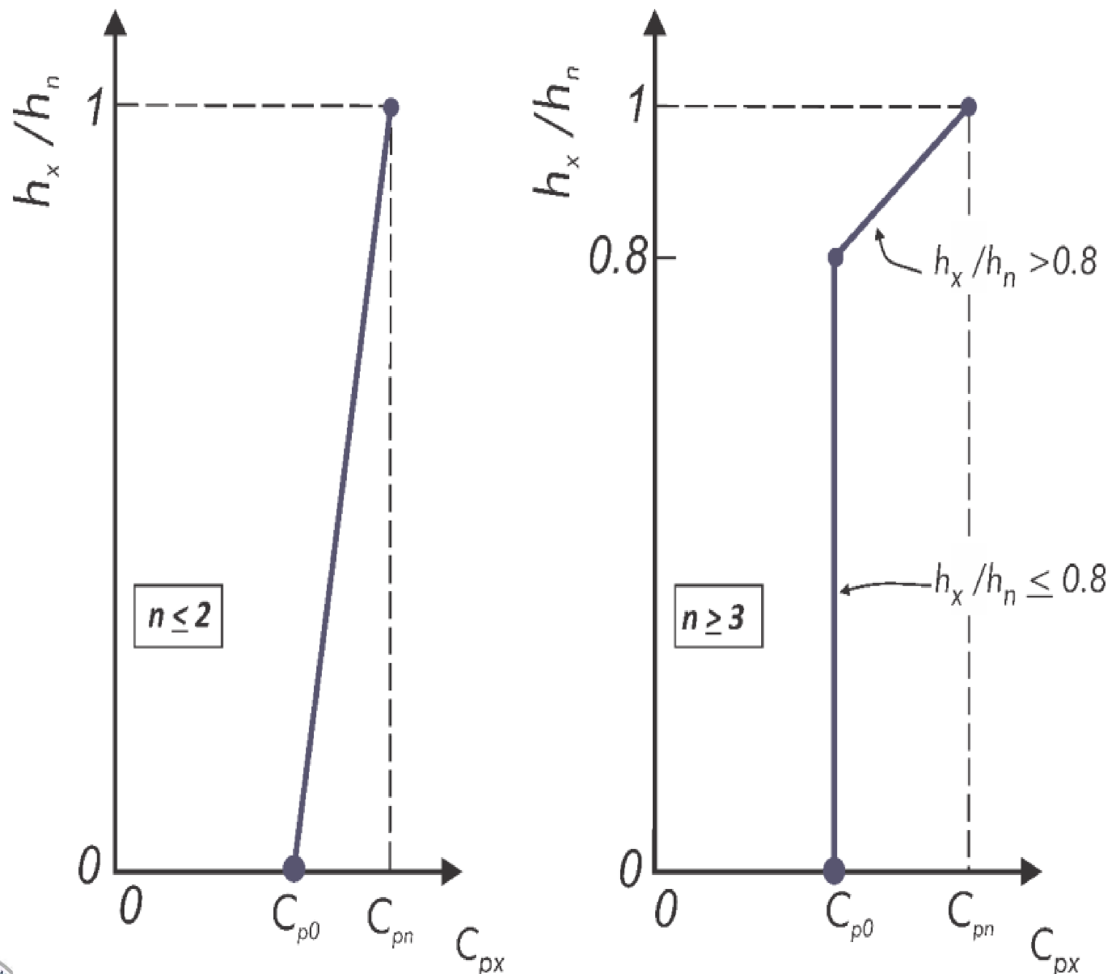
$$\geq 0.2S_{DS}\, I_e\, w_{px}$$

C_{px} comes from C_{p0}, C_{pi}, and C_{pn}

Note: C_{pi} is not used in the 2015 NEHRP *Provisions*

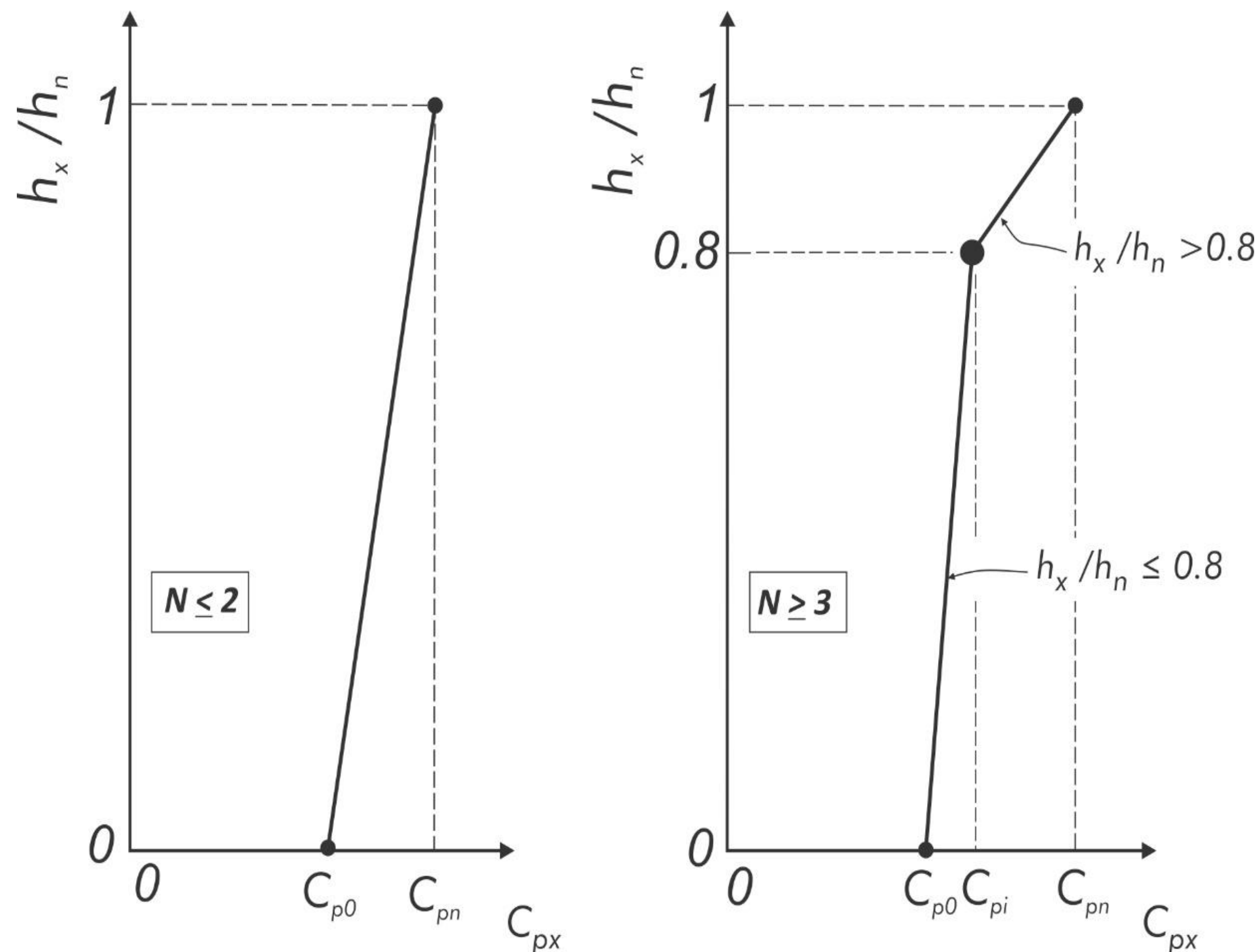
Diaphragm Design

2015 NEHRP
Provisions



Diaphragm Design

ASCE 7-16



Diaphragm Design

$$C_{p0} = 0.4\, S_{DS}\, I_e$$

$$C_{pn} = \sqrt{(\Gamma_{m1}\Omega_0 C_S)^2 + (\Gamma_{m2} C_{S2})^2} \geq C_{pi}$$

Note: The lower-bound limit on C_{pn} is in ASCE 7-16 only, not in the 2015 NEHRP *Provisions*.

Diaphragm Design

- $\Gamma_{m1} = 1 + 0.5z_s\,(1 - 1/N)$
- $\Gamma_{m2} = 0.9z_s\,(1 - 1/N)^2$

where z_s = modal contribution coefficient modifier dependent on seismic force-resisting system.

Diaphragm Design

<u>Values of mode shape factor z_s</u>

- 0.3 for buildings designed with Buckling Restrained Braced Frame systems
- 0.7 for buildings designed with Moment-Resisting Frame systems
- 0.85 for buildings designed with Dual Systems with Special or Intermediate Moment Frames capable of resisting at least 25% of the prescribed seismic forces
- 1.0 for buildings designed with all other seismic force-resisting systems

Diaphragm Design

C_{pi} is the greater of values given by:

$C_{pi} = C_{p0}$

$C_{pi} = 0.9\,\Gamma_{m1}\Omega_0 C_S$

Diaphragm Design

$C_S = V/W$ or V_t/W

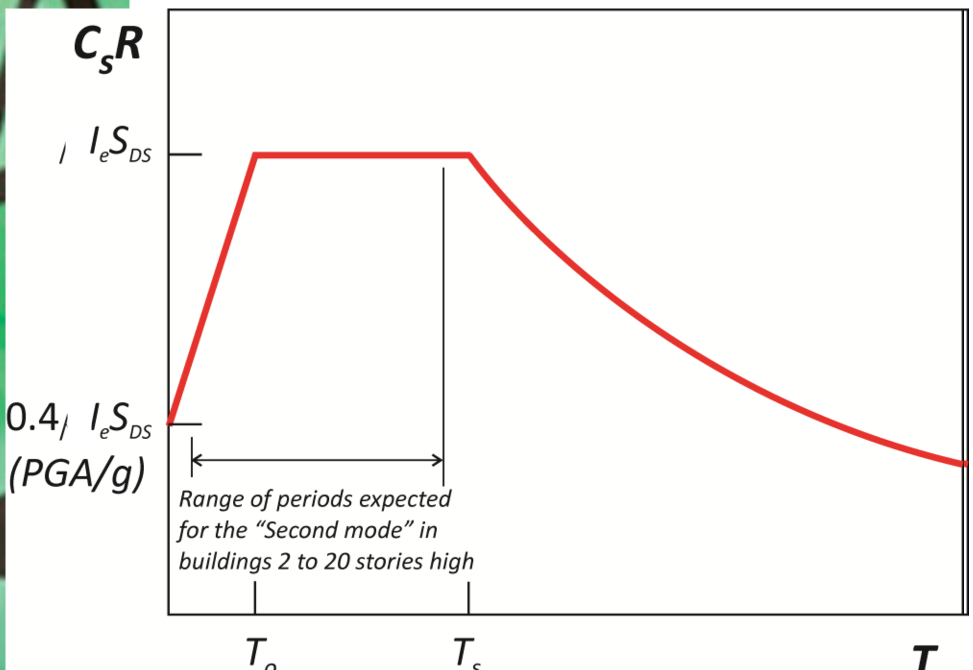
C_{S2} = minimum of:

$(0.15N + 0.25)\, I_e S_{DS}$

$I_e S_{DS}$

$I_e S_{D1}/[0.03(N - 1)]$ for $N \geq 2$ or 0 for $N = 1$

Consistent Look into the Design Spectra C_sR



For the "Second mode", R = 1

$$C_S(T_2) = \min(0.15N+0.25,\ 1)I_eS_{DS}$$

$$\leq I_eS_{D1} / [0.03(N-1)]$$

N: number of levels above ground, $N \geq 2$

Diaphragm Capacity

Why are we not seeing inadequate performance of diaphragms in seismic events?

Diaphragm design force reduction factor, R_s, To account for ductility and overstrength in the Diaphragm.

Diaphragm Design

Flexure-controlled diaphragm: Diaphragm with a well-defined flexural yielding mechanism, which limits the force that develops in the diaphragm.

The factored shear resistance shall be greater than the shear corresponding to flexural yielding.

Diaphragm Design

Shear-controlled diaphragm: Diaphragm that does not meet the requirements of a flexure-controlled diaphragm.

Diaphragm Design (NEHRP *Provisions* – Part 1*)*

Diaphragm Design Force Reduction Factor, R_s

Diaphragm System	Shear-Controlled	Flexure-Controlled
Cast-in-place concrete designed in accordance with ACI 318	1.5	2
Precast concrete designed in accordance with Section 14.2.4 and ACI 318, EDO	0.7	0.7
Precast concrete designed in accordance with Section 14.2.4 and ACI 318, BDO	1.0	1.0
Precast concrete designed in accordance with Section 14.2.4 and ACI 318, RDO	1.4	1.4
Wood sheathed designed in accordance with AF&PA (now AWC) Special Design Provisions for Wind and Seismic	3.0	NA

Diaphragm Design (NEHRP *Provisions* – Part 3)

Diaphragm Design Force Reduction Factor, R_s

Diaphragm System		Shear-Controlled	Flexure-Controlled
Untopped steel deck designed in accordance with AISI S100 or SDI RD	-	2.0	NA
Topped steel deck designed in accordance with AISI S100 or SDI C and SDI NC	Reinforced topped steel deck with shear stud connection to framing	2.0	2.5
	Other topped steel deck with structural concrete fill	1.5	2.0
Wood sheathed designed in accordance with AISI S213	-	2.0	NA

Diaphragm Design (ASCE 7-16)

Diaphragm System		Shear-Controlled	Flexure-Controlled
Cast-in-place concrete designed in accordance with Section 14.2 and ACI 318	-	1.5	2
Precast concrete designed in accordance with Section 14.2.4 and ACI 318	EDO [1]	0.7	0.7
	BDO [2]	1.0	1.0
	RDO [3]	1.4	1.4
Wood sheathed designed in accordance with Section 14.5 and AF&PA (now AWC) *Special Design Provisions for Wind and Seismic*	-	3.0	NA

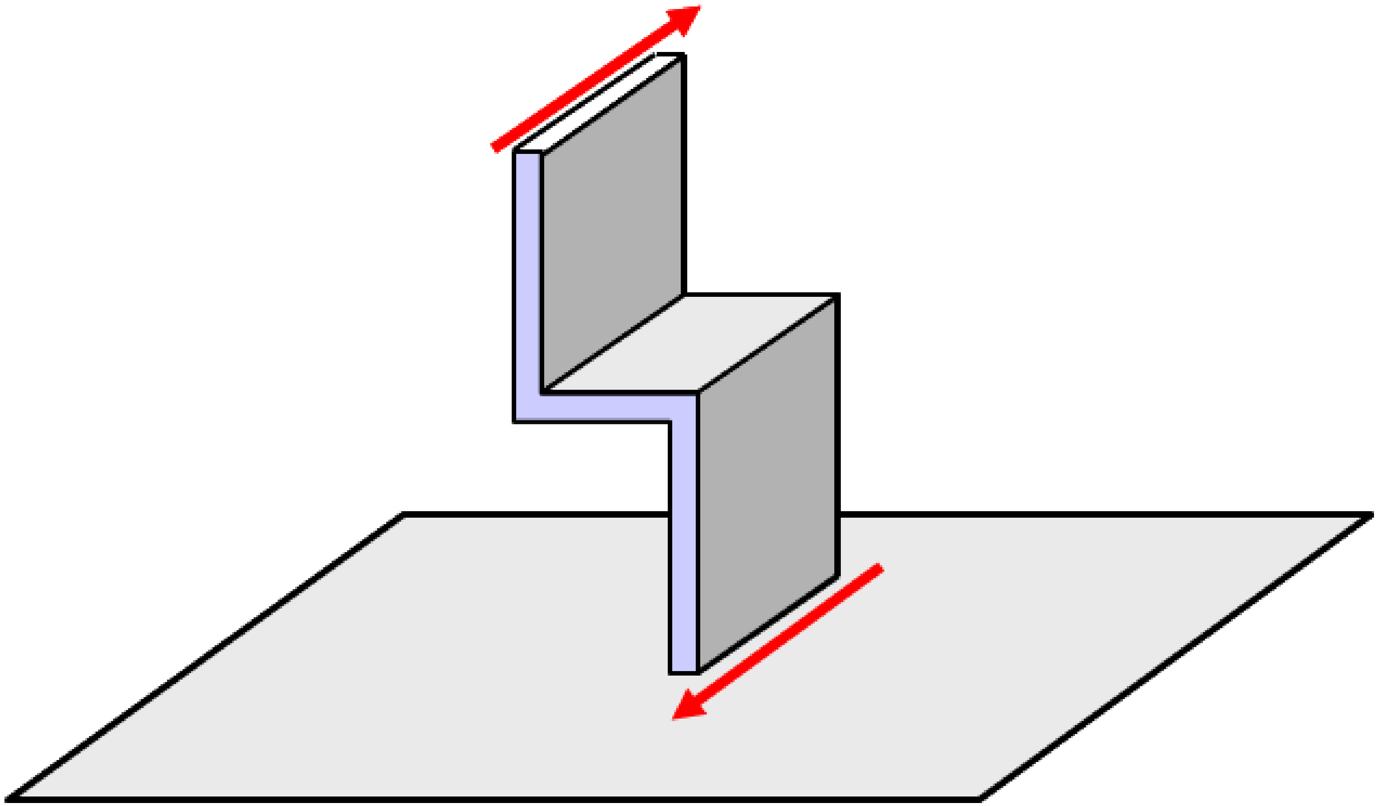
1. EDO is precast concrete diaphragm Elastic Design Option.
2. BDO is precast concrete diaphragm Basic Design Option.
3. RDO is precast concrete diaphragm Reduced Design Option.

Transfer Diaphragms

ASCE 7-10 Section 12.10.1.1, 4th paragraph

Where the diaphragm is required to transfer design seismic forces from the vertical resisting elements above the diaphragm to other vertical resisting elements below the diaphragm due to offsets in the placement of the elements or changes in relative lateral stiffness in the vertical elements, these forces shall be added to those determined from Eq. 12.10-1. The redundancy factor, ρ, applies to the design of diaphragms in structures assigned to Seismic Design Category D, E, or F. For inertial forces calculated in accordance with Eq. 12.10-1, the redundancy factor shall equal 1.0. For transfer forces, the redundancy factor, ρ, shall be the same as that used for the structure.

Transfer Diaphragms



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Transfer Diaphragms

ASCE 7-16 Section 12.10.1.1, 4th paragraph

All diaphragms shall be designed for the inertial forces determined from Eq. 12.10-1 through 12.10-3 and for all applicable transfer forces. For structures having a horizontal structural irregularity of Type 4 in Table 12.3-1, the transfer forces from the vertical seismic force-resisting elements above the diaphragm to other vertical seismic force-resisting elements below the diaphragm shall be increased by the overstrength factor of Section 12.4.3 prior to being added to the diaphragm inertial forces. For structures having other horizontal or vertical structural irregularities of the types indicated in Section 12.3.3.4, the requirements of that section shall apply.

Transfer Diaphragms

<u>12.10.3.3 Transfer Forces in Diaphragms</u>

All diaphragms shall be designed for the inertial forces determined from Eq. 12.10.3-1 and 12.10.3-2 and for all applicable transfer forces. For structures having a horizontal structural irregularity of Type 4 in Table 12.3-1, the transfer forces from the vertical seismic force-resisting elements above the diaphragm to other vertical seismic force-resisting elements below the diaphragm shall be increased by the overstrength factor of Section 12.4.3 prior to being added to the diaphragm inertial forces. For structures having other horizontal or vertical structural irregularities of the types indicated in Section 12.3.3.4, the requirements of that section shall apply.

Transfer Diaphragms

ASCE 7-16 Section 12.10.1.1, 4th paragraph

ASCE 7-16 Section 12.10.3.3,

Exception: One- and two-family dwellings of light frame construction shall be permitted to use $\Omega_0 = 1.0$.

Collectors

12.10.3.4 Collectors - Seismic Design Categories C through F

In structures assigned to Seismic Design Category C, D, E, or F, collectors and their connections including connections to vertical elements shall be designed to resist 1.5 times the diaphragm inertial forces from Section 12.10.3.2 plus 1.5 times the design transfer forces.

EXCEPTION: 1. Any transfer force increased by the overstrength factor of Section 12.4.3 need not be further amplified by 1.5.

Precast Diaphragm Design

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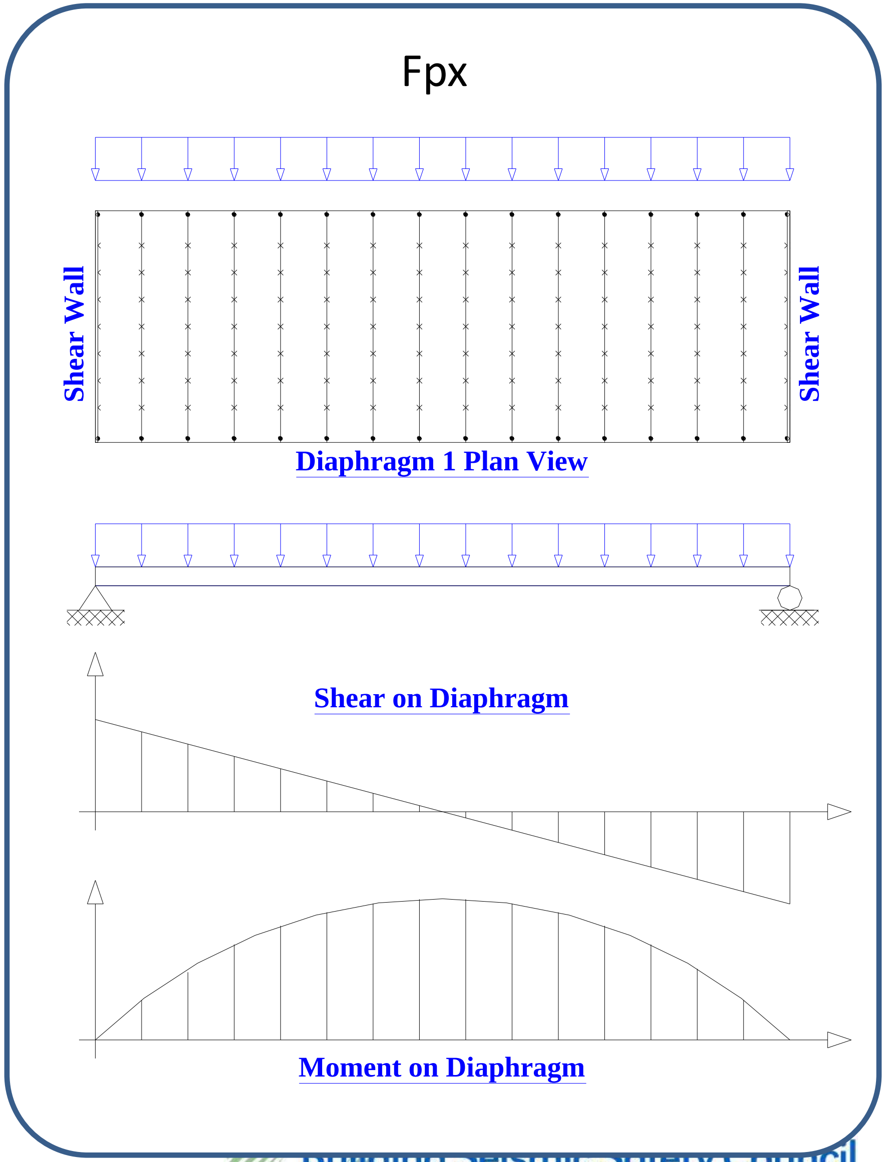
Diaphragm Seismic Design Concept

Design Method

1. Modify F_{px} to develop desired yielding under
   - Design Earthquake
   - Max Considered Earthquake
2. Prevent Shear Failure



Diaphragm Design Options

Elastic Design Option (EDO)	Basic Design Option (BDO)	Reduced Design Option (RDO)
Diaphragm remains elastic in DBE and MCE	Diaphragm remains elastic in DBE but <u>Not Necessarily in MCE</u>	Some Diaphragm yielding in DBE, significant in MCE
Highest diaphragm design force	Lower diaphragm design force than EDO	Lowest diaphragm design force
Connections can include LDE, MDE and HDE	Connections can include MDE and HDE	Connections must be High Deformation Elements (HDE)
No shear overstrength needed since elastic design	Shear overstrength factor is needed	Shear overstrength factor is needed

Connector Qualification Protocol

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Questions

Nonlinear Response-History Analysis: Contrast of Chapter 16 Versions for the NEHRP Provisions and ASCE 7-16

Project by: Large Issue Team

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BSSC PUC Meeting | August 29, 2017

FEMA

Building Seismic Safety Council
Issue Team 4 on Response History Analysis

National Institute of BUILDING SCIENCES

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- Mike Tong, FEMA

Chapter 16: Overall Structure

- **Section 16.1:** General Requirements
- **Section 16.2:** Ground Motions
- **Section 16.3:** Modeling and Analysis
- **Section 16.4:** Analysis Results and Accept. Criteria
- **Section 16.5:** Design Review

Section 16.1 (General)

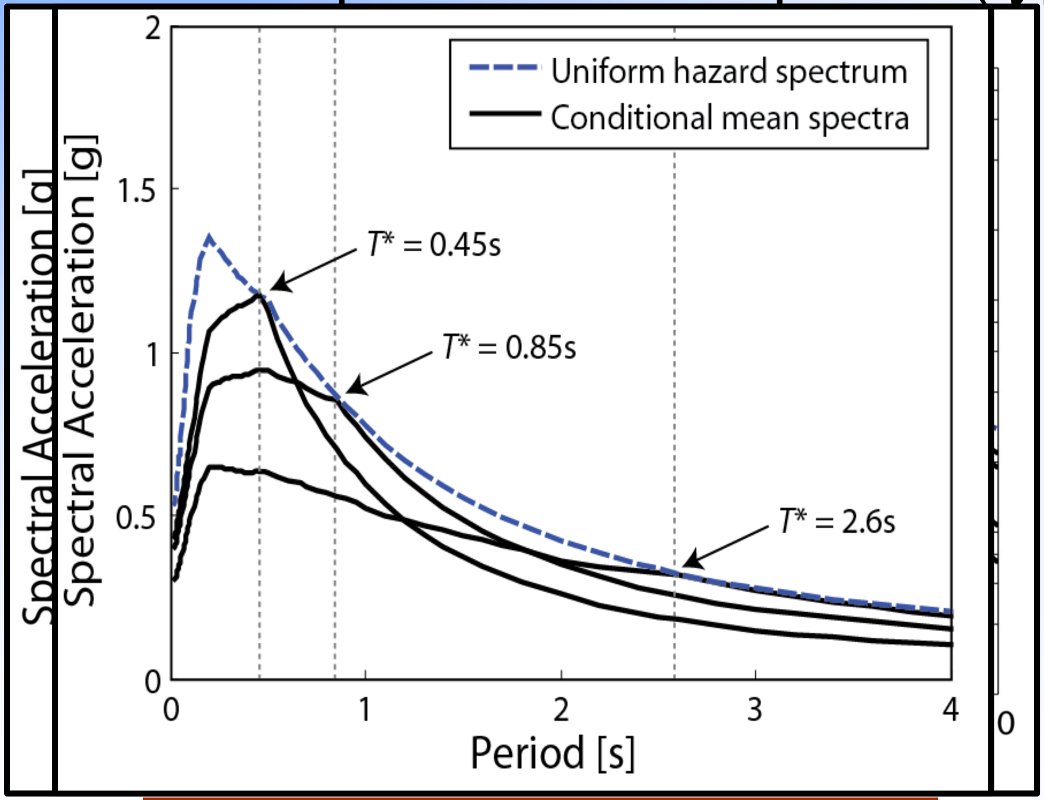
- The basic structure of the design approach is:
  - Linear DBE-level analysis (to enforce minimum base shear, basic load cases, etc.).
  - Nonlinear MCE-level response-history analysis.

Section 16.2 (Ground Motion)

- Ground motion level:
  - MCE_R (to better link to what is being assessed)
- Number of ground motions:
  - 11 motions (to better estimate the mean responses)

Section 16.2 (Ground Motion)

- Target spectrum:
  - Method 1: Typical MCE_R spectrum
  - Method 2: Multiple "scenario" spectra (typically two)



Section 16.2 (Ground Motion)

- Selection of motions:
  - Same general language.
  - Added: "*and shall have similar spectral shape to the target spectrum.*"
  - For near-fault: Include an appropriate ratio of pulse-type motions (with ASCE-7-16 making this language more specific).

Section 16.2 (Ground Motion)

- Scaling of motions:
  - Scale the maximum direction Sa to the target spectrum (which is maximum direction).
- Period range for scaling:
  - Range from $0.2T_1$ to $2.0T_1$ (higher for MCE_R), unless a lower $1.5T_1$ value can be justified.
  - Also require period range to cover 90% modal mass (which can control).

Section 16.2 (Ground Motion)

- Near-Fault versus Far-Field
  - BSSC: Left this fairly non-prescriptive.
  - ASCE-7-16: Added specificity in Chapter 11 (near-fault is $R < 15km$ if $M > 7.0$ and $R < 10km$ if $7.0 > M > 6.5$).
- Orientation of Ground Motions:
  - **Near-Fault:** Apply pairs of records in FN/FP orientation
  - **Far-Field:**
    - BSSC: Apply pairs of records with "random orientation"
    - ASCE-7-16: Added a more specific +/- 10% requirement)
  - No need to rotate pairs 90 degrees

Section 16.2 (Ground Motion)

- Spectral matching:
  - Average matched spectra must meet a slightly higher threshold of 110% of the target spectrum.
  - This is an intentional penalty for the use of spectrum matching, because studies have shown that it can lead to conservatively biased results if not done correctly.
  - Only allowed for near-fault sites if it is shown that the pulse properties are maintained.

Sec. 16.3 (Modeling & Analysis)

- This section says what to do but <u>not</u> how to do it.
- This was intentionally <u>not</u> written to be a nonlinear analysis guideline.
- Gravity loads: Specified cases and ASCE-7-16 added an exception.
- Torsion:
  - Interesting topic with lots of divergent opinions!
  - BSSC: Leave this to the linear design step.
  - ASCE-7-16: Allow the above if no Type 1a/1b irregularity exists, otherwise require 5% mass offsets in the NL model.

Section 16.4 (Accept. Criteria)

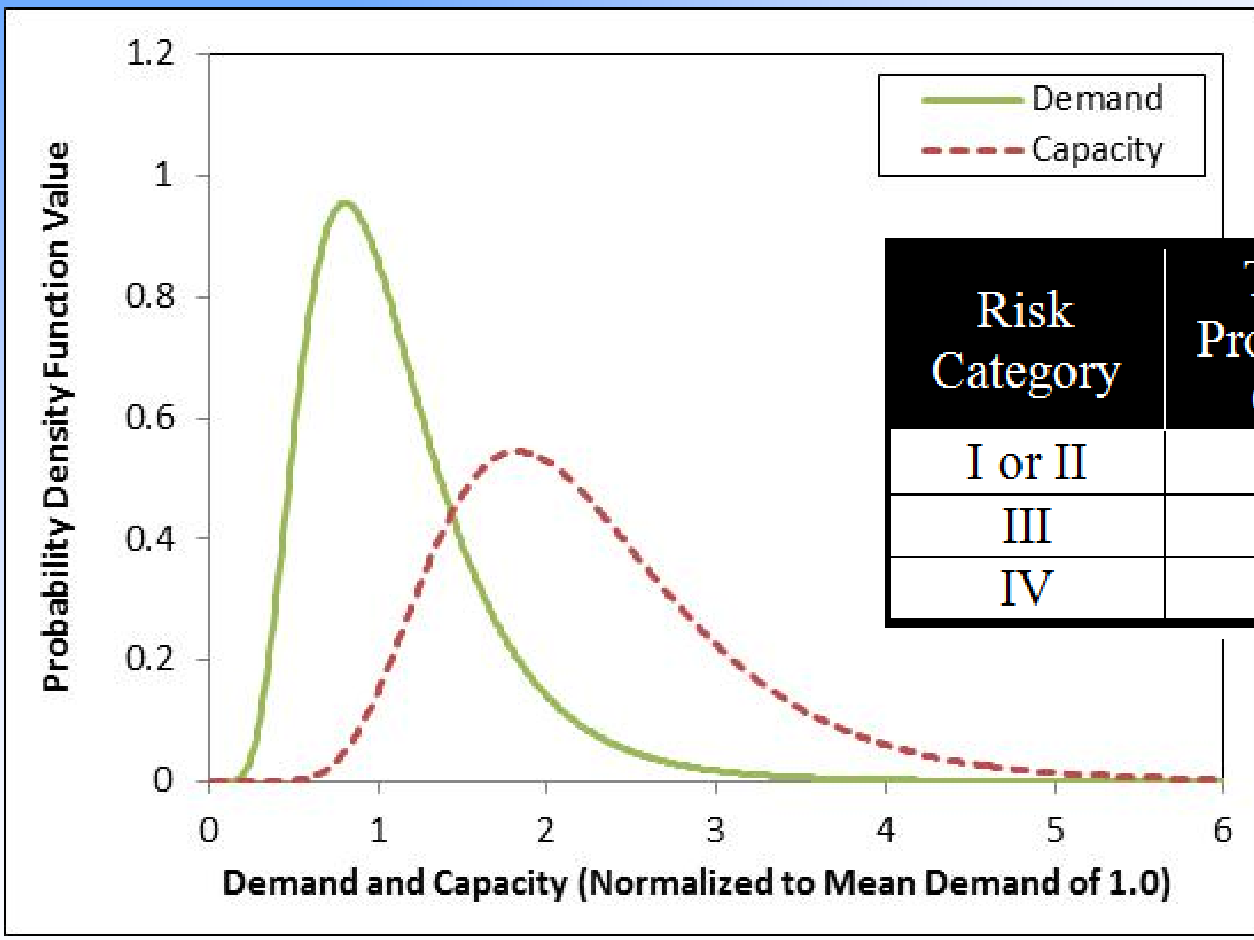
- **Big Focus:** Develop acceptance criteria more clearly tied to the ASCE7 safety goals.

Risk Category	Tolerable Probability of Collapse	Ground Motion Level
I or II	10%	MCE_R
III	6%	MCE_R
IV	3%	MCE_R

- **Explicit Goal:** Acceptable collapse probability.
- **Implicit Verification Approach:** Use <u>mean</u> structural responses (with 11 motions) to show compliance.

Section 16.4 (Accept. Criteria)

- Force-controlled (brittle) components:



Risk Category	Tolerable Probability of Collapse	Ground Motion Level
I or II	10%	MCE_R
III	6%	MCE_R
IV	3%	MCE_R

Section 16.4 (Accept. Criteria)

- Force-controlled (brittle) components:

$2.0\ I_e\ F_u \leq F_e$ for “critical” (same as PEER-TBI)

$1.5\ I_e\ F_u \leq F_e$ for “ordinary”

$1.0\ I_e\ F_u \leq F_e$ for “non-critical” (judgment)

F_u = mean demand (from 11 motions) [ASCE-7-16: Modified equation format and only scale the non-seismic loads]

F_e = expected strength

Critical = failure causes immediate global collapse
Ordinary = failure causes local collapse (one bay)
Non-critical = failure does not cause collapse

Section 16.4 (Accept. Criteria)

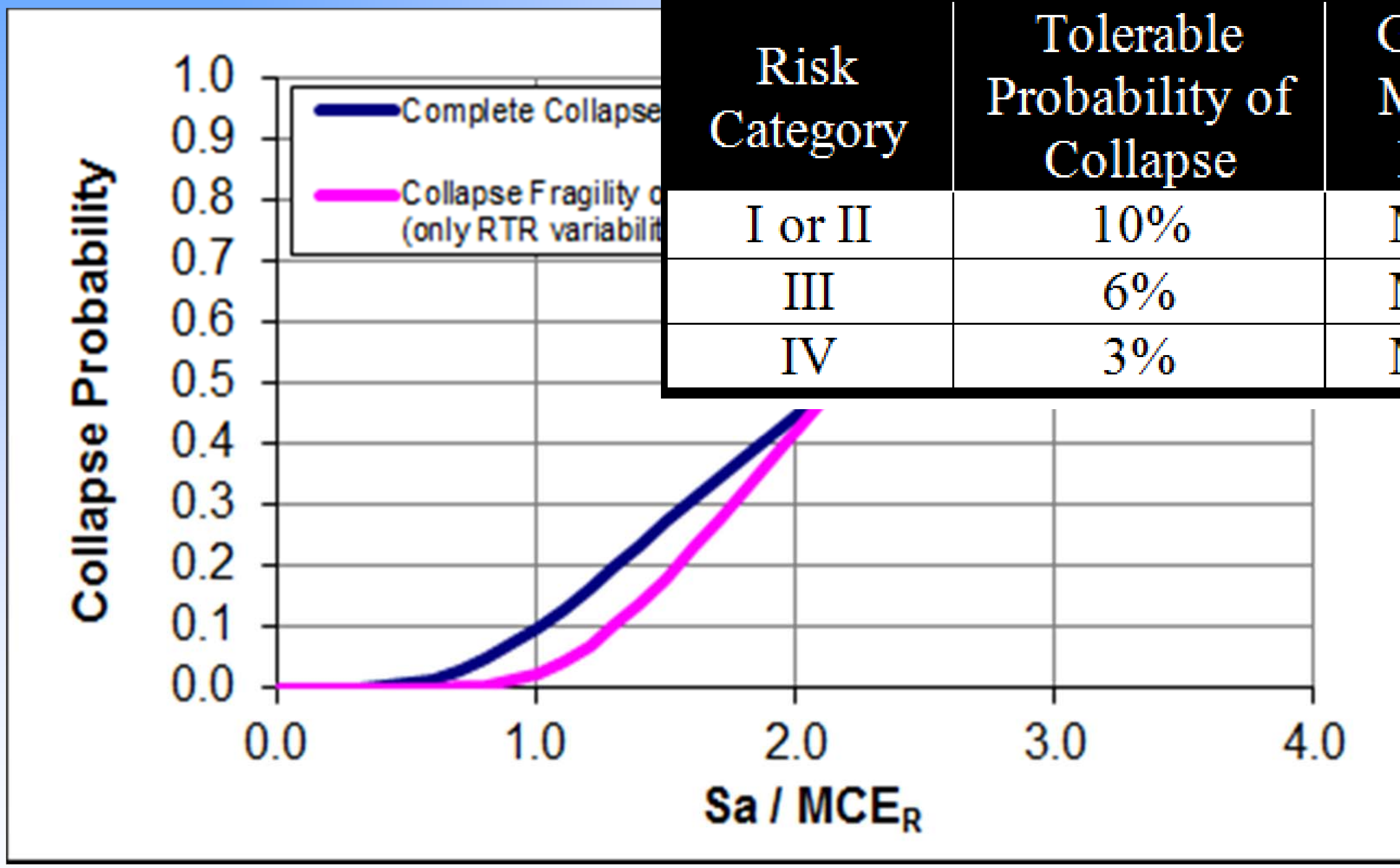
- Deformation-controlled (ductile) components:
  - BSSC:
    - Similar statistical approach used (as with force-controlled components).
    - “Pre-approved” uses of ASCE41 are also provided.
  - ASCE-7-16:
    - Swapped the above, so the ASCE41 criteria are the default and the statistical approach is an alternative.

Section 16.4 (Accept. Criteria)

- Drift limits:
  - Mean drift ≤ 2.0*(normal limit)
  - The factor of two comes from:
    - ✓ 1.5 = MCE / DBE
    - ✓ 1.25 = Approx. ratio of R / Cd
    - ✓ 1.1 = A little extra because we trust NL RHA more

Section 16.4 (Accept. Criteria)

- **Statistical collapse study:**



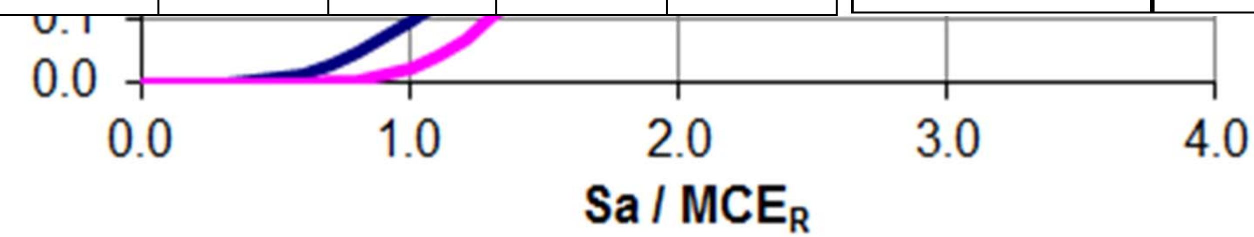
Risk Category	Tolerable Probability of Collapse	Ground Motion Level
I or II	10%	MCE$_R$
III	6%	MCE$_R$
IV	3%	MCE$_R$

Section 16.4 (Accept. Criteria)

- **Statistical collapse study:**

Number of Collapses	Likelihood for Various P[C|MCER] Values				
	0.05	0.10	0.15	0.20	0.30
0 of 11	93%	74%	51%	30%	7%
1 of 11	7%	23%	36%	38%	21%
2 of 11	0%	3%	11%	22%	29%
3 of 11	0%	0%	2%	8%	24%
4 of 11	0%	0%	0%	2%	13%
5 of 11	0%	0%	0%	0%	5%

Number of Collapses	Likelihood if P[C|MCER] = 10%
≥ 1 of 11	26%
≥ 2 of 11	3%
≥ 3 of 11	0%
≥ 4 of 11	0%
≥ 5 of 11	0%



Section 16.4 (Accept. Criteria)

- **Final Criterion for Collapses, or “Unacceptable Responses”:**
  - Basic Case: Allow up to 1/11 “collapses” but not 2/11.
  - With Spectral Matching: Require 0/11 collapses.
  - For Risk Categories III-IV: Require 0/11 collapses.

  - ASCE-7-16: Same but reworded as an exception.

Section 16.5 (Design Review)

- Typical requirements and language…not covered here…

More Information: Publications

ASCE 7 Chapter 16 Project Documentation:

- Earthquake Spectra papers just published:
  1. Provisions Development (1 of 2)
  2. Provisions Development (2 of 2)
  3. Example Applications
  4. Evaluation Studies

Questions/Comments?

- Thanks you for your time.
- Please contact me if there is anything else I can do to help with this.
- Contact:
  - E-mail: curt@hbrisk.com
  - Website: www.hbrisk.com
  - Direct: (530) 514-8980

New Site-Specific Ground Motion Requirements of ASCE 7-16

2017 SEAOC Convention – San Diego - September 14, 2017

Charlie Kircher

Kircher & Associates
Palo Alto, California

SEI
ASCE

USGS
science for a changing world

National Institute of BUILDING SCIENCES
An Authoritative Source of Innovative Solutions for the Built Environment

Building Seismic Safety Council

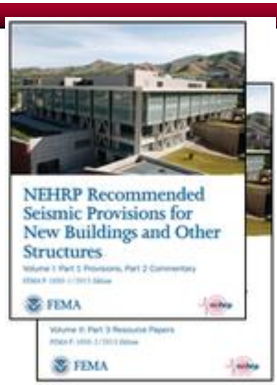
U.S. DEPARTMENT OF HOMELAND SECURITY
FEMA

nehrp

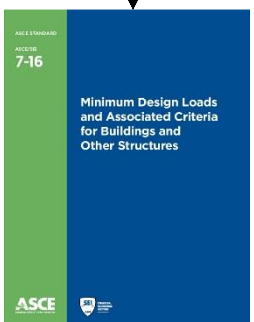
Content

1. Background Material
2. The “Problem” with ELF (MRSA) Methods
3. Interim Solution (ASCE 7-16)
4. New Site-Specific Requirements of Section 11.4.8
5. Examples of Seismic Response Coefficient
6. Summary and Conclusion

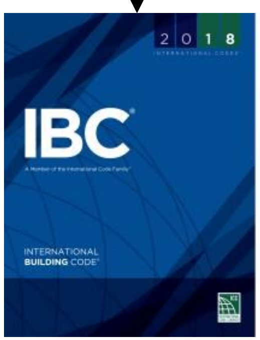
Seismic Code Development Process



- 2015 NEHRP Recommended Provisions
  - Building Seismic Safety Council (BSSC) for the Federal Emergency Management Agency (FEMA)
    - **Provisions Update Committee (PUC)**



- ASCE 7-16 - Minimum Design Loads on Buildings and Other Structures
  - Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE)
    - **ASCE 7 Seismic Subcommittee (SSC)**



- 2018 International Building Code (IBC)
  - International Code Council, Codes and Standards
    - **IBC Structural Committee**

Summary of New ASCE 7-16 Ground Motions

What's New (or Changed)?

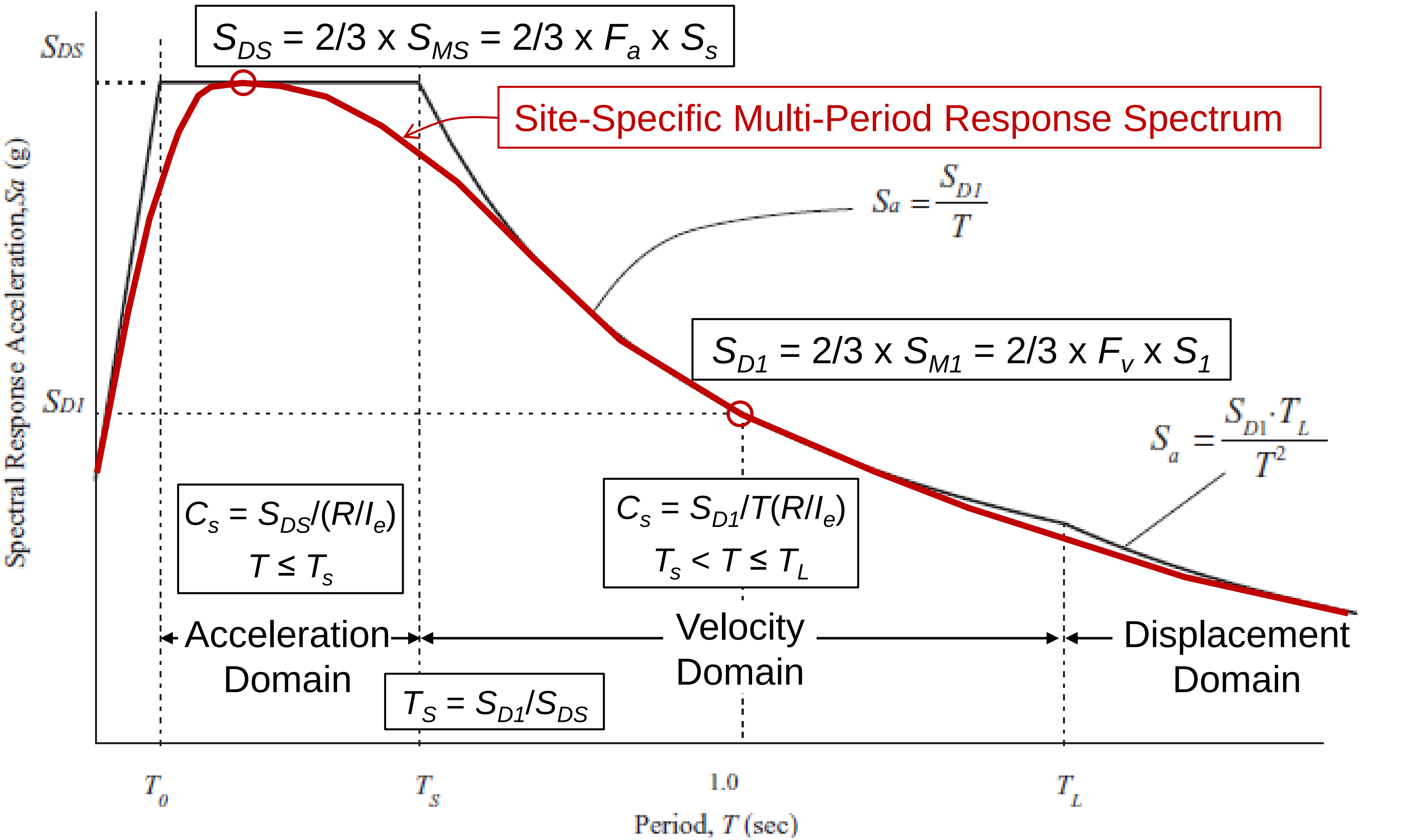
- **Site Class Coefficients**
  - **Tables 11.4-1 and 11.4-2**
- Ground Motion Parameter Values
  - MCE_R Ground Motion Maps, Section 11.4.2 (Chapter 22)
- **Site-Specific Procedures**
  - **Section 11.4.8**
  - **Sections 21.4,** 21.2.3, 21.3
- Vertical Ground Motions
  - Section 11.9
- Nonlinear RHA Ground Motions
  - Section 16.2
  - Section 11.4.1 (Near-Fault)

What's Not New?

- Site Classification
  - Section 11.4.3 (Table 20.3-1)
- Ground Motion Parameter Definitions and Formulas
  - Sections 11.4.4 and 11.4.5
- Design Response Spectrum
  - Figure 11.4-1 (Section 11.4.6)
- Probabilistic and Deterministic MCE_R Definitions and Methods
  - Section 21.2 (except 21.2.3)
- Nonlinear RHA Ground Motions (Isolation/Damping Systems)
  - Section 17.3 and Section 18.2.2

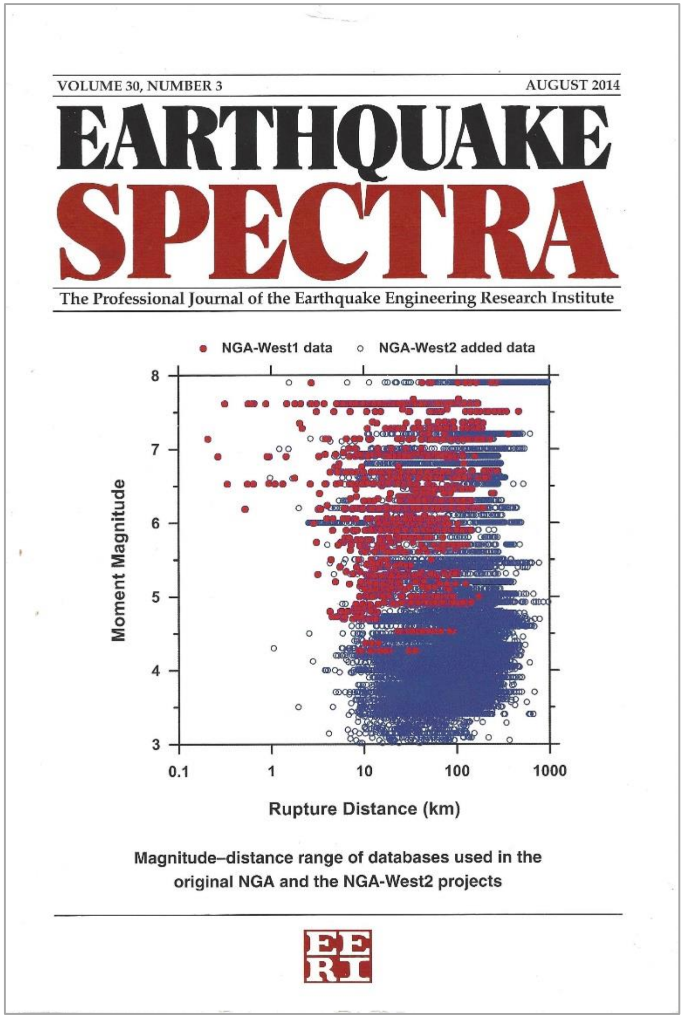
Design Response Spectrum

(Figure 11.4-1, ASCE 7-10 and ASCE 7-16 with annotation)



Basis for New MCE_R Ground Motion Maps of ASCE 7-16

2014 National Seismic Hazard Maps (USGS)



NGA–West2 Project (PEER)

Research Projects Contributing to 2014 USGS NSHM Updates (Luco, USGS)

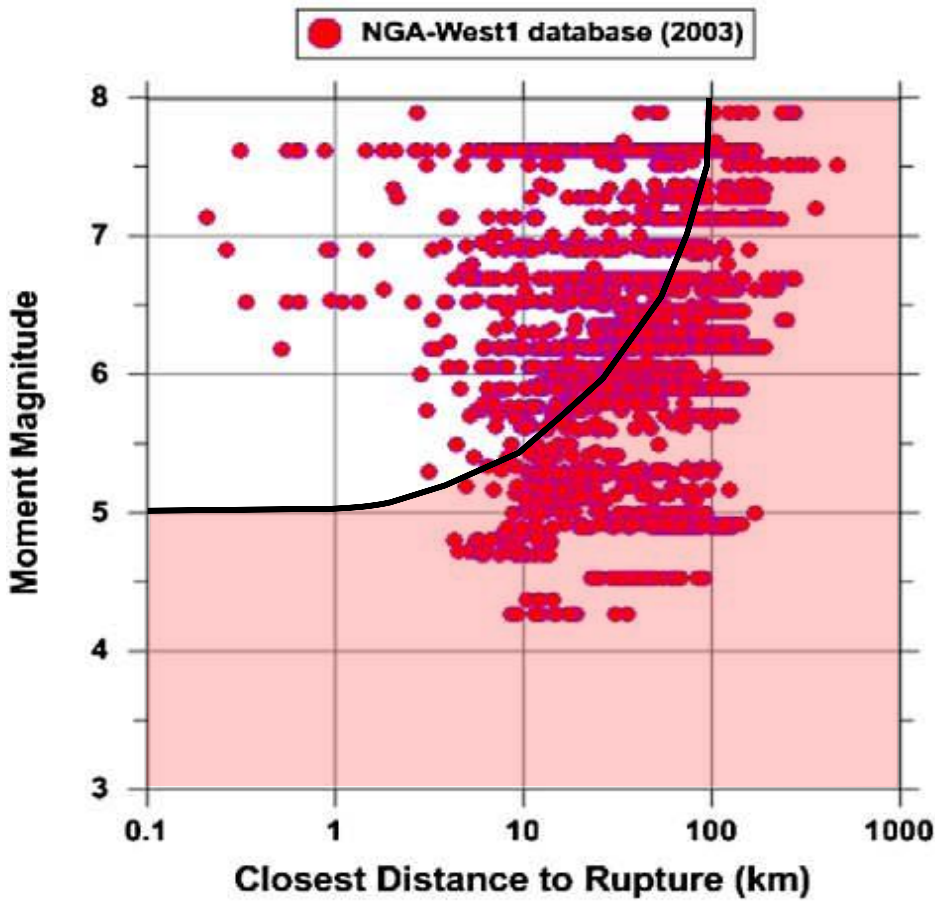
Project Name	Lead(s)	Duration	Sponsors
Central & Eastern US Seismic Source Characterization for Nuclear Facilities **(CEUS-SSC)**	Consultants	2008-2011	US DOE, EPRI, US NRC
Uniform California Earthquake Rupture Forecast, Version 3 **(UCERF3)**	USGS, CGS, SCEC (WGCEP)	2010-2013	CEA
Next Generation Attenuation Relations for Western US, Version 2 **(NGA-West2)**	PEER	2010-2013	CEA, Caltrans, PG&E

+ Dozens of other updates summarized in the Commentary to Chapter 22 of ASCE 7-16 and explained in the December 2015 Special Issue of *Earthquake Spectra* journal

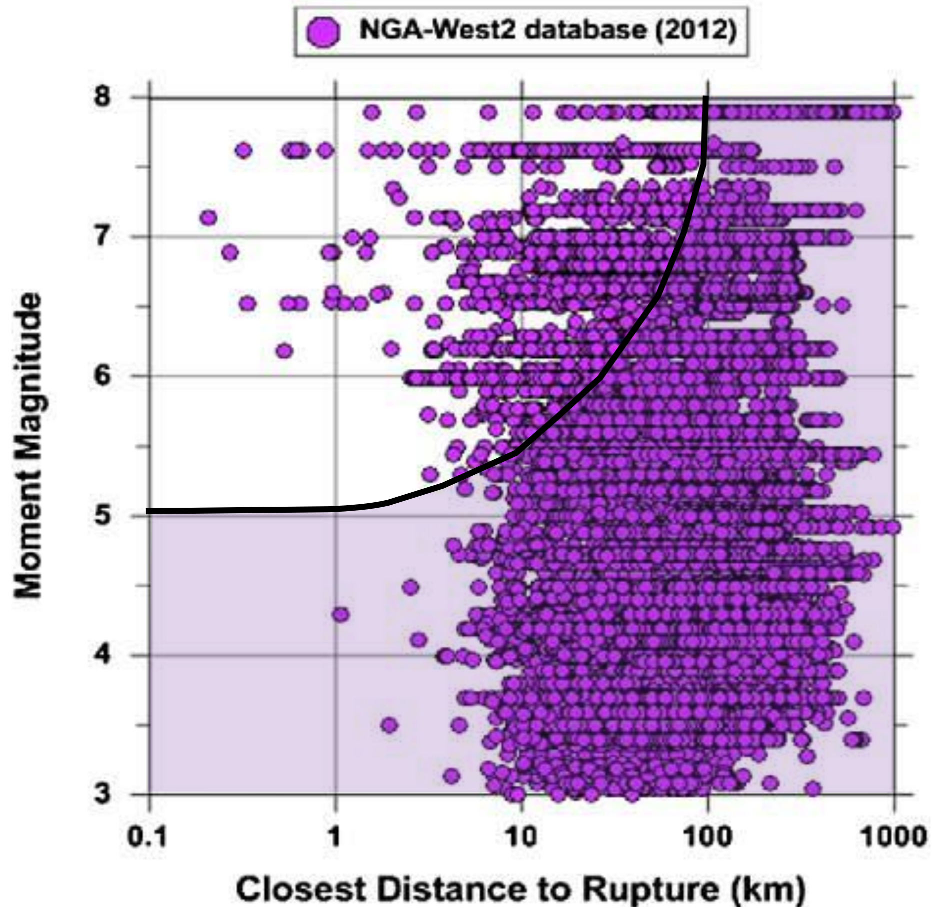
PEER NGA-West1 and NGA-West2 Earthquake Databases and GMPEs

(Bozorgnia et al., *Earthquake Spectra*, Vol. 30, No. 3, August 2014, EERI)

NGA-West1 Database – 3,550 Records
(West1 GMPEs used for ASCE 7-10 maps)

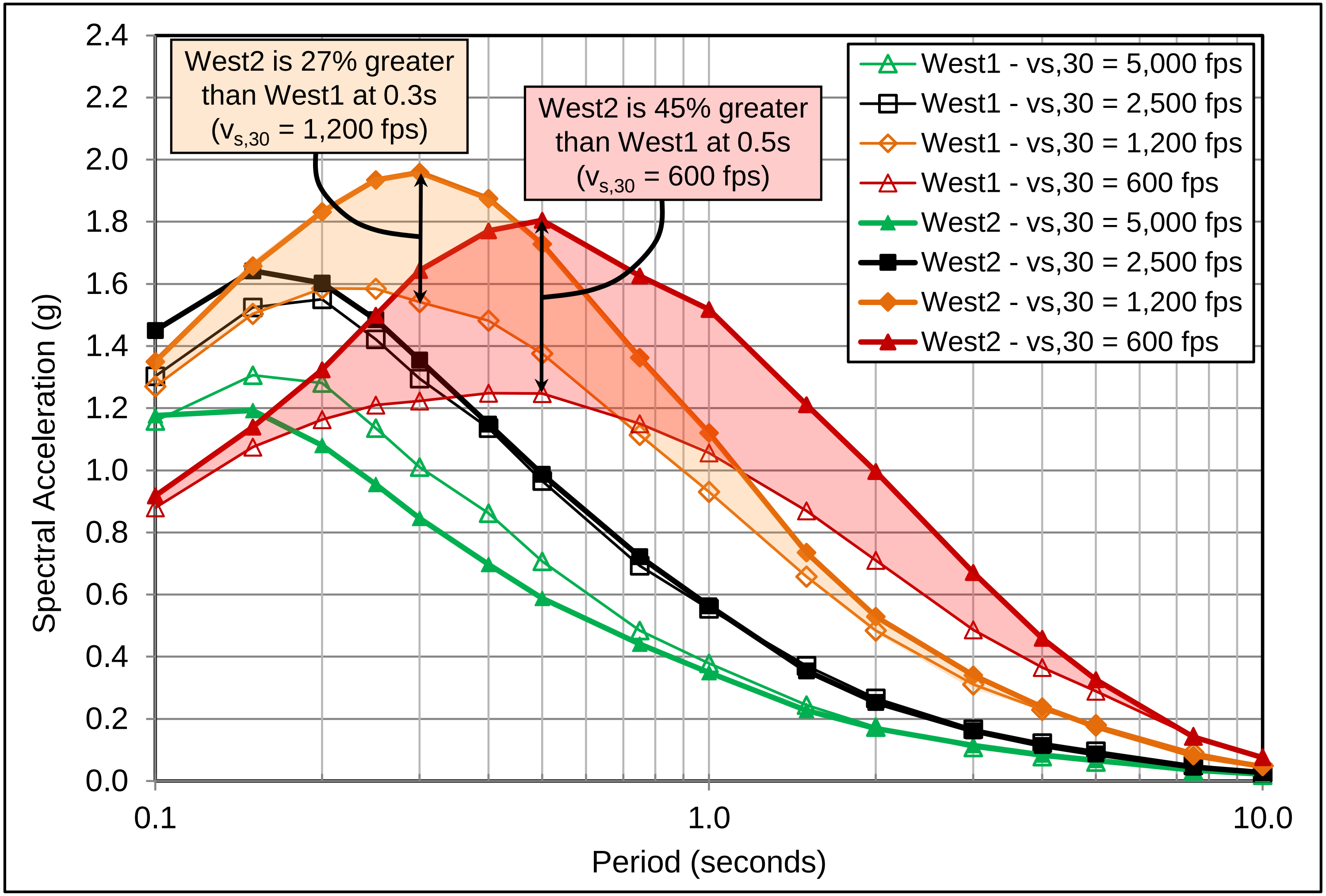


NGA-West2 Database – 21,332 Records
(West2 GMPEs used for ASCE 7-16 maps)



Example Comparison of Deterministic MCE_R Ground Motions

NGA West1 and NGA West2 GMPEs (M7.0 at R_x = 6 km, Site Class boundaries)



PEER NGA GMPE spreadsheet calculations: West1 based on Al Atik, 2009, West2 based on Seyhan, 2014)

New Values of the Site Coefficient, F_a (Table 11.4-1 of ASCE7-16) (shown as proposed changes to ASCE 7-10)

Table 11.4-1 Site Coefficient, F_a

Site Class	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at Short Period					
	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S = 1.25$	$S_S \geq 1.5$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	~~1.0~~ 0.9	~~1.0~~ 0.9	~~1.0~~ 0.9	~~1.0~~ 0.9	~~1.0~~ 0.9	0.9
C	~~1.2~~ 1.3	~~1.2~~ 1.3	~~1.1~~ 1.2	~~1.0~~ 1.2	~~1.0~~ 1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0
E	~~2.5~~ 2.4	1.7	~~1.2~~ 1.3	See Section 11.4.8		
F	See Section 11.4.8					

Note: Use straight-line interpolation for intermediate values of S_S. At the Site Class B-C boundary, F_a = 1.0 for all S_s levels. If site class~~es~~ A or B is established without the use of on-site geophysical measurements of shear wave velocity, use F_a = 1.0.

Note – Site Class B is no longer the "reference" site class of MCE_R ground motion parameters S_s and S_1 (i.e., new coefficients reflect Site Class BC boundary of 2,500 f/s) and Site Class D is no longer the "default" site class (when Site Class C amplification is greater, i.e., $S_S \geq 1.0$)

Note – Site-Specific analysis required for Site Class E sites where $S_S \geq 1.0$ w/exception

New Values of the Site Coefficient, F_v (Table 11.4-2 of ASCE7-16) (shown as proposed changes to ASCE 7-10)

Table 11.4-2 Site Coefficient, F_v

Site Class	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at 1-s Period					
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 = 0.5$	$S_1 \geq 0.6$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	~~1.0~~ 0.8	~~1.0~~ 0.8	~~1.0~~ 0.8	~~1.0~~ 0.8	~~1.0~~ 0.8	0.8
C	~~1.7~~ 1.5	~~1.6~~ 1.5	1.5	~~1.4~~ 1.5	~~1.3~~ 1.5	1.4
D	2.4	~~2.0~~ 2.2	~~1.8~~ 2.0	~~1.6~~ 1.9	~~1.5~~ 1.8	1.7
E	~~3.5~~ 4.2	See Section 11.4.8				
F	See Section 11.4.8					

Note: Use straight-line interpolation for intermediate values of S_1. At the Site Class B-C boundary, F_v = 1.0 for all S_1 levels. If site classes A or B are established without the use of on-site geophysical measurements of shear wave velocity, use F_v = 1.0.

Note – Site Class B is no longer the "reference" site class of MCE_R ground motion parameters S_s and S_1 (i.e., new coefficients reflect Site Class BC boundary of 2,500 f/s).

Note - Site-Specific analysis required for Site Class D sites where $S_1 \geq 0.2$ w/exceptions

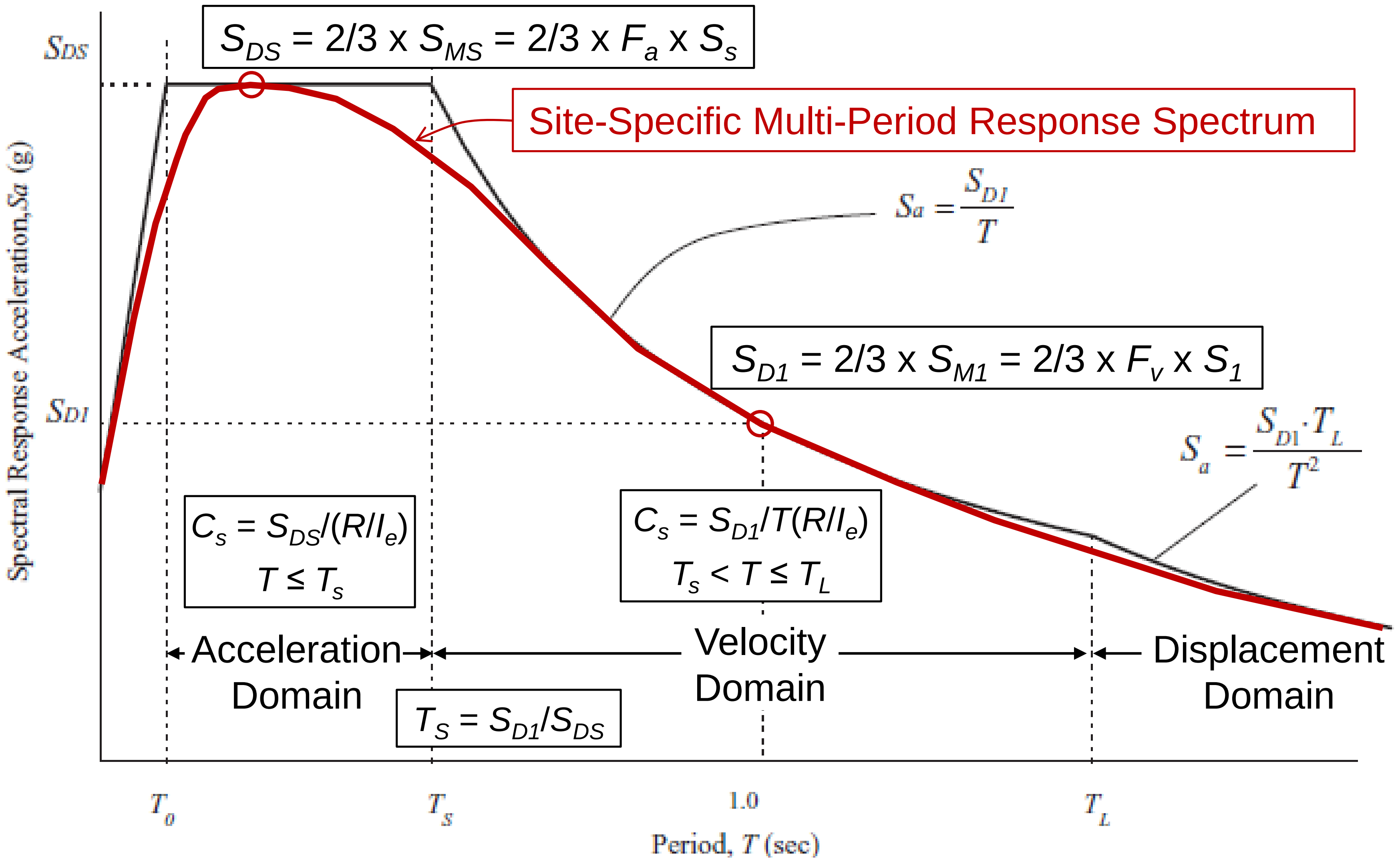
Site-Specific analysis required for Site Class E sites where $S_1 \geq 0.2$ w/o exception

The “Problem” with ELF (MRSA) Methods

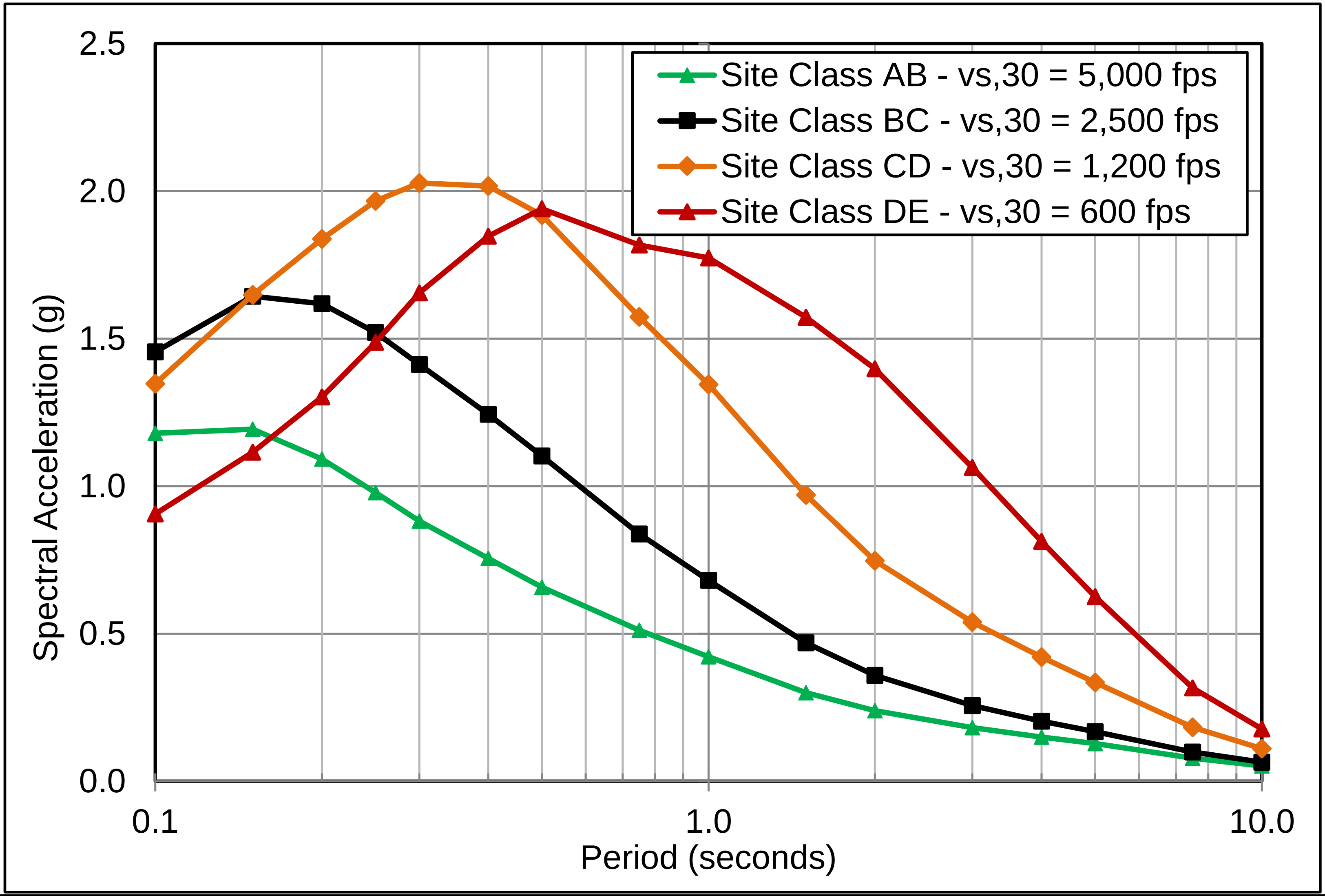
- Use of only two response periods (0.2s and 1.0s) to define ELF (and MRSA) design forces is not sufficient, in general, to accurately represent response spectral acceleration for all design periods of interest
  - **Reasonably Accurate (or Conservative)** – When peak MCE_R response spectral acceleration occurs at or near 0.2s and peak MCE_R response spectral velocity occurs at or near 1.0s for the site of interest
  - **Potentially Non-conservative** – When peak MCE_R response spectral velocity occurs at periods greater than 1.0s for the site of interest
    - <u>Softer soil sites whose seismic hazard is dominated by large magnitude events</u>

Design Response Spectrum

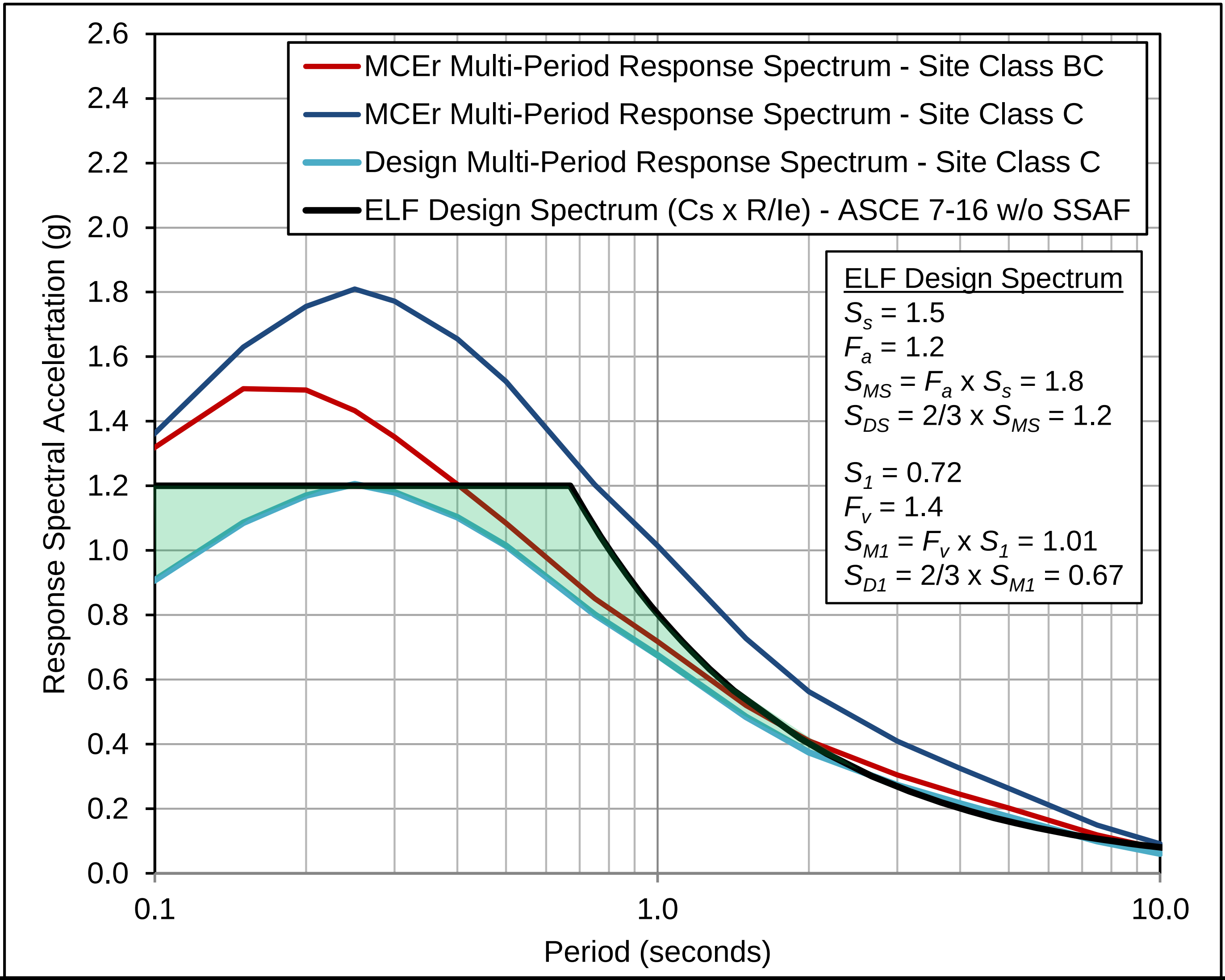
(Figure 11.4-1, ASCE 7-10 and ASCE 7-16 with annotation)



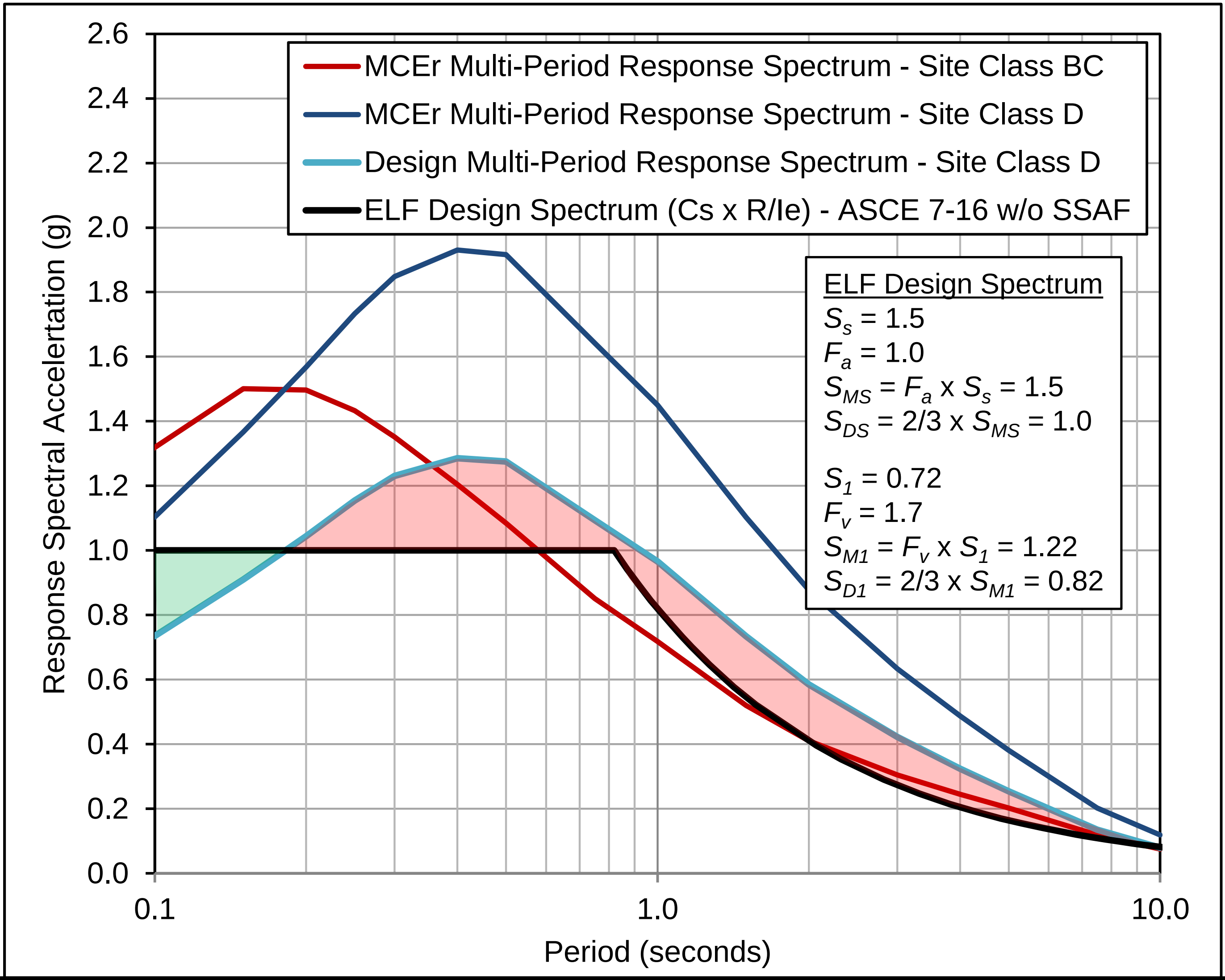
Example Design Spectra - Deterministic MCE_R Ground Motions (ASCE 7-16) PEER NGA West2 GMPEs (M8.0 at R_x = 8.5 km, Site Class boundaries)



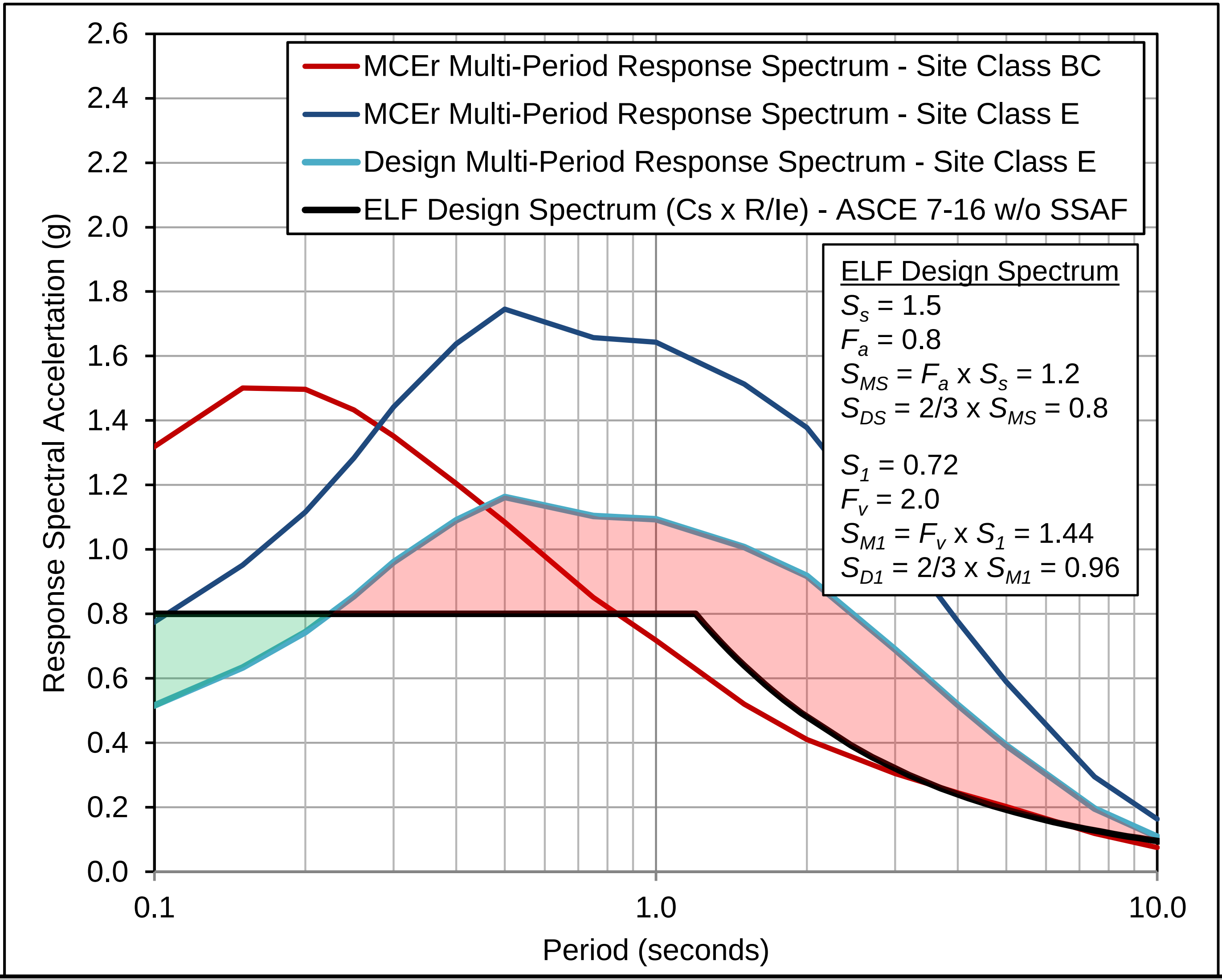
Example ELF "Design Spectrum" - ASCE 7-16 w/o New Site-Specific Requirements
M8.0 earthquake ground motions at R_X = 9.9 km, Site Class C



Example ELF "Design Spectrum" - ASCE 7-16 w/o New Site-Specific Requirements
M8.0 earthquake ground motions at R_X = 9.9 km, Site Class D



Example ELF "Design Spectrum" - ASCE 7-16 w/o New Site-Specific Requirements
M8.0 earthquake ground motions at R_X = 9.9 km, Site Class E



Long-Term Solution (*Project 17*/ASCE 7-22)

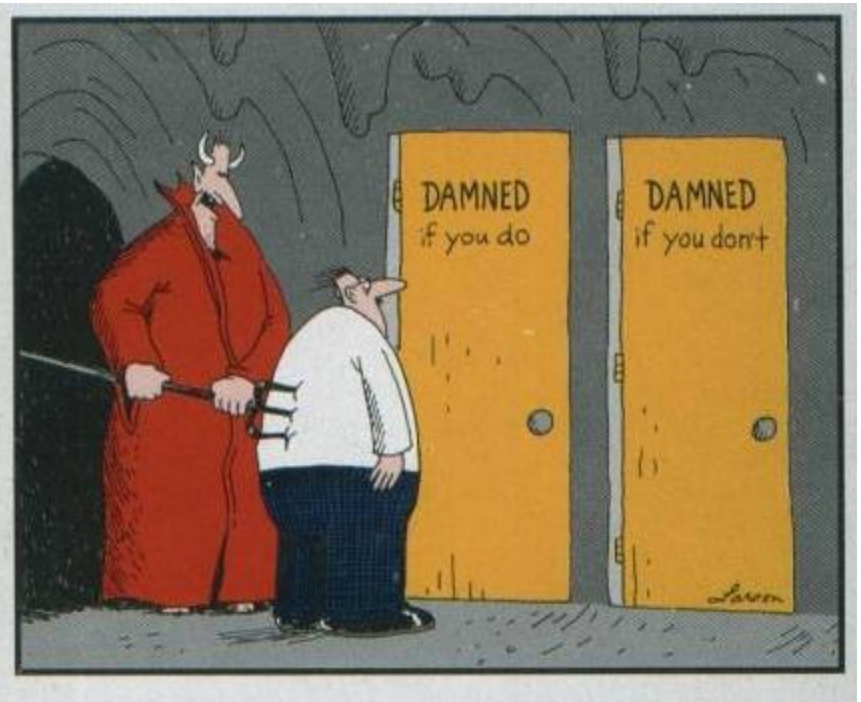
- Develop and adopt multi-period design spectrum approach
  - Not feasible in current code cycle (ASCE 7-16)
- Multi-period spectrum approach will require:
  - Reworking of seismic design requirements and criteria now based on two response periods
  - Development of new ground motion design parameters (by the USGS) for each new response period of interest
  - Development of new site factors for each new response period of interest (or embed site effects directly in ground motion design values)

Interim Solution (ASCE 7-16)

- Require site-specific analysis when site factors (alone) are not sufficiently conservative
- Provide exceptions to site-specific requirements that allow designers the option to design for conservative forces in lieu of performing a site-specific analysis
- Perform a study to provide the basis for the new requirements and conservative criteria of exceptions

Interim Solution Options (BSSC PUC)

- Option 1 - Re-formulate seismic parameters to eliminate potential non-conservatism in ELF (and MRSA) seismic forces
- Option 2 - Require site-specific analysis when ELF (and MSRA) seismic forces could be potentially non-conservative



"C'mon, c'mon — it's either one or the other."

Interim Solution Homework (NIBS BSSC "ELF" Study)

- FEMA-funded NIBS BSSC study (Kircher & Associates):

  "Investigation of an Identified Short-coming in the Seismic Design Procedures of ASCE 7-10 and Development of Recommended Improvements For ASCE 7-16"

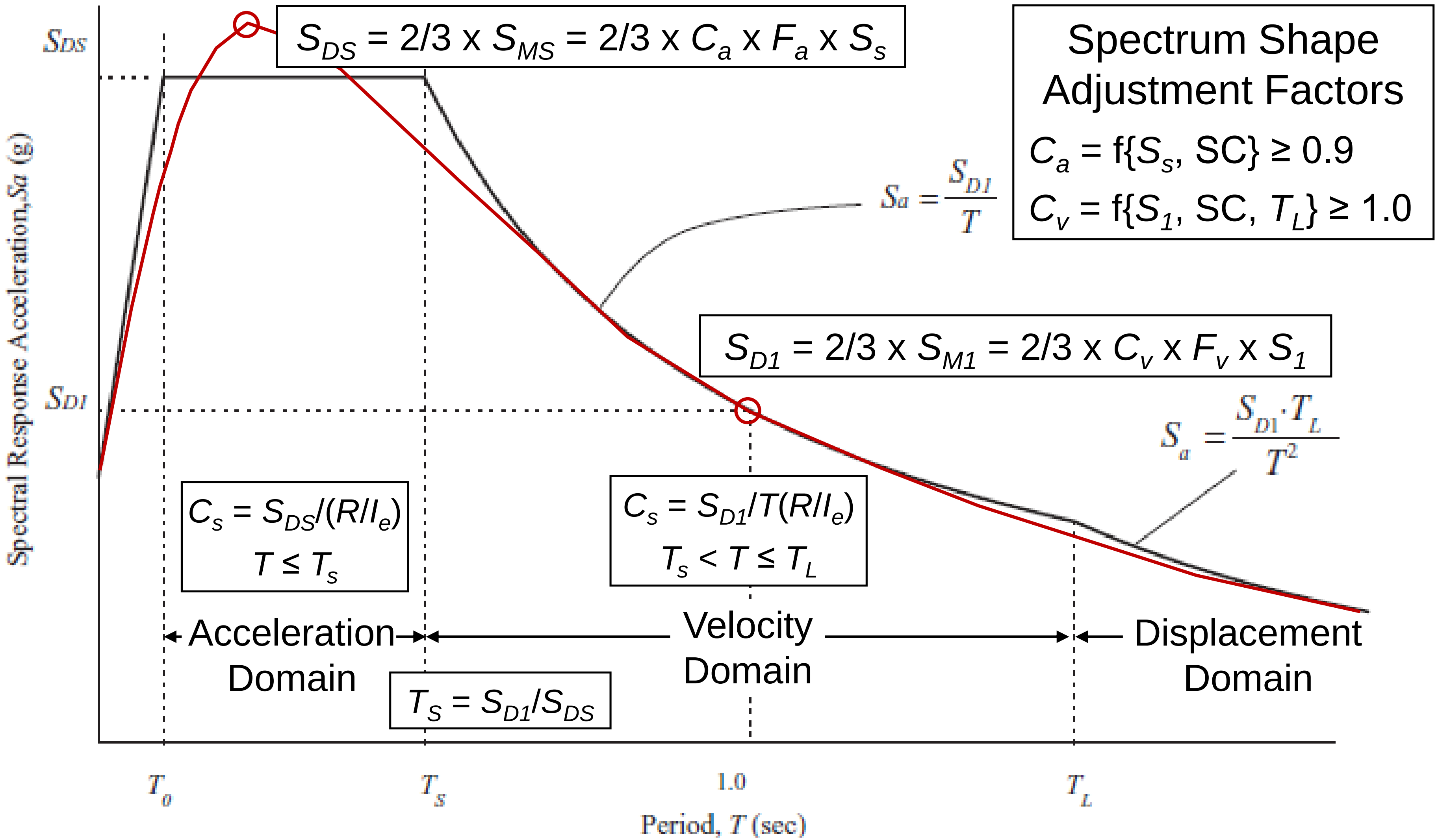
  https://www.nibs.org/resource/resmgr/BSSC2/Seismic_Factor_Study.pdf

- Study Advisors and Contributors:
  - Nico Luco (USGS)
  - Sanaz Rezaeian (USGS)
  - C. B. Crouse (URS)
  - Jonathan Stewart (UCLA)
  - Kevin Milner (SCEC)
  - David Bonnevile (Degenkolb) – BSSC PUC Chair
  - John Hooper (MKA) – ASCE 7-16 SSC Chair

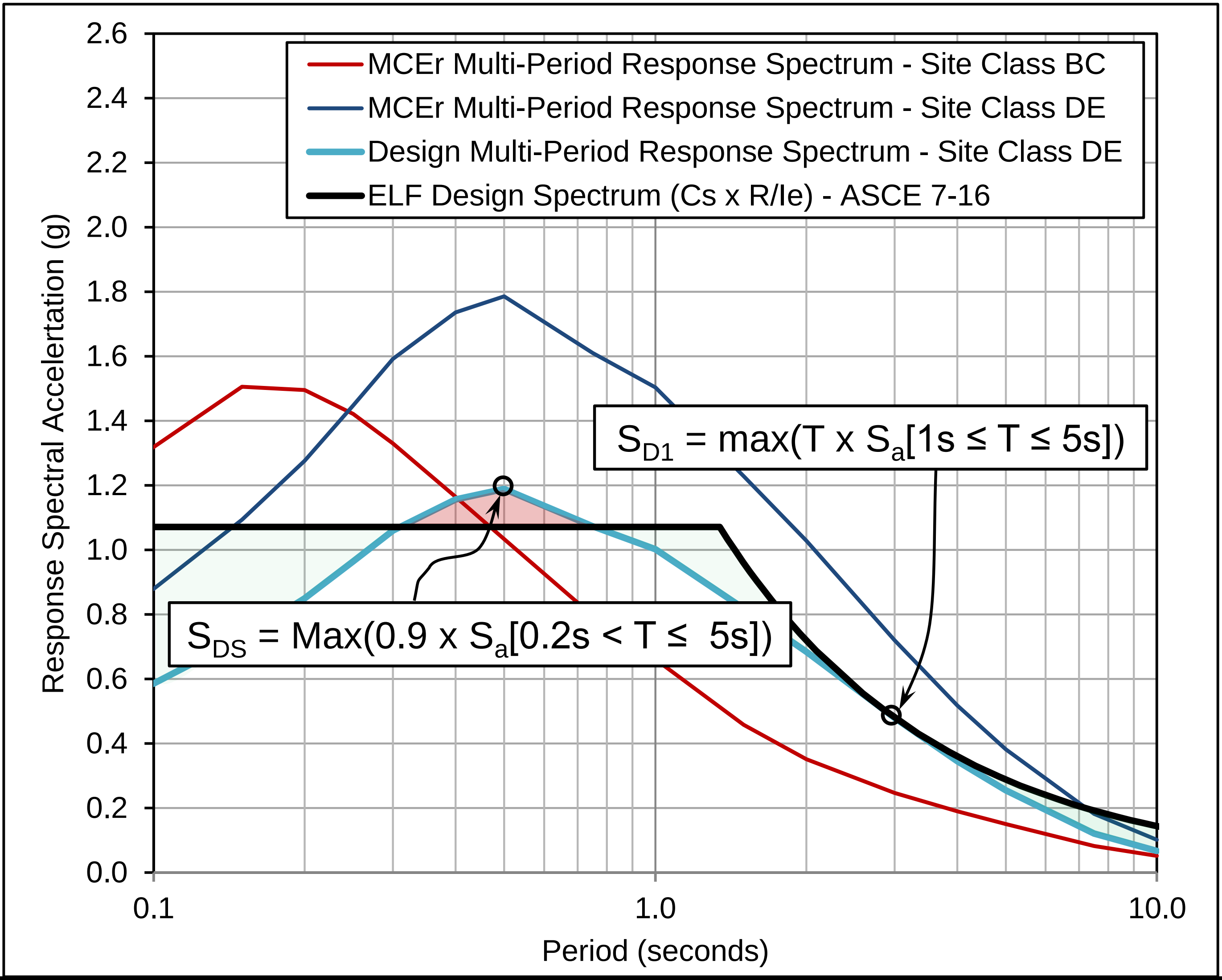
- PEER Center - Next Generation Attenuation Relations
  - Linda Al Atik (PEER NGA West1 GMPEs spreadsheet)
  - Emil Seyhan (PEER NGA West2 GMPEs spreadsheet)

Option 1 - Spectrum Shape Adjustment Factor Reformulation

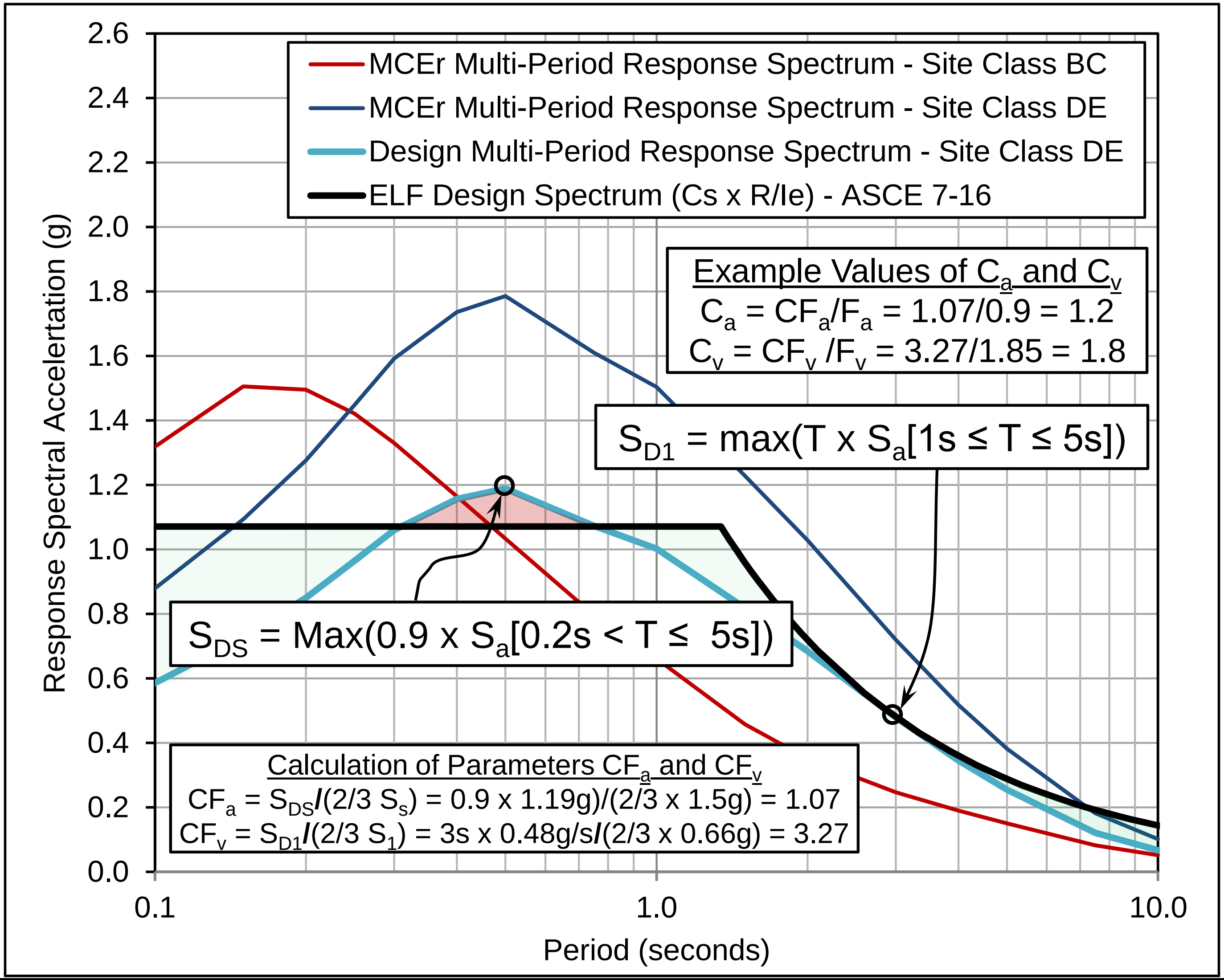
(Figure 11.4-1 annotated to show proposed new spectrum shape Adjustment Factors, C_a and C_v)



Example Values of S_{DS} and S_{D1} using the New Requirements of Section 21.4 (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class DE)



Example Calculation of Spectrum Shape Factors, C_a and C_v (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class DE)



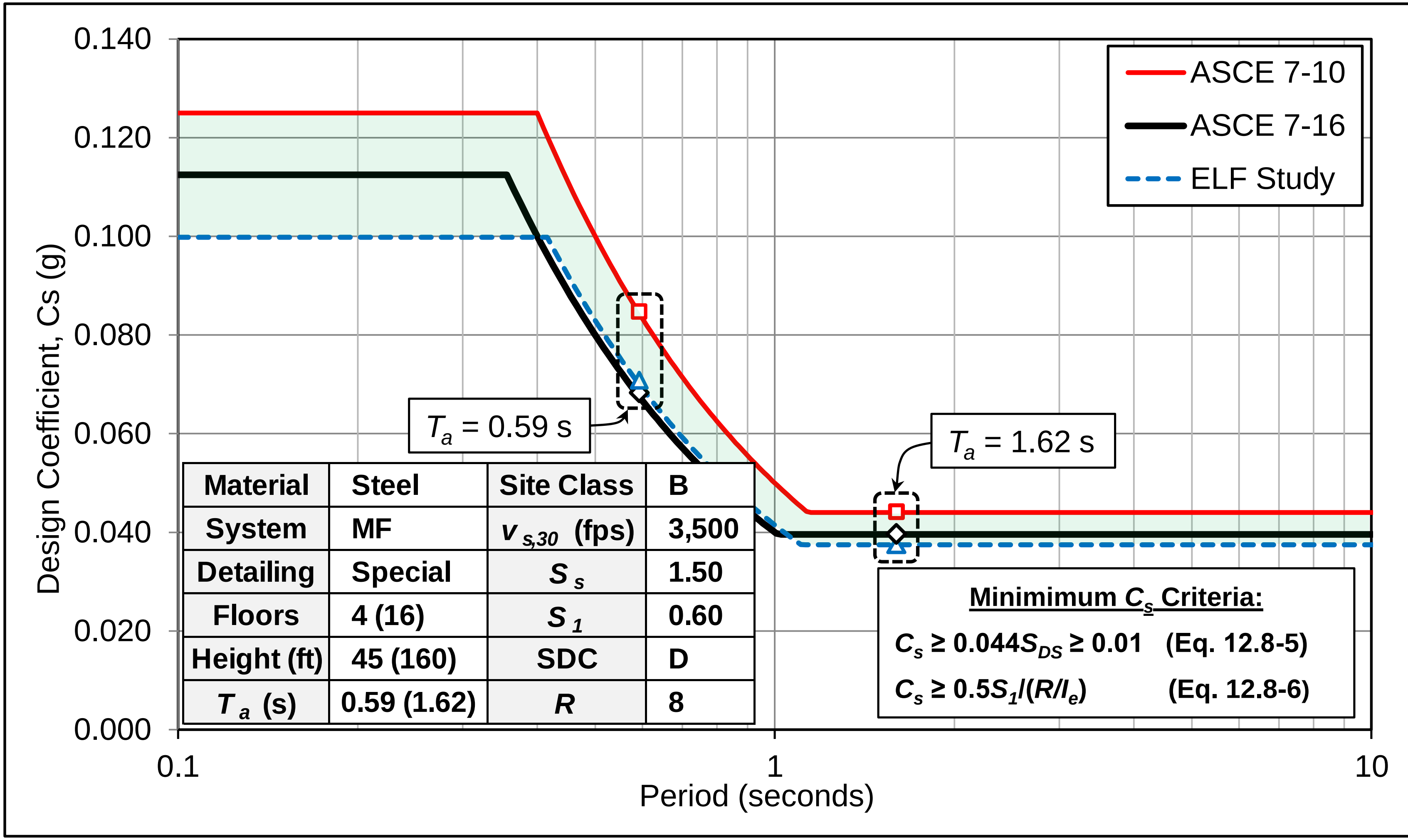
New Requirements of Section 11.4.8 of ASCE 7-16

- Require site-specific ground motion procedures for:
  - structures on Site Class E sites with S_S greater than or equal to 1.0.
  - structures on Site Class D and E sites with S_1 greater than or equal to 0.2.
- Permit ELF (and MRSA) design using conservative values of seismic coefficients:
  - Structures on Site Class E sites with S_S greater than or equal to 1.0, provided the site coefficient F_a is taken as equal to that of Site Class C.
  - Structures on Site Class D sites with S_1 greater than or equal to 0.2, provided the value of the seismic response coefficient C_s is increased by up to 50 percent at periods greater than T_s (by effectively extending the acceleration domain to $1.5T_s$).
  - Structures on Site Class E sites with S_1 greater than or equal to 0.2, provided that T is less than or equal to T_s and the equivalent static force (ELF) procedure is used for design.

Example Values of the Design Coefficient (C_s)

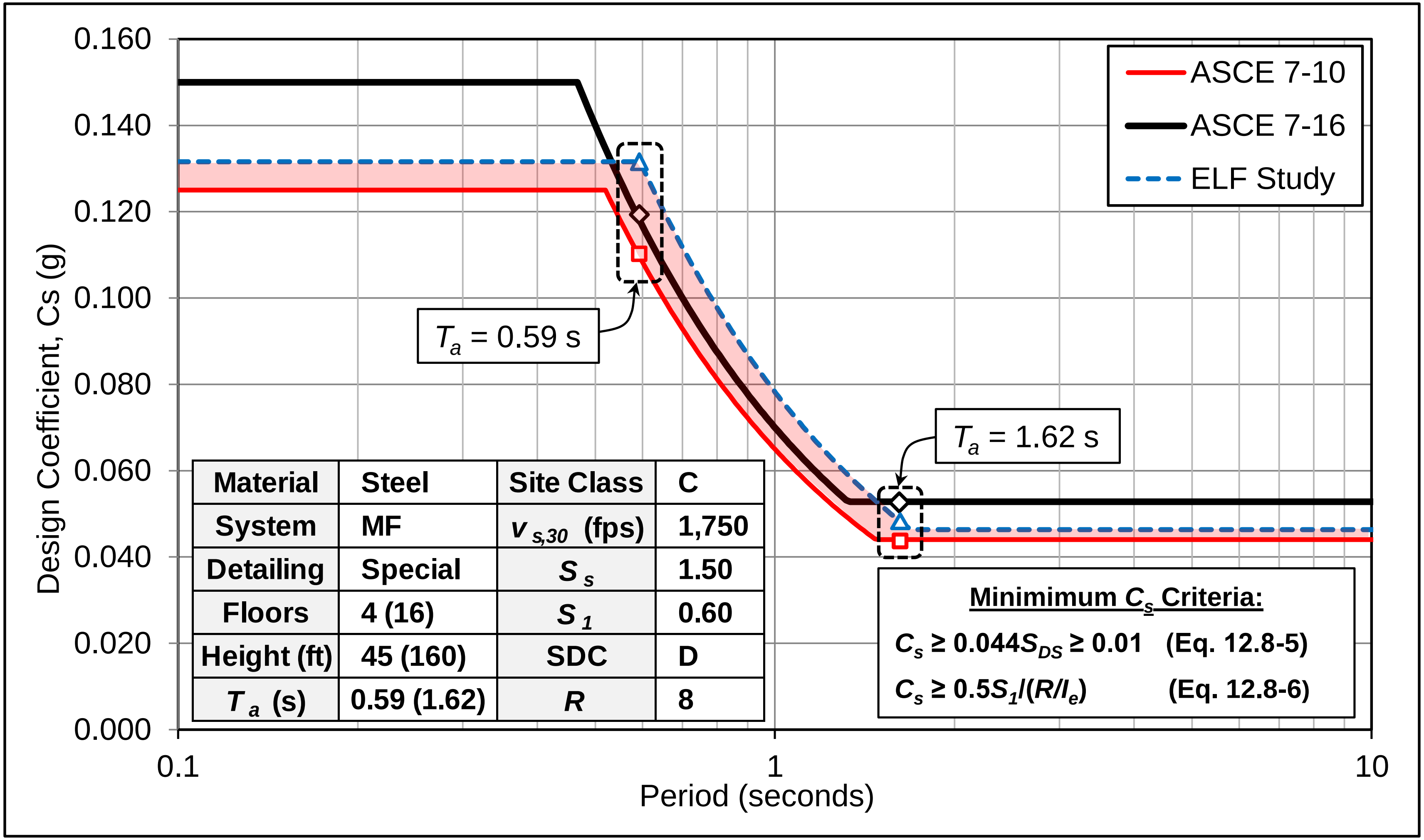
- One (High Seismic) Site - S_s = 1.5 g, S_1 – 0.6 g
- Two Structural Systems:
  - 4-Story Steel SMF Building – T_a = 0.59 s (acceleration domain)
  - 15-Story Steel SMF Building – T_a = 1.62 s (velocity domain)
- Three Site Conditions (each system) – Site Class B, C, D and E
- Three Sets of ELF Design Criteria (each example):
  - ASCE 7-10 – Existing design requirements of ASCE 7-10
  - **ASCE 7-16 – New design requirements of ASCE 7-16 including the new site-specific requirements <u>and exceptions</u> of Section 11.4.8**
  - ELF Study - What if ASCE 7-16 had adopted the spectrum shape adjustment factors (SSAFs) of BSSC PUC "ELF" Study (Kircher et al., 2015) to modify the frequency content of the Design Spectrum?

Example Comparison of the Design Coefficient (C_s)
4-Story and 15-Story Steel Special Moment Frame Buildings - Site Class B



Material	Steel	Site Class	B
System	MF	$v_{s,30}$ (fps)	3,500
Detailing	Special	S_s	1.50
Floors	4 (16)	S_1	0.60
Height (ft)	45 (160)	SDC	D
T_a (s)	0.59 (1.62)	R	8

Example Comparison of the Design Coefficient (C_s)
4-Story and 15-Story Steel Special Moment Frame Buildings - Site Class C



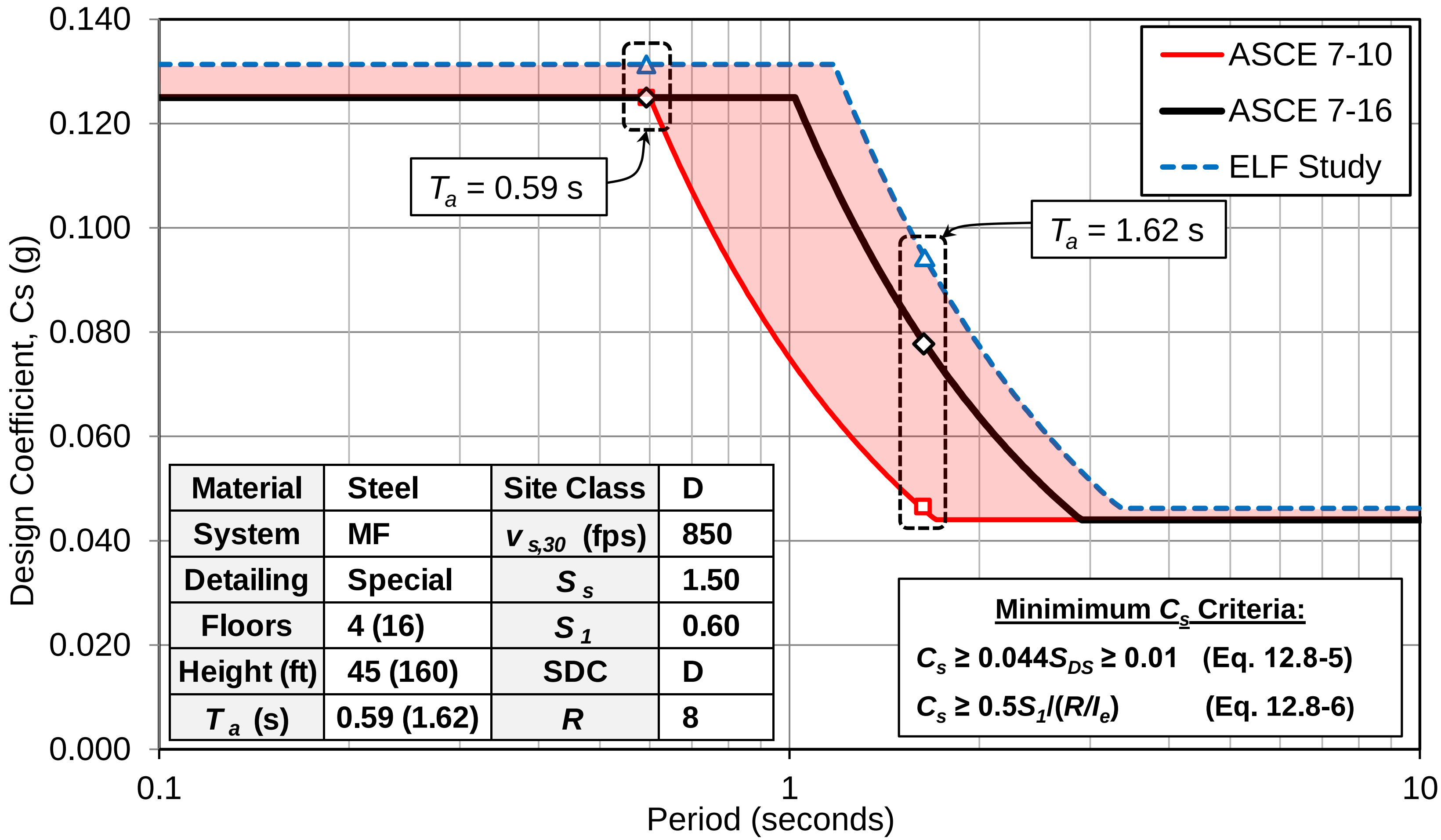
Material	Steel	Site Class	C
System	MF	$v_{s,30}$ (fps)	1,750
Detailing	Special	S_s	1.50
Floors	4 (16)	S_1	0.60
Height (ft)	45 (160)	SDC	D
T_a (s)	0.59 (1.62)	R	8

Minimum C_s Criteria:

$C_s \geq 0.044 S_{DS} \geq 0.01$ (Eq. 12.8-5)

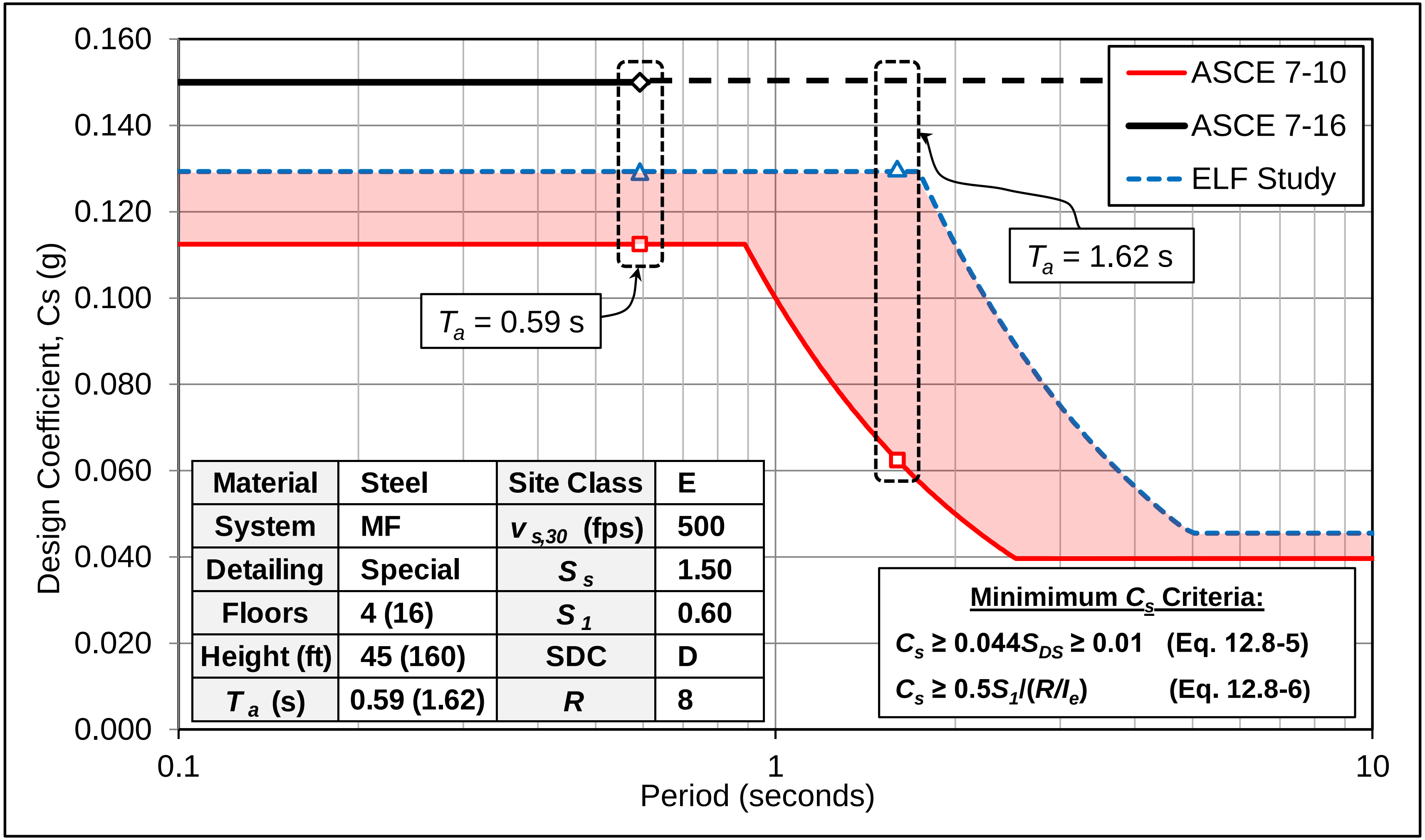
$C_s \geq 0.5 S_1 / (R/I_e)$ (Eq. 12.8-6)

Example Comparison of the Design Coefficient (C_s)
4-Story and 15-Story Steel Special Moment Frame Buildings - Site Class D



Material	Steel	Site Class	D
System	MF	$v_{s,30}$ (fps)	850
Detailing	Special	S_s	1.50
Floors	4 (16)	S_1	0.60
Height (ft)	45 (160)	SDC	D
T_a (s)	0.59 (1.62)	R	8

Example Comparison of the Design Coefficient (C_s)
4-Story and 15-Story Steel Special Moment Frame Buildings - Site Class E



Material	Steel	Site Class	E
System	MF	$v_{s,30}$ (fps)	500
Detailing	Special	S_s	1.50
Floors	4 (16)	S_1	0.60
Height (ft)	45 (160)	SDC	D
T_a (s)	0.59 (1.62)	R	8

Minimum C_s Criteria:

$C_s \geq 0.044 S_{DS} \geq 0.01$ (Eq. 12.8-5)

$C_s \geq 0.5 S_1/(R/I_e)$ (Eq. 12.8-6)

Summary and Conclusions

- **Impact on New Building Design**. The new site-specific requirements (and exceptions) of Section 11.4.8 of ASCE 7-16 will have a significant impact on the design of mid-period buildings at Site Class D and E sites (e.g., 50+ percent increase in design forces).
  – Existing Building Safety. Implications for existing buildings (??).
- **Interim Solution**. The new site-specific design requirements of Section 11.4.8 of ASCE 7-16 provide an interim solution that can and should be replaced by a more appropriate long-term solution in the next Code cycle (ASCE 7-22).
- **Long-Term Solution**. A long-term solution would necessarily include seismic criteria described by multi-period MCE_R response spectra (currently under development by *Project '17*).
  – Design Spectrum Shape. Ideally, multi-period design spectra directly incorporate site, basin and other effects that influence the shape (i.e., frequency content) of the design spectrum.

Questions?