Project 17 – Development of Next-Generation Seismic Design Values Maps

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Multi-Period Response Spectra and Design Parameters (of the 2020 NEHRP Provisions and ASCE 7-22)

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PUC Meeting – November 29, 2017

Project 17 Teleconference – January 29, 2018

PUC Meeting – April 4-5, 2018

ASCE 7 SSC Meeting – July 13-14, 2018

SCEC UGMS Meeting – November 7, 2018

PUC Meeting – December 4-5, 2018

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Presentation Topics

- Background Material
  - *Project 17* and BSSC PUC
  - Design Response Spectrum (Figure 11.4-1 of ASCE 7-16)
- The Problem – Root Cause
- Interim Solution (ASCE 7-16)
  - Revise Site-Specific Requirements
- Long-Term Solution (ASCE 7-22)
  - *Project 17* – multi-period response spectra (MPRS)
  - **MPRS Study – ATC project funded by FEMA**
  - USGS – Mapped values of MPRS
  - BSSC PUC – 2020 NEHRP Provisions
  - ASCE 7 – ASCE 7-22

Approach for Developing Multi-Period Spectra for All Sites of Interest (US plus non-US sites)

- Administrative Issues:
  - "Science" must be augmented with judgment for some (e.g., non-WUS) sites (beyond USGS comfort level)
  - Project 17/PUC/ASCE 7 to approve the approach and methods; USGS to implement methods (e.g., of a referenceable report)
- MPRS Study (ATC/FEMA)
  - Considerable effort required to develop methods and document in a referenceable report (basis for proposal)
- Technical Issues (numerous):
  - Develop process to "fill in the blanks" for US regions with incomplete hazard data (e.g., use reliable GMPEs to define generic response spectrum shapes)
  - Verify applicability to sites with different hazard (site and source) characteristics (e.g., multiple contributing sources)

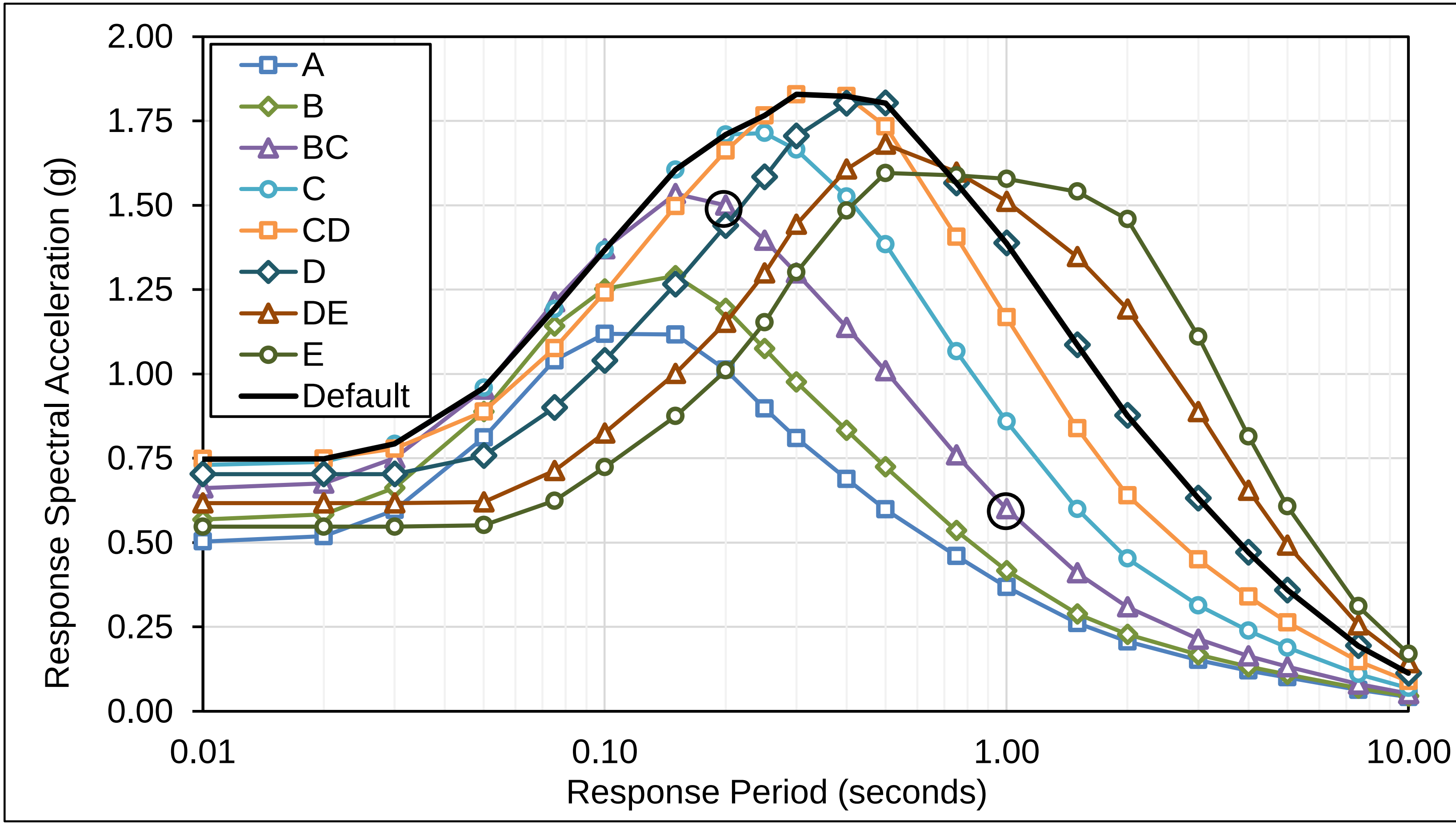
Matrix showing the combinations of twenty-one response periods and eight site classes proposed as the standard format of multi-period response spectra

- Regions with GMPEs for all 21 x 8 combinations:
  - WUS
  - CEUS
- Regions with only two combinations (S_S and S_1):
  - Alaska
  - Hawaii
  - Puerto Rico and the VI
  - Guam and American Samoa
  - U.S. military sites world-wide (UFC criteria)

T (s)	Site Class							
	A	B	BC	C	CD	D	DE	E
0.010								
0.020								
0.030								
0.050								
0.075								
0.10								
0.15								
0.20			X					
0.25								
0.30								
0.40								
0.50								
0.75								
1.0			X					
1.5								
2.0								
3.0								
4.0								
5.0								
7.5								
10.0								

Example MCE Multi-Period Response Spectra (MPRS)

(proposed Deterministic MCE Lower Limit, new Table 21.2-1, anchored to $S_S = S_{SD} = 1.5$ g, $S_1 = S_{1D} = 0.6$ g)



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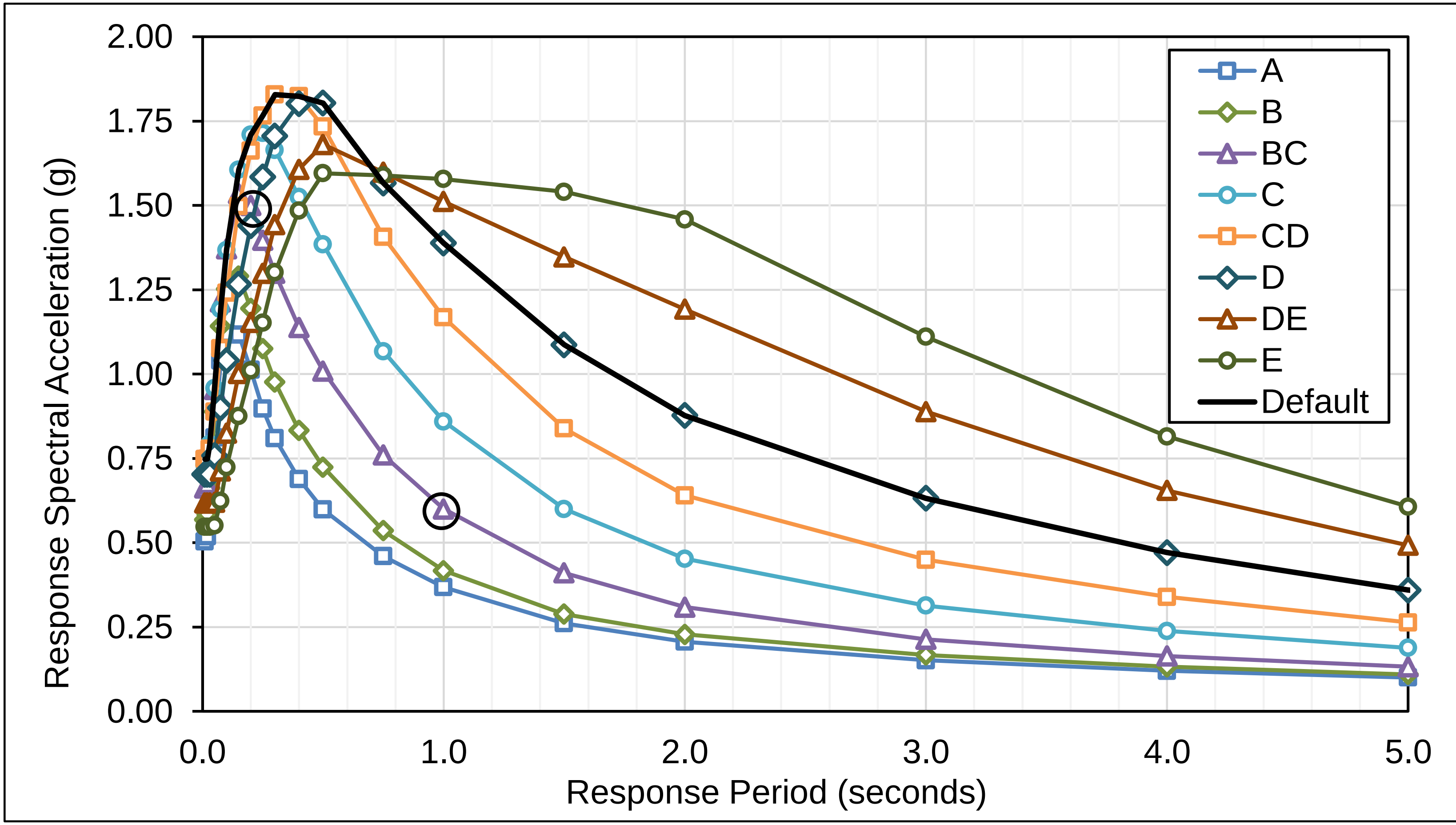

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MPRS Study (ATC-136)

- Purpose
  - Compliment MPRS proposals to the PUC for the 2020 *NEHRP Recommended Provisions*
- Primary Objective
  - Provide technical basis for USGS (or others) to develop MPRS for regions where existing GMPES do not adequately define response at all periods and site classes
- Deliverables
  - FEMA/ATC Report
- Schedule
  - 100% draft report February 2019 (PUC ballot #7)

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MPRS Study Report (draft outline)

1. Introduction
2. Background
3. Approach
4. Probabilistic MCE MPRS
5. Deterministic MCE MPRS
6. Validation
7. Example Applications
8. Conclusion

Appendices (with MPRS data)

MPRS Study Approach

- Common MPRS Format (all regions)
  - Same matrix of 21 response periods (plus PGA) x 8 site classes for sites of interest
- Key Hazard Parameters are:
  - Important to spectrum shape (frequency content)
  - Available for all sites of interest
    - S_S (M_S), S_1 (M_1) and T_L
- Develop Generic MCE MPRS Shapes
  - Function of key hazard parameters
  - Based on PEER NGA-West2 GMPEs (like F_a and F_v)
  - Different for Probabilistic MCE and Deterministic MCE
  - Different for short-period and long-period response (Deterministic)
- Develop Site-Specific Methods (e.g., based on S_S and S_1)

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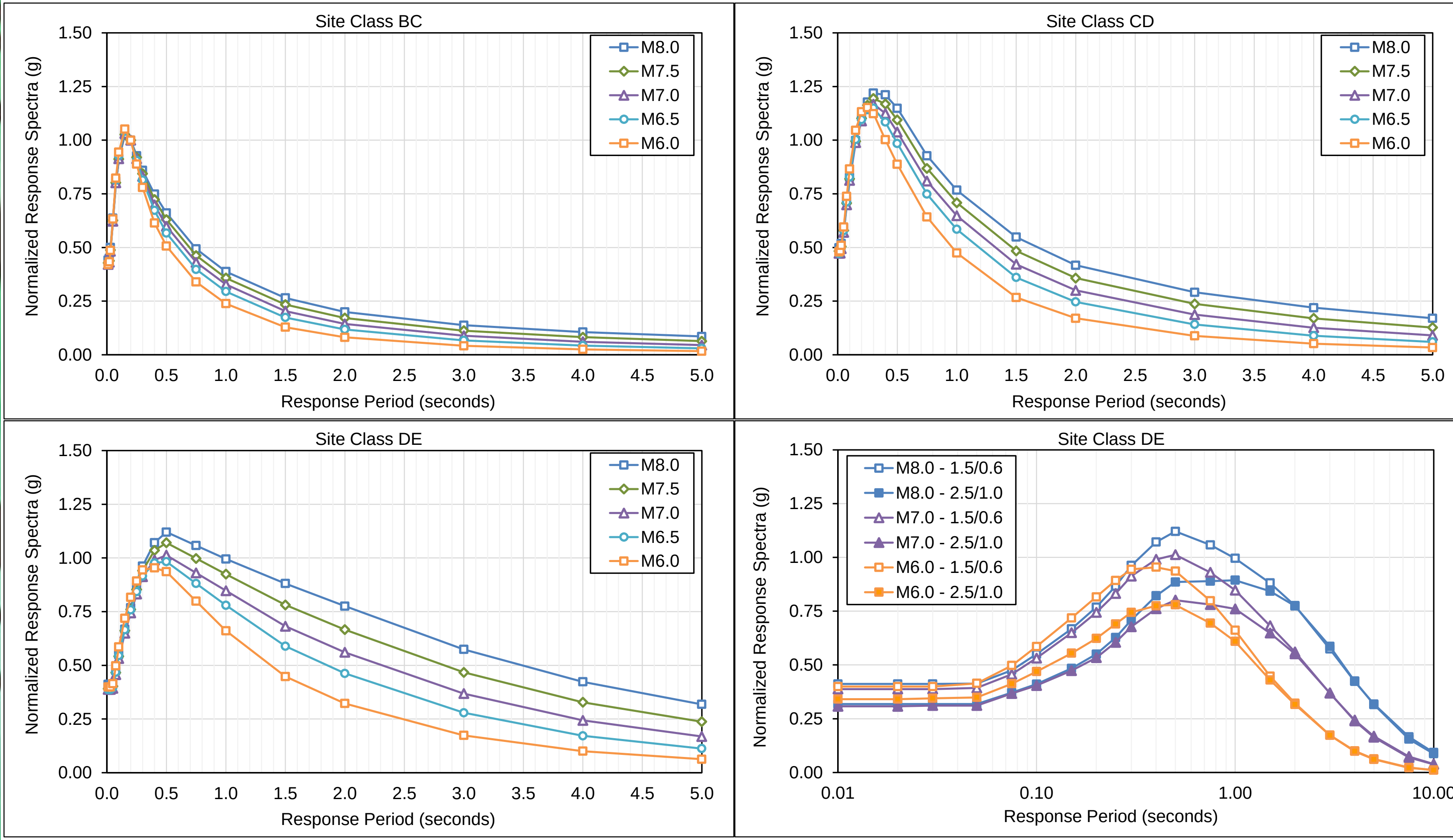
Deterministic MCE MPRS Approach

- Develop Generic MCE MPRS Shapes
  - Based directly on NGA-West-2 GMPEs as a:
  - Function of site class (i.e., A, B, BC, C, CD, D, DE, E)
  - Function of magnitude M (e.g., M6.0 to M8.0)
  - Function of shaking level (e.g., S_S = 1.5 g/S_1 = 0.6 g)
- Site-Specific MCE MPRS Procedure
  - Select generic shape(s) that best represent magnitude (governing hazard) level of shaking for the site of interest
  - Short-period range (e.g., 0.0 s to period of peak acc. resp.)
    - Scale generic MCE MPRS shape to S_S
  - Long-period range (e.g., period of peak vel. resp. to 10 s)
    - Scale generic MCE MPRS shape to S_1
  - Mid-period range
    - "Blend" short-period and long-period MCE MPRS

Example Generic Deterministic MCE MPRS Shapes

Site Class BC, CD and DE – S_S = 1.5 g/S_1 = 0.6 g

S_S = 1.5 g/S_1 = 0.6 g, S_S = 2.5 g/S_1 = 1.0 g – Site Class DE (lower right)



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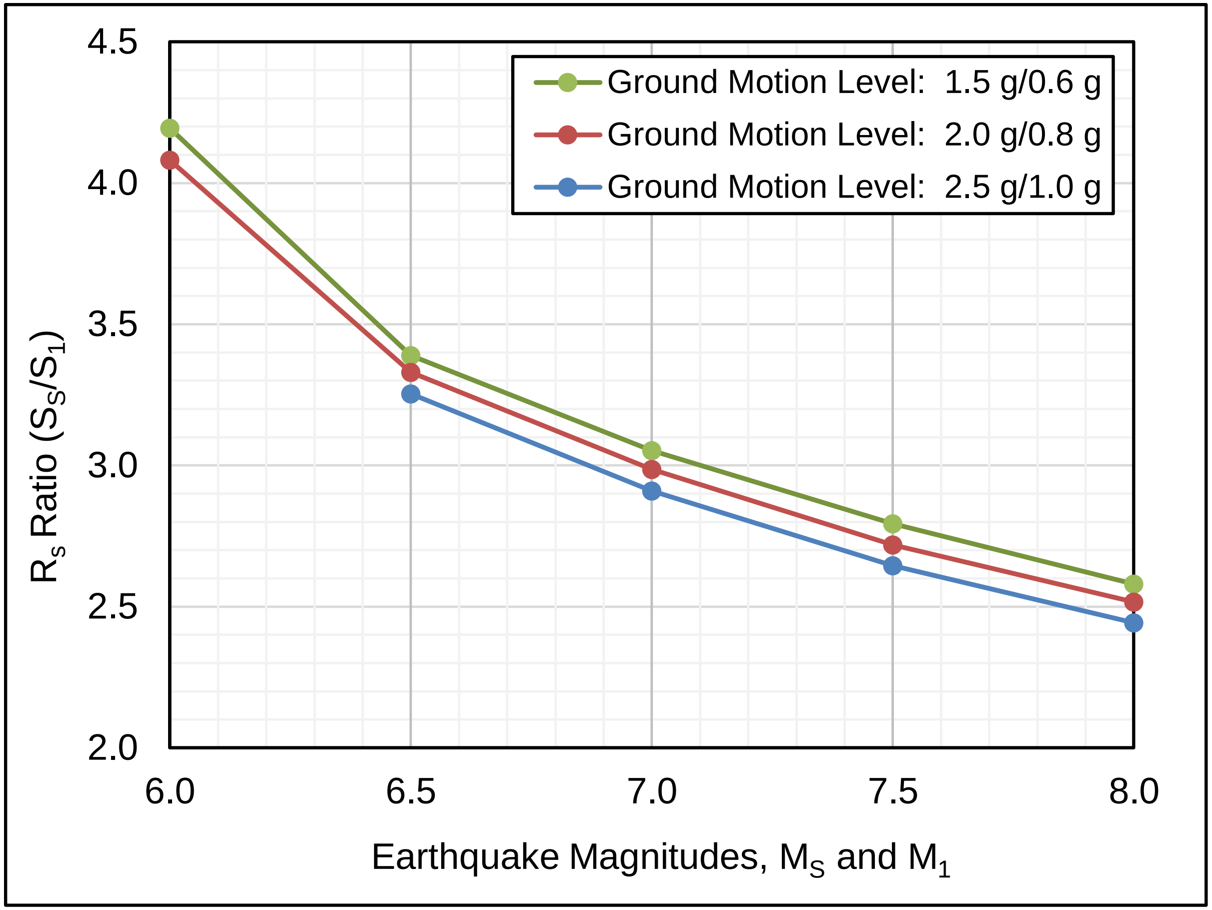
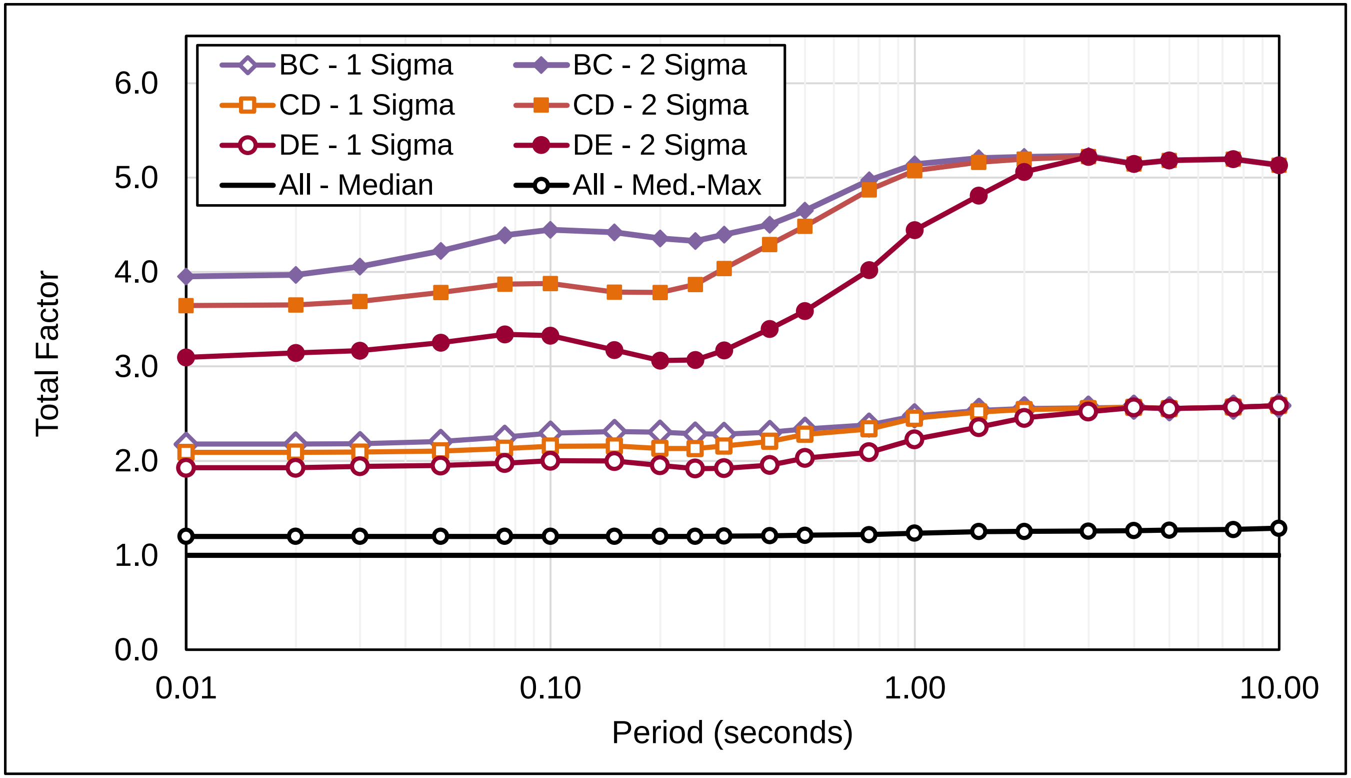
Relationship of Magnitude M and $R_S = S_S/S_1$
(for estimating values of governing magnitudes M_S and M_1)



Example Period-Dependent Factors Relating Median Geo-mean Ground Motions to Maximum Direction Deterministic MCE (+ 1 Sigma) and Very Rare (+2 Sigma) Probabilistic MCE Ground Motions - Magnitude M8.0 at 12.5 km NGA-West2 Ground Motions

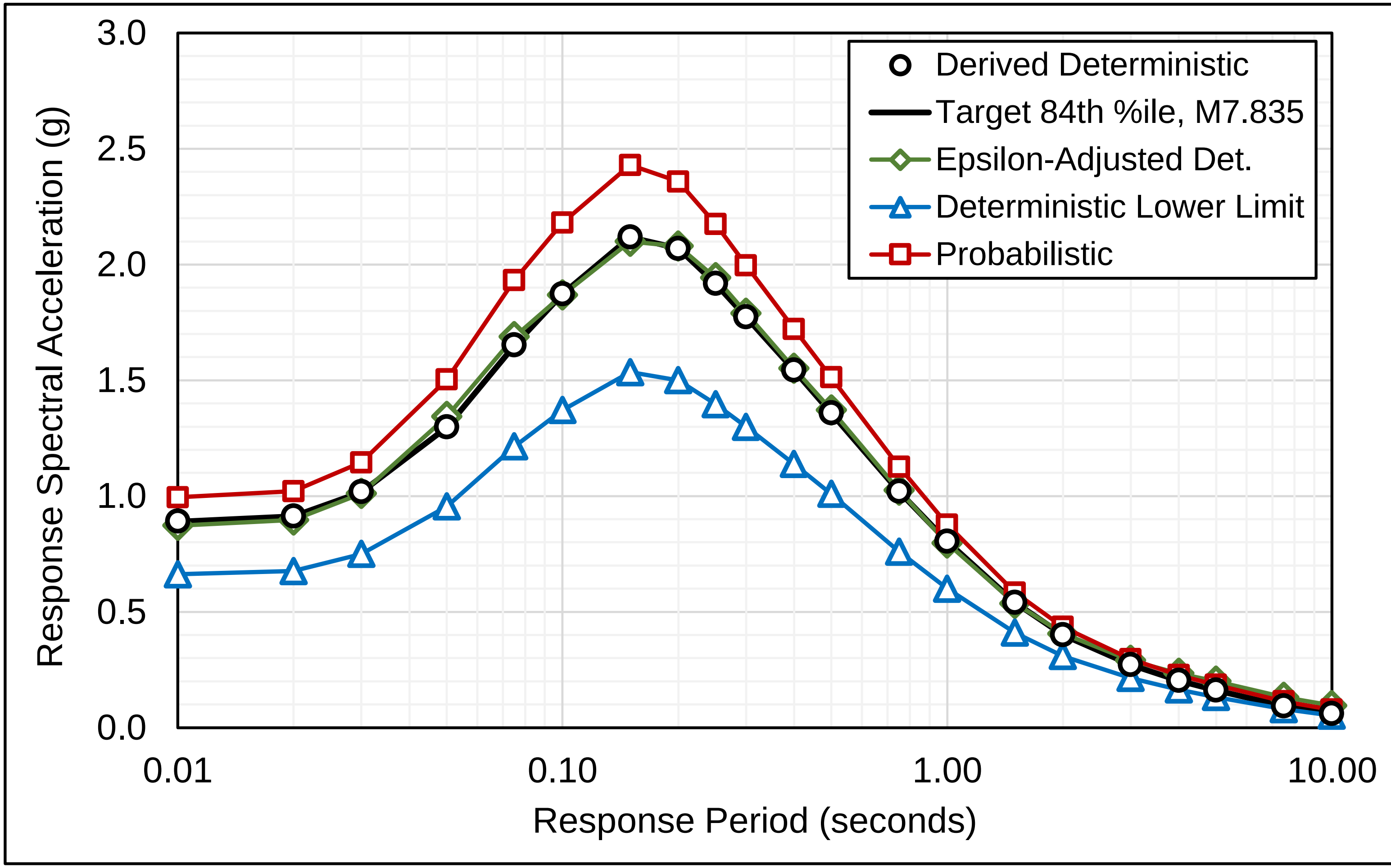


Example Deterministic MCE MPRS for the San Mateo Site (37.55, -122.3)

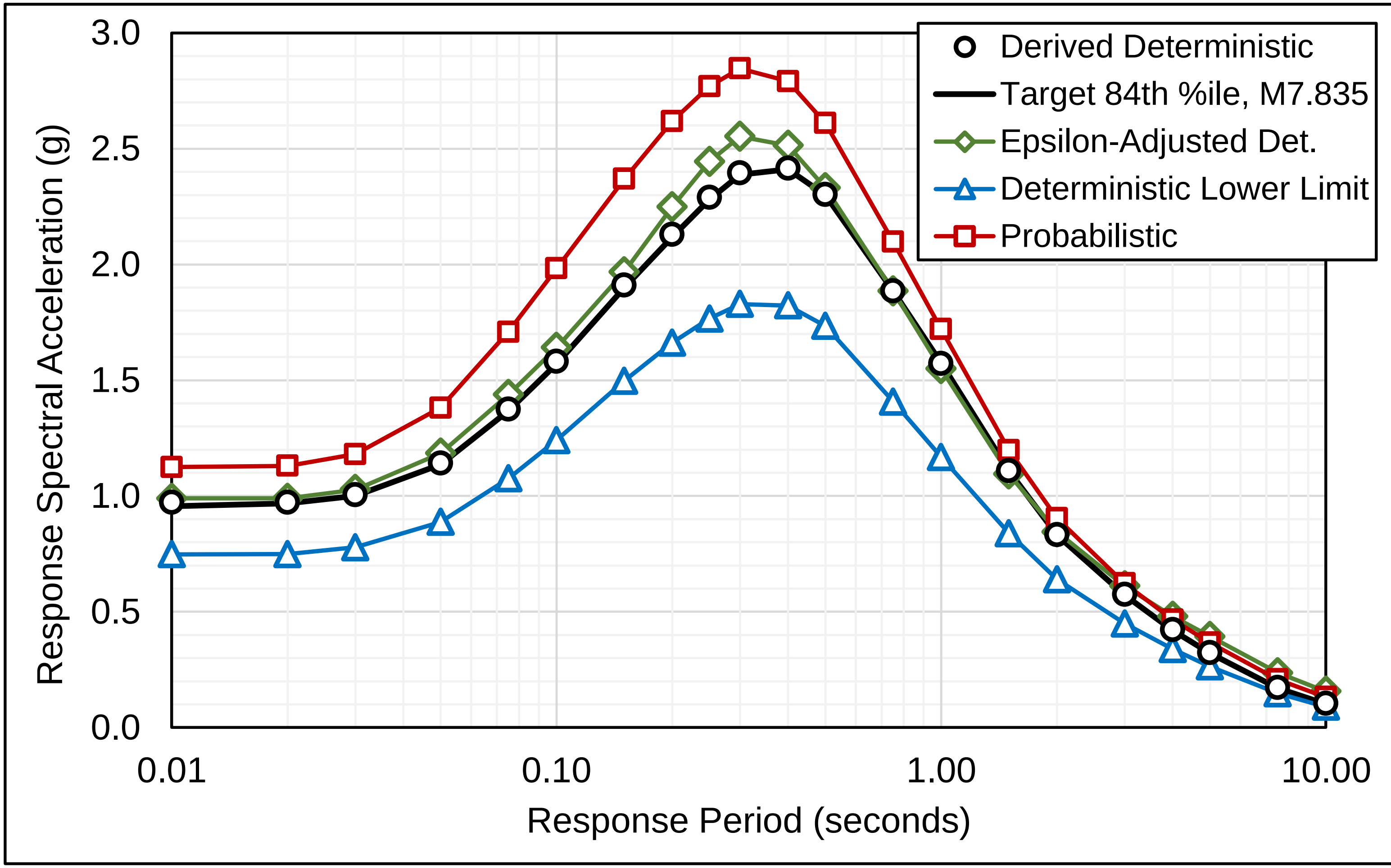
Example Deterministic MCE MPRS for the San Mateo Site (37.55, -122.3)

- Site-Specific Parameters (Luco, 2018)
  - S_S ($S_S = S_{SD}$) = 2.079 g
  - S_1 ($S_1 = S_{1D}$) = 0.797 g
  - $M_S = M_1$ = M7.835 (based on $R_S = S_S/S_1 = 2.6$
  - R_x = 6.26 km
- Compare Deterministic MCE MPRS "Derived" from Site-Specific Parameters with:
  - "Target" (84th percentile) MPRS – M7.835 at R_x = 6.26 km
  - "Epsilon-adjusted" deterministic MCE MPRS (Luco, 2018)
  - Probabilistic MCE MPRS motions (Luco, 2018)
  - Lower limit Deterministic MCE MPRS (as proposed for new Table 21.2-1)

Comparison of MCE Response Spectra for the San Mateo Site (37.55, -122.3) assuming Site Class BC Conditions



Comparison of MCE Response Spectra for the San Mateo Site (37.55, -122.3) assuming Site Class CD Conditions



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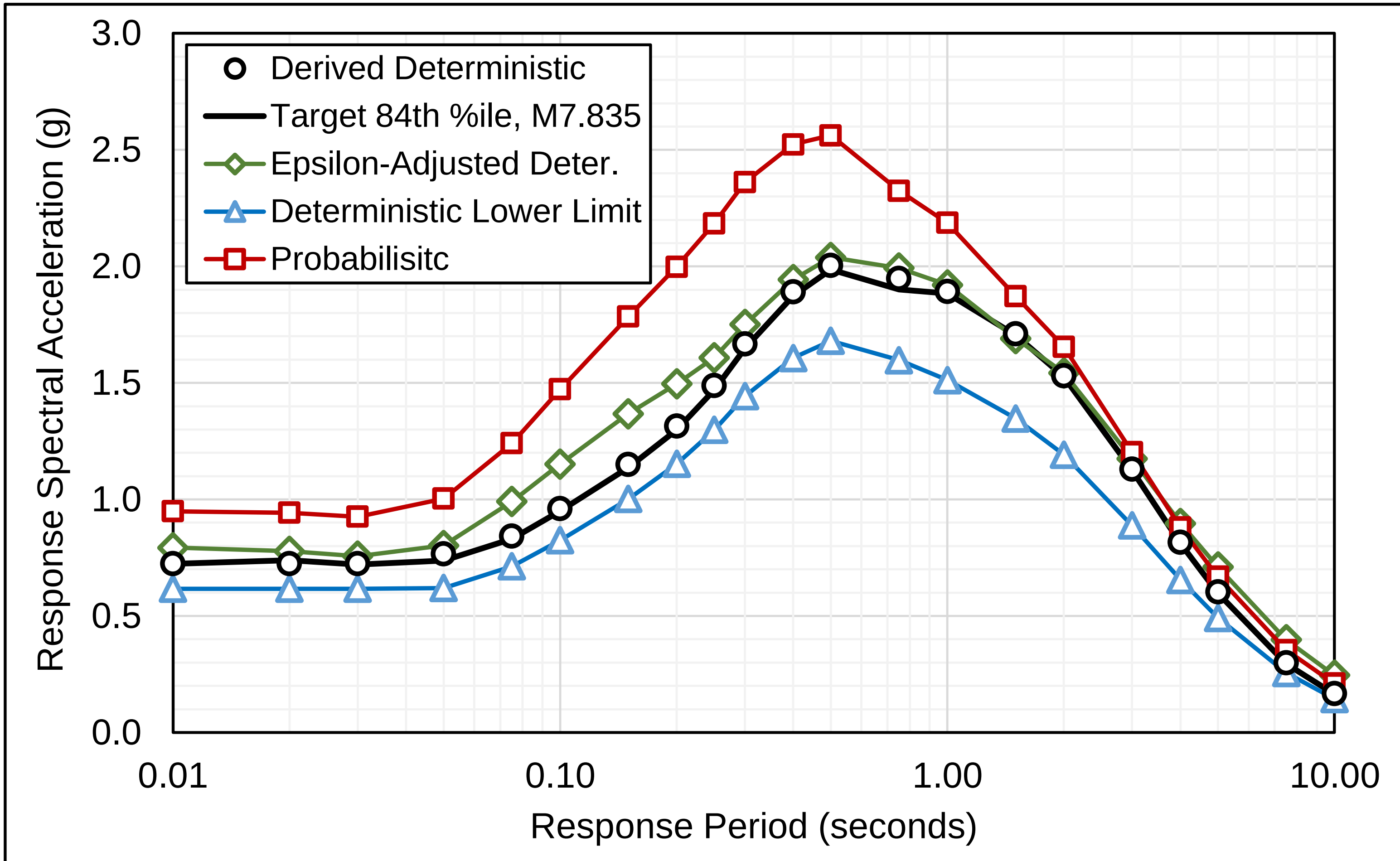
Comparison of MCE Response Spectra for the San Mateo Site (37.55, -122.3) assuming Site Class DE Conditions



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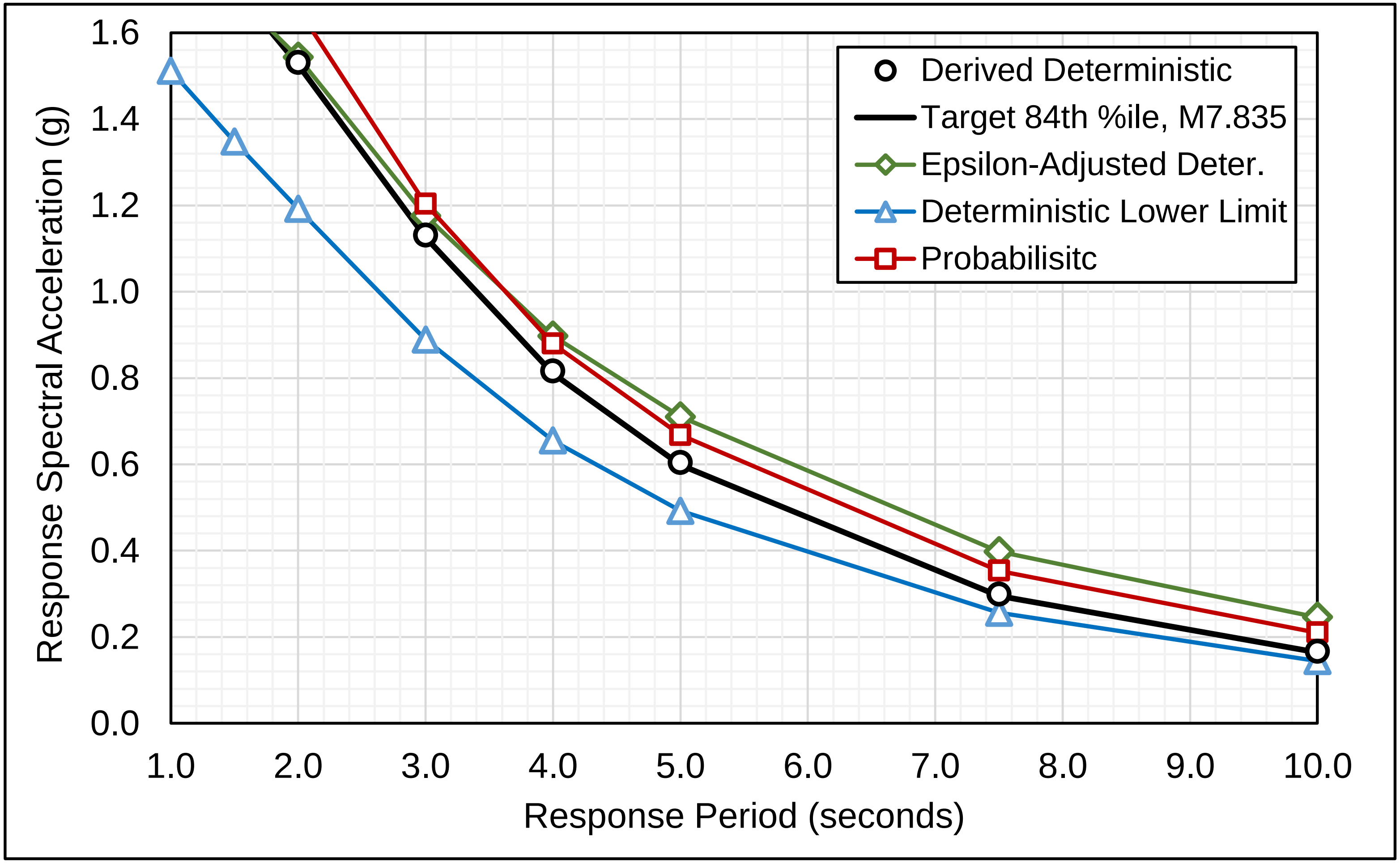
Comparison of MCE Response Spectra for the San Mateo Site (37.55, -122.3) assuming Site Class DE Conditions



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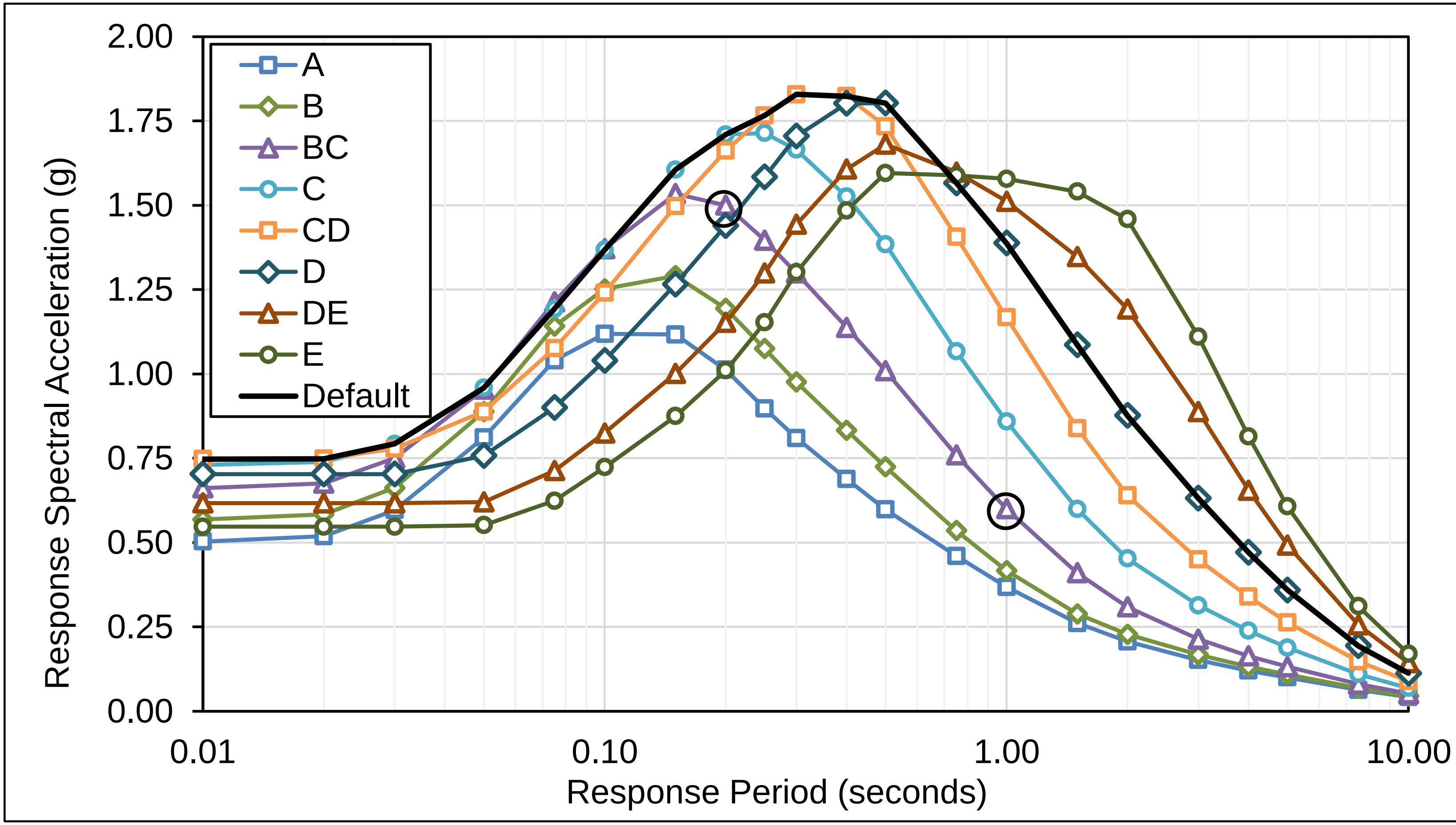
Example MCE Multi-Period Response Spectra (MPRS)

(proposed Deterministic MCE Lower Limit, new Table 21.2-1, anchored to $S_S = S_{SD} = 1.5$ g, $S_1 = S_{1D} = 0.6$ g, 2015 *NEHRP Provisions*)



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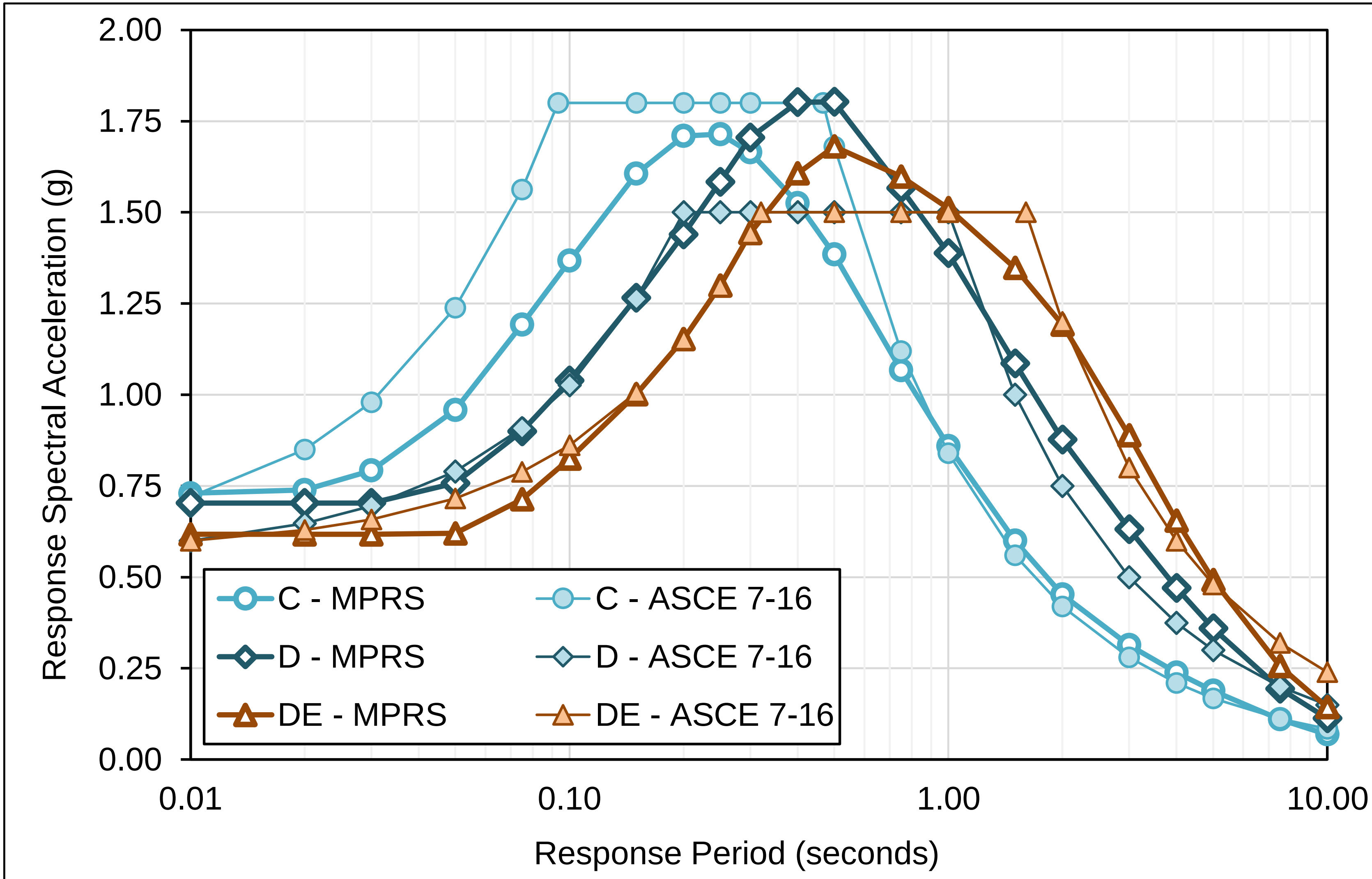
Comparison of Lower Limit Deterministic MCE response spectra, Site Classes C, D, DE, ASCE 7-16 and MPRS (as proposed)



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What If a Smaller Magnitude is Used to Define the Lower Limit?

Ratio of Proposed Lower Limit Deterministic MCE MPRS based on a Magnitude M8.0 Earthquake to those based on a Magnitude M7.5 Earthquake

Period *T (s)*	5%-Damped Response Spectral Acceleration or PGA by Site Class (g)								
	A	**B**	**BC**	**C**	**CD**	**D**	**DE**	**E**	**Default**
PGA	102.9%	102.9%	103.0%	103.2%	103.4%	103.5%	103.6%	104.8%	103.4%
0.010	102.9%	102.9%	103.0%	103.2%	103.2%	103.0%	105.1%	104.8%	103.2%
0.020	102.7%	102.7%	102.8%	103.0%	103.1%	103.0%	105.1%	104.8%	103.1%
0.030	102.3%	102.3%	102.4%	102.6%	102.8%	103.0%	105.1%	104.8%	102.6%
0.050	101.5%	101.5%	101.7%	101.9%	102.2%	102.4%	102.8%	102.2%	101.9%
0.075	100.7%	100.7%	100.9%	101.2%	101.5%	101.7%	102.0%	102.1%	101.2%
0.10	100.1%	100.1%	100.3%	100.6%	100.9%	101.2%	101.5%	101.6%	100.6%
0.15	99.5%	99.5%	99.7%	100.0%	100.3%	100.6%	100.9%	101.0%	100.0%
0.20	100.0%	100.0%	**100.0%**	100.3%	100.6%	100.8%	101.1%	101.2%	100.3%
0.25	100.0%	100.0%	99.6%	100.6%	101.2%	101.4%	101.5%	101.6%	101.2%
0.30	100.2%	100.2%	99.6%	99.2%	102.1%	102.2%	102.2%	102.3%	102.1%
0.40	100.8%	100.8%	99.8%	99.1%	101.9%	103.6%	103.5%	103.4%	101.9%
0.50	101.5%	101.5%	100.1%	99.3%	101.8%	103.7%	104.7%	104.5%	103.7%
0.75	101.9%	101.9%	99.9%	99.0%	101.2%	103.6%	104.1%	104.0%	103.6%
1.0	102.3%	102.3%	**100.0%**	98.9%	101.0%	103.9%	104.3%	103.9%	103.9%
1.5	105.6%	105.6%	104.6%	104.1%	103.3%	107.0%	107.3%	107.0%	107.0%
2.0	107.7%	107.7%	107.7%	107.7%	106.8%	109.2%	109.4%	109.3%	109.2%
3.0	113.5%	113.5%	113.5%	113.5%	113.1%	113.5%	113.5%	113.5%	113.5%
4.0	119.2%	119.2%	119.2%	119.2%	119.2%	119.2%	119.2%	119.2%	119.2%
5.0	123.8%	123.8%	123.8%	123.8%	123.8%	123.8%	123.8%	123.8%	123.8%
7.5	133.1%	133.1%	133.1%	133.1%	133.1%	133.1%	133.1%	133.1%	133.1%
10	135.6%	135.6%	135.6%	135.6%	135.6%	135.6%	135.6%	135.6%	135.6%

Questions/Comments?

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Project 17 Planning Committee Report Recommendations – Scope - Multi-Period Spectral Values

- During the closing months of the 2015 PUC cycle, study was undertaken of compatibility of current Site Class coefficients, F_a and F_v with the NGA ground motion prediction equations (GMPEs) used by USGS to produce the design maps. In the course of this study, it was discovered that the standard spectral shape derived from the S_{DS}, S_{D1}, and T_L parameters is not appropriate for soft soil sites (Site Class D or softer) where hazard is dominated by large magnitude events. Specifically, on such sites, the standard spectral shape overstates the spectral demands for short period structures, and substantially understates spectral demand for moderately long period structures. The PUC initiated a proposal to move to specification of spectral acceleration values over a range of periods, abandoning the present three parameter format, as this would provide better definition of likely ground motion demands. However, this proposal was ultimately not adopted due to both the complexity of implementing such a revision in the design procedure and time constraints. Instead, the PUC adopted a proposal prohibiting the use of the general three-parameter spectrum, and instead requiring site-specific hazard determination for longer period structures on soft soil sites.
- Project 17 is charged with re-evaluating the use of multi-period spectra as a replacement or supplement to the present three-parameter spectral definition. If the multi-period spectral definition is indeed adopted, then Project 17 should also evaluate whether basin effects, near field effects and other effects typically included in site-specific studies should be considered in development of the maps. It will also be necessary for the Project 17 Committee to consider how the basic design procedures embedded in ASCE 7 should be modified for compatibility with the multi-period spectra.

Project 17 Planning Committee Report Recommendations – Level of Effort

- **Task Committee Multi-Period Spectral Values:**

  This committee should include approximately 7 persons including practicing structural and geotechnical engineers; and, USGS representatives. It is envisioned that this task committee will meet once per quarter for a period of 18 months, then twice per year for the remaining project duration.

- **Multi-Period Spectra Task Committee (MPS TC) Members:**

  Charlie Kircher – CKA (Chair)
  Nico Luco - USGS
  Sanaz Razaeian – USGS
  C.B. Crouse - AECOM
  Jonathan Stewart - UCLA
  John Hooper – MKA
  David Bonneville - Degendkolb

Schedule of Meetings and Deliverables

- *Project 17*:
  - May 17, 2016 – MPS TC developed conceptual improvements
  - July 18, 2016 – *Project 17* approved conceptual approach
  - November 7, 2017 – MPS TC reviewed/updated draft proposals (Chapters 11, 20, 21 and 22)
  - January 29, 2017 – *Project 17* approved revised draft proposals
- MPRS Study (ATC)
  - December 2018 – Draft MPRS report for BSSC PUC review
- BSSC PUC:
  - April 4-5, 2018 – Tentative approval of draft MPRS proposals with recommended modifications
  - December 4-5, 2018 – Resolution of straw ballot comments
  - April 2019 – Resolution of final (?) ballot comments

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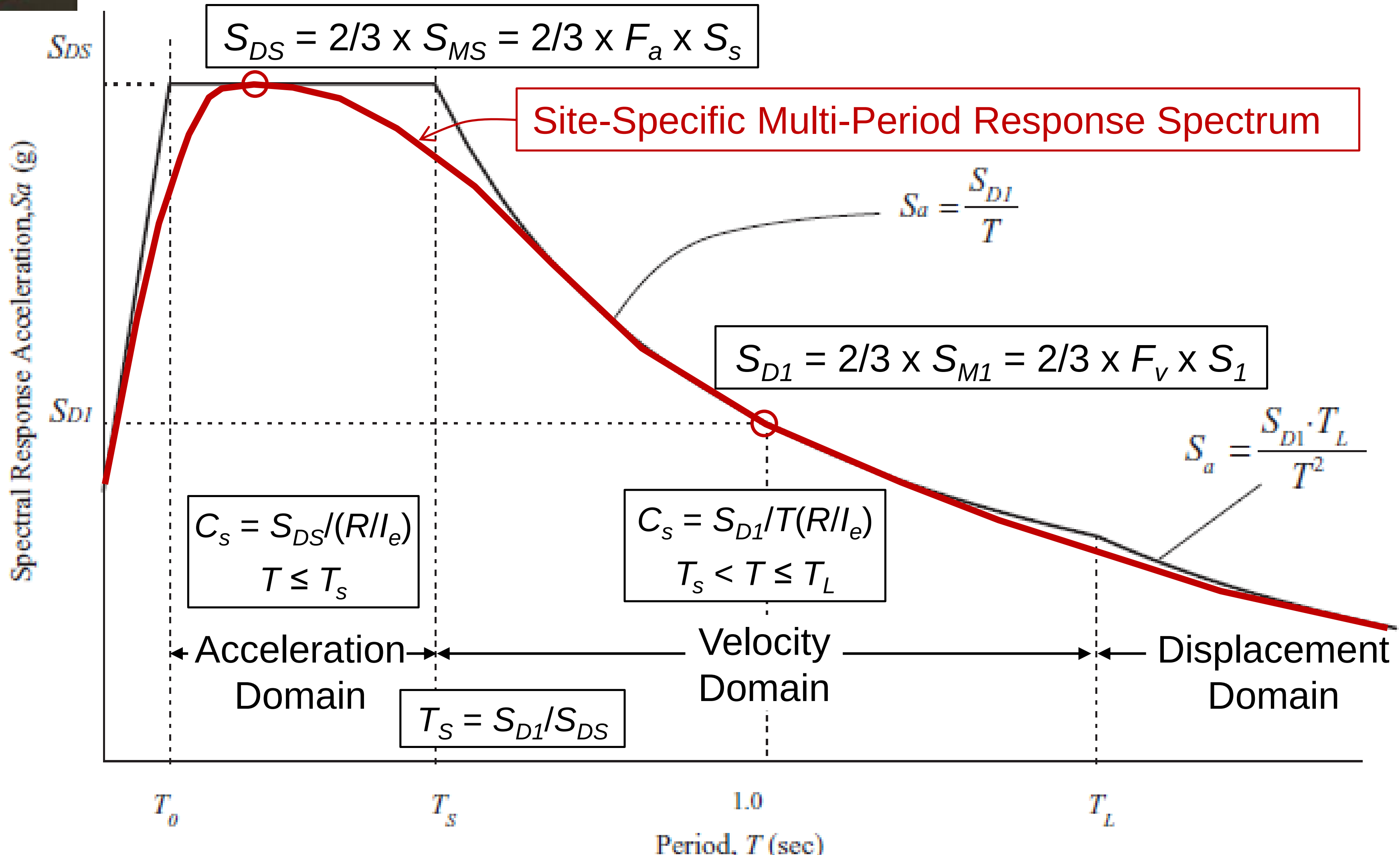
Design Response Spectrum

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



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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>

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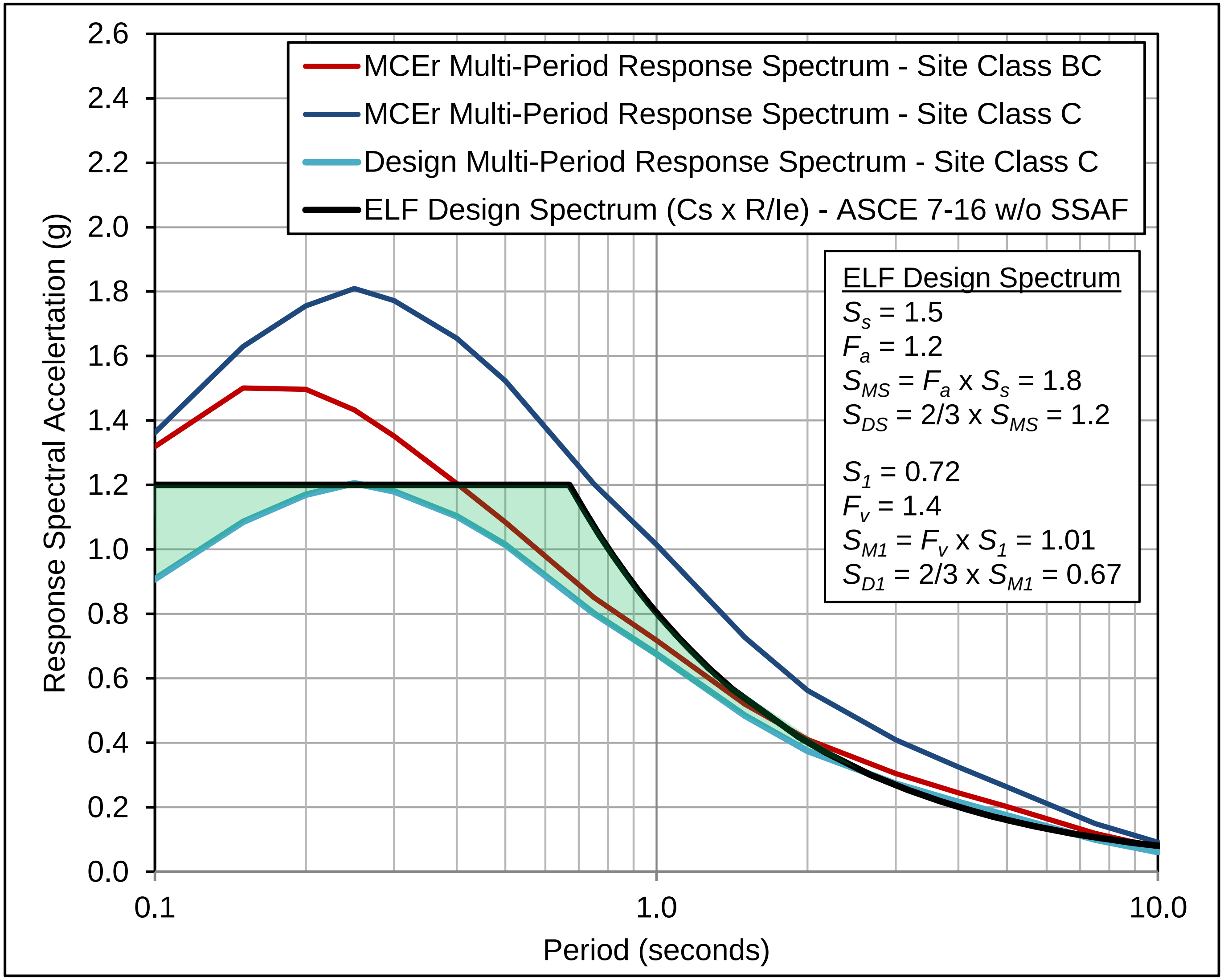
Example ELF “Design Spectrum” - ASCE 7-16 w/o New Site-Specific Requirements (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class C)



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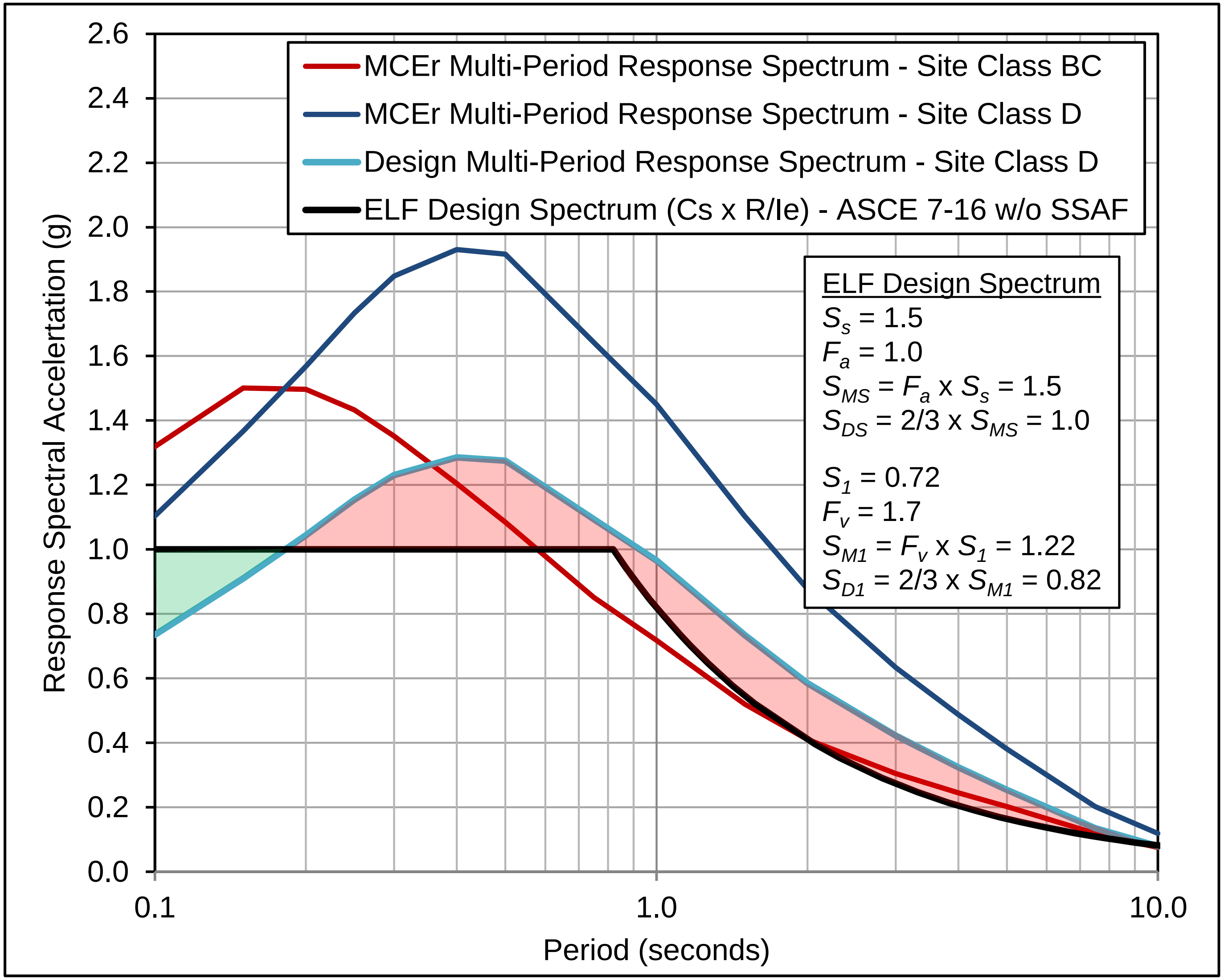
Example ELF "Design Spectrum" - ASCE 7-16 w/o New Site-Specific Requirements (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class D)



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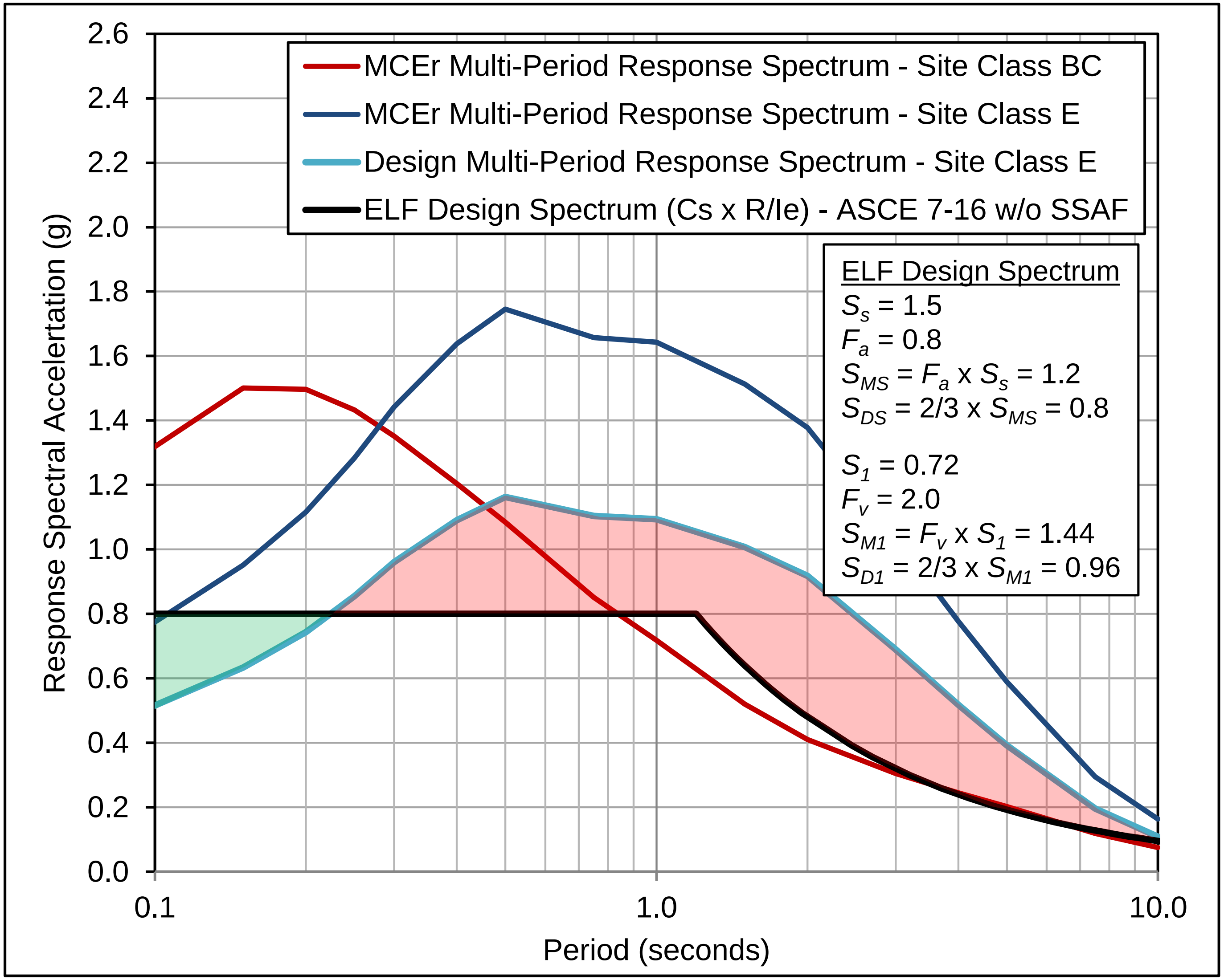
Example ELF "Design Spectrum" - ASCE 7-16 w/o New Site-Specific Requirements (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class E)



New Site-Specific Requirements of Section 11.4.7 of ASCE 7-16

- Site-specific ground motion procedures required 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.
- Exceptions 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 <u>site coefficient F_a is taken as equal to that of Site Class C</u>.
  - Structures on Site Class D sites with S_1 greater than or equal to 0.2, provided the value of the <u>seismic response coefficient C_s is increased by up to 50 percent at periods greater than T_s</u> (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 <u>T is less than or equal to T_s and the equivalent static force procedure is used for design</u>.

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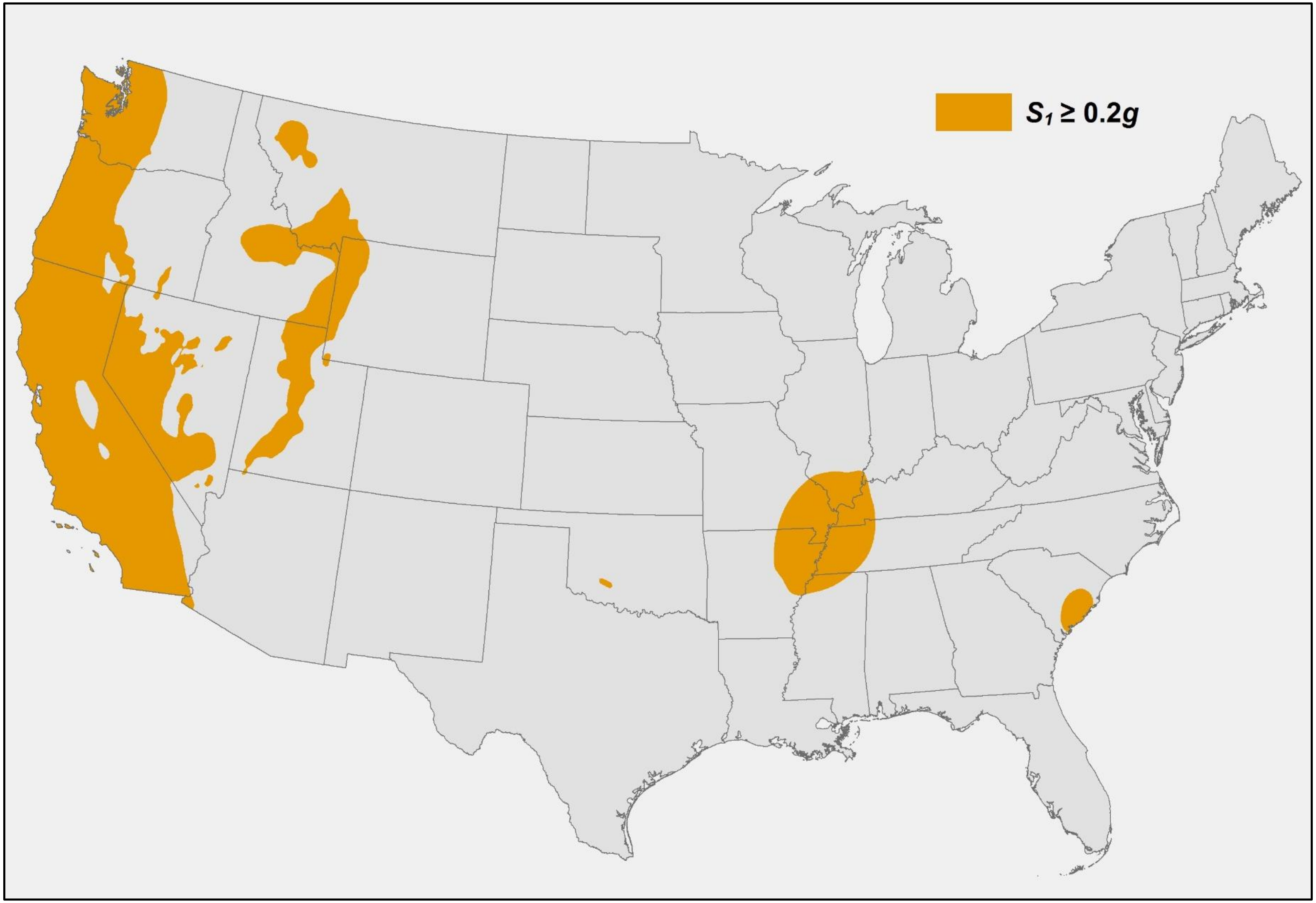
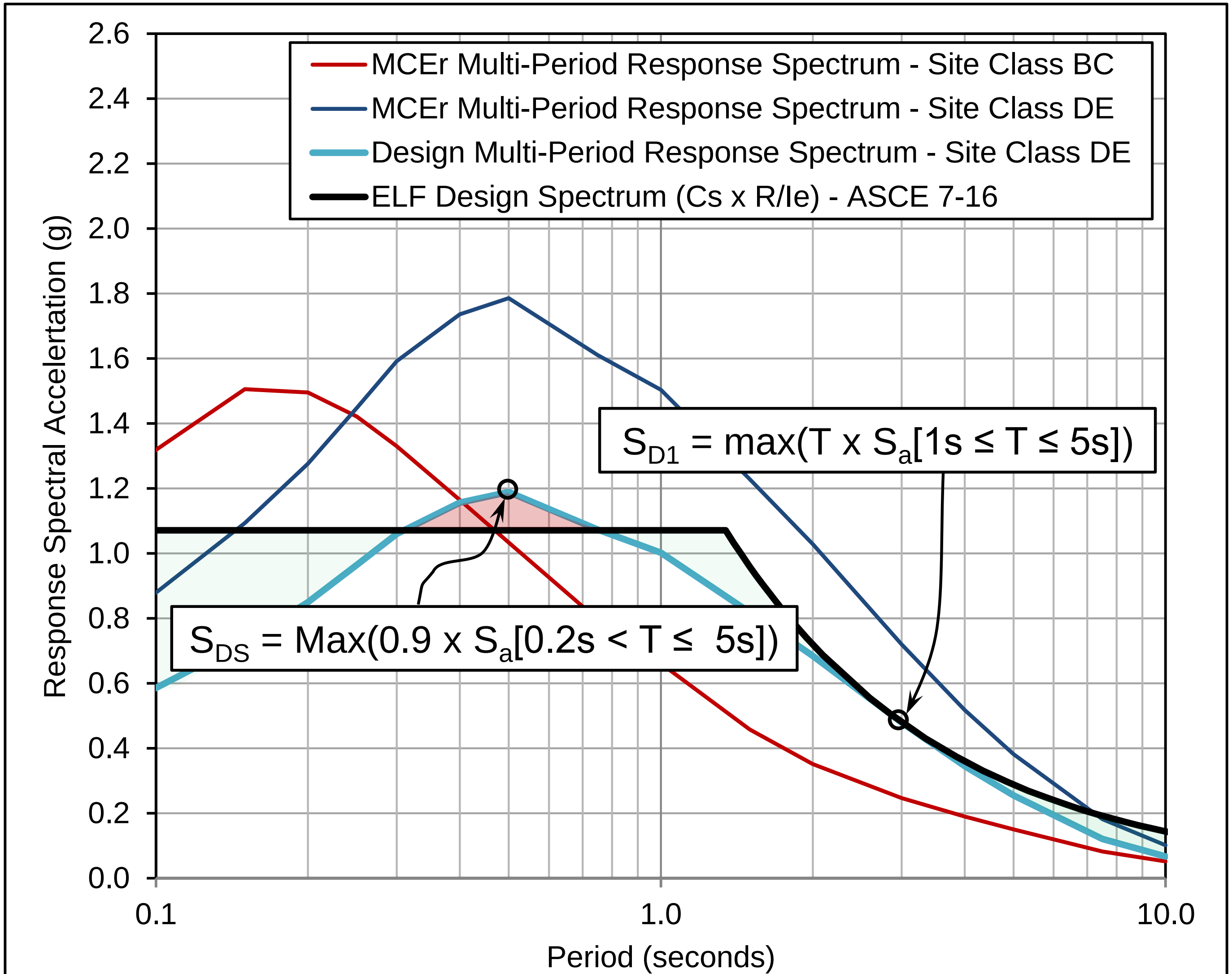
Conterminous United States Regions with $S_1 \geq 0.2g$



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

- Develop and adopt multi-period design spectrum approach
  - Not feasible in the last code update cycle (ASCE 7-16)
- Multi-period spectrum approach will require:
  - Reworking of seismic design requirements and criteria now based on two response periods (by Project 17/PUC proposals)
  - Development of new ground motion design parameters (by the USGS) for each new response period of interest
    - Incorporating site effects (and spectrum shape effects) directly in multi-period spectra and ground motion design values
- Challenges:
  - Technical (non-WUS sites)? – Multi-period GMPEs with built-in site amplification are not available for all U.S. regions
  - Administrative (too many maps/too many tables)? – Can ground motion design parameters be provided electronically (e.g., via the web) without direct inclusion in ASCE 7 or the IBC?

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



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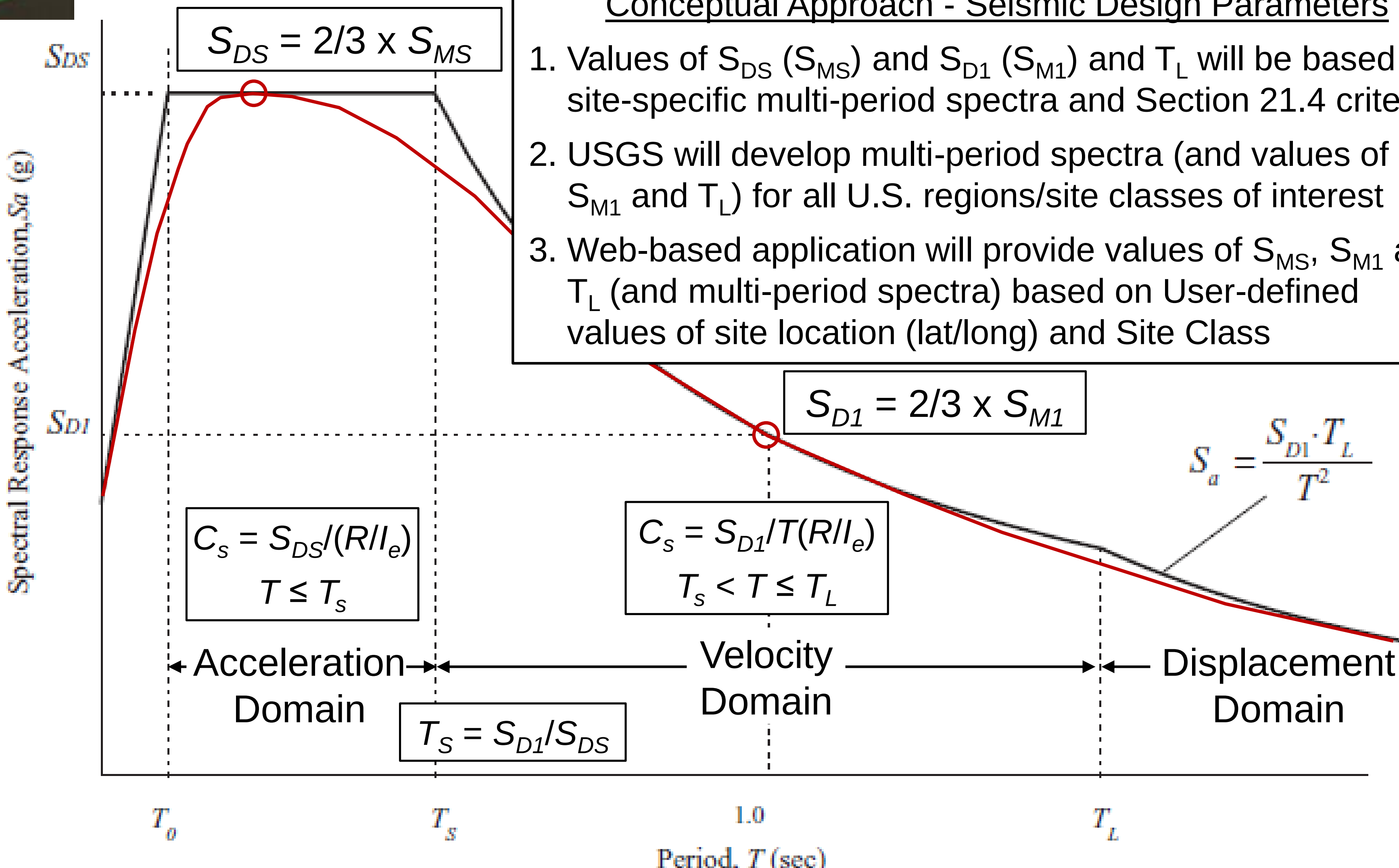
Proposed 2-Period Design Response Spectrum
(Figure 11.4-1, ASCE 7-22)



<u>Conceptual Approach - Seismic Design Parameters</u>

1. Values of S_{DS} (S_{MS}) and S_{D1} (S_{M1}) and T_L will be based on site-specific multi-period spectra and Section 21.4 criteria
2. USGS will develop multi-period spectra (and values of S_{MS}, S_{M1} and T_L) for all U.S. regions/site classes of interest
3. Web-based application will provide values of S_{MS}, S_{M1} and T_L (and multi-period spectra) based on User-defined values of site location (lat/long) and Site Class

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Proposed Revision of Table 20.3-1 to Include Three New Site Classes (BC, CD and DE) at Current Site Class Boundaries

Site Class		Geotechnical Criteria (average upper 100 ft)		
Name	**Description**	**v_s (fps)**	**N or N_{ch}**	**s_u (psf)**
A	Hard rock	> 5,000	NA	NA
B	Medium rock	3,000 - 5,000	NA	NA
BC	**Soft rock**	**2,100 - 3,000**	NA	NA
C	Very dense soil or hard clay	1,450 - 2,100	> 50	> 2,000
CD	**Dense sand or very stiff clay**	**1,000 - 1,450**		
D	Medium dense sand or stiff clay	700 - 1,000	15 to 50	1,000 - 2,000
DE	**Loose sand or medium stiff clay**	**500 - 700**		
E	Very loose sand or soft clay	< 500	< 15	< 1,000
F	Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

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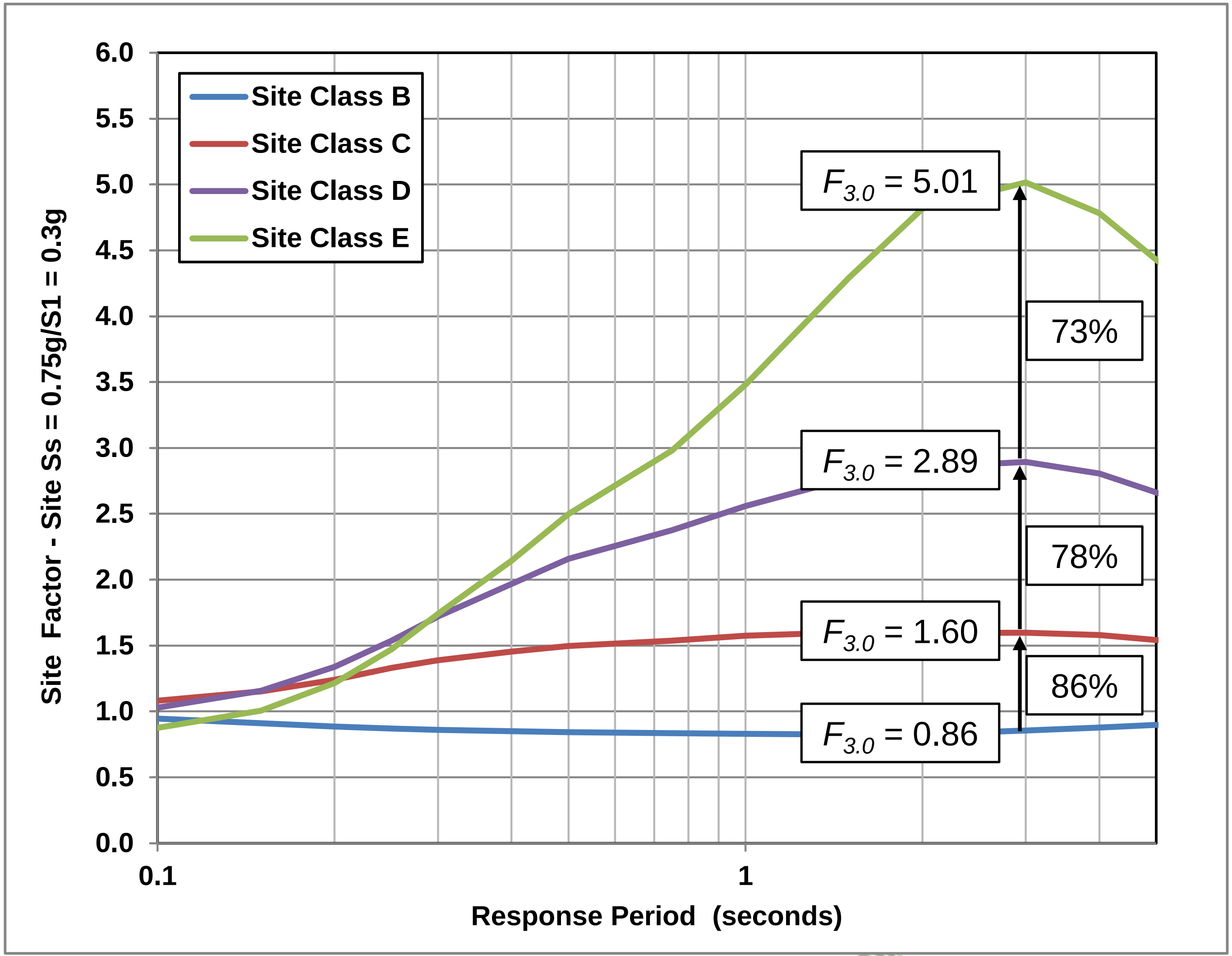
Example Site Amplification Curves of Different Site Classes Showing Large Differences in Amplification at Longer Periods

(PEER NGA West 2 GMPEs, S_s = 0.75g and S_1 = 0.3g, default basin depth parameters)



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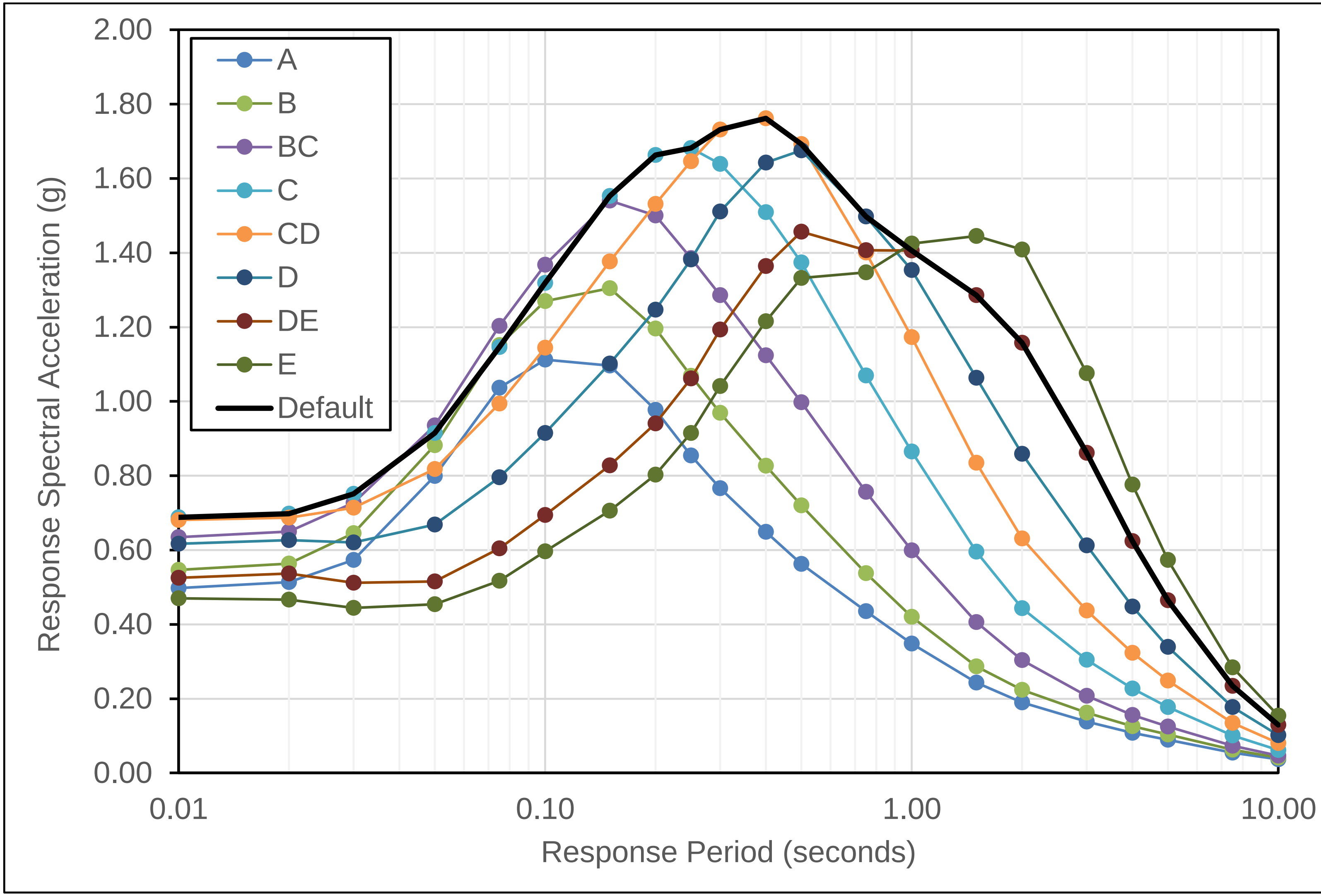
Example MCE_R Multi-Period Spectrum, Default Site Class (Derived from West 2 GMPEs M7.9, R_x = 21 km, S_S = 1.5 g)



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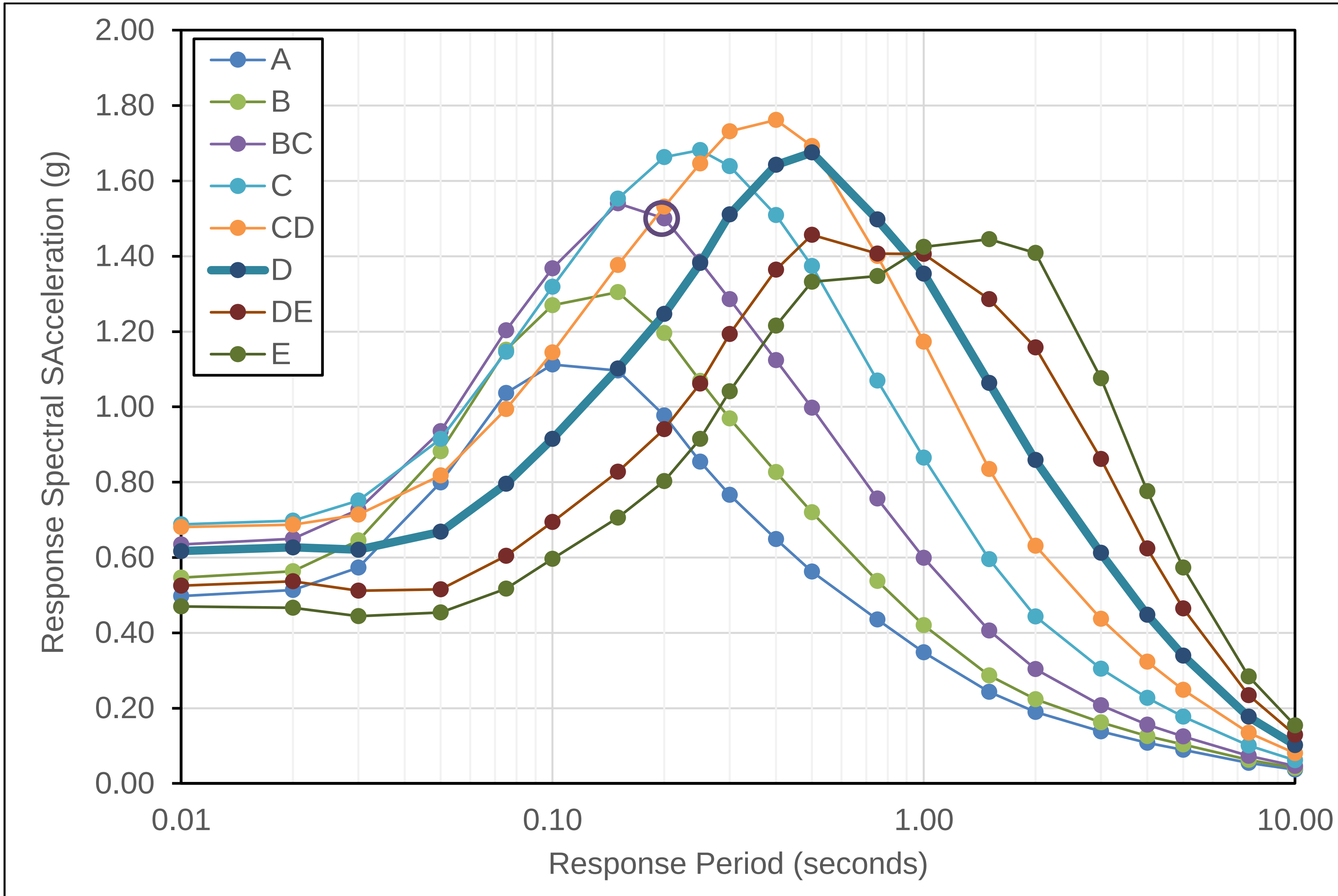
Example matrix of twenty-one response periods and nine site classes proposed as the standard format of multi-period response spectra

T (s)	Site Class							
	A	B	BC	C	CD	D	DE	E
0.010								
0.020								
0.030								
0.050								
0.075								
0.10								
0.15								
0.20			X					
0.25								
0.30								
0.40								
0.50								
0.75								
1.0			X					
1.5								
2.0								
3.0								
4.0								
5.0								
7.5								
10.0								

Approach for Developing Multi-Period Spectra for All Sites of Interest (US plus non-US sites)

- Administrative Issues:
  - "Science" must be augmented with judgment for some (e.g., non-WUS) sites (beyond USGS comfort level)
  - Project 17/PUC/ASCE 7 to approve the approach and methods; USGS to implement methods (e.g., of a referenceable report)
- MPRS Study (ATC/FEMA)
  - Considerable effort and time required to develop methods and document in a referenceable report (basis for proposal)
- Technical Issues (numerous):
  - Develop process to "fill in the blanks" for US regions with incomplete hazard data (e.g., use reliable WUS GMPEs to define generic response spectrum shapes)
  - Verify applicability to sites with different hazard (site and source) characteristics (e.g., multiple contributing sources)

Example MCE_R Multi-Period Spectrum, Site Class D, S_S = 1.5 g
(Based on Notional Spectrum Shapes for S_s/S_1 = 2.5, ε_0 = 1.5)



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Questions?

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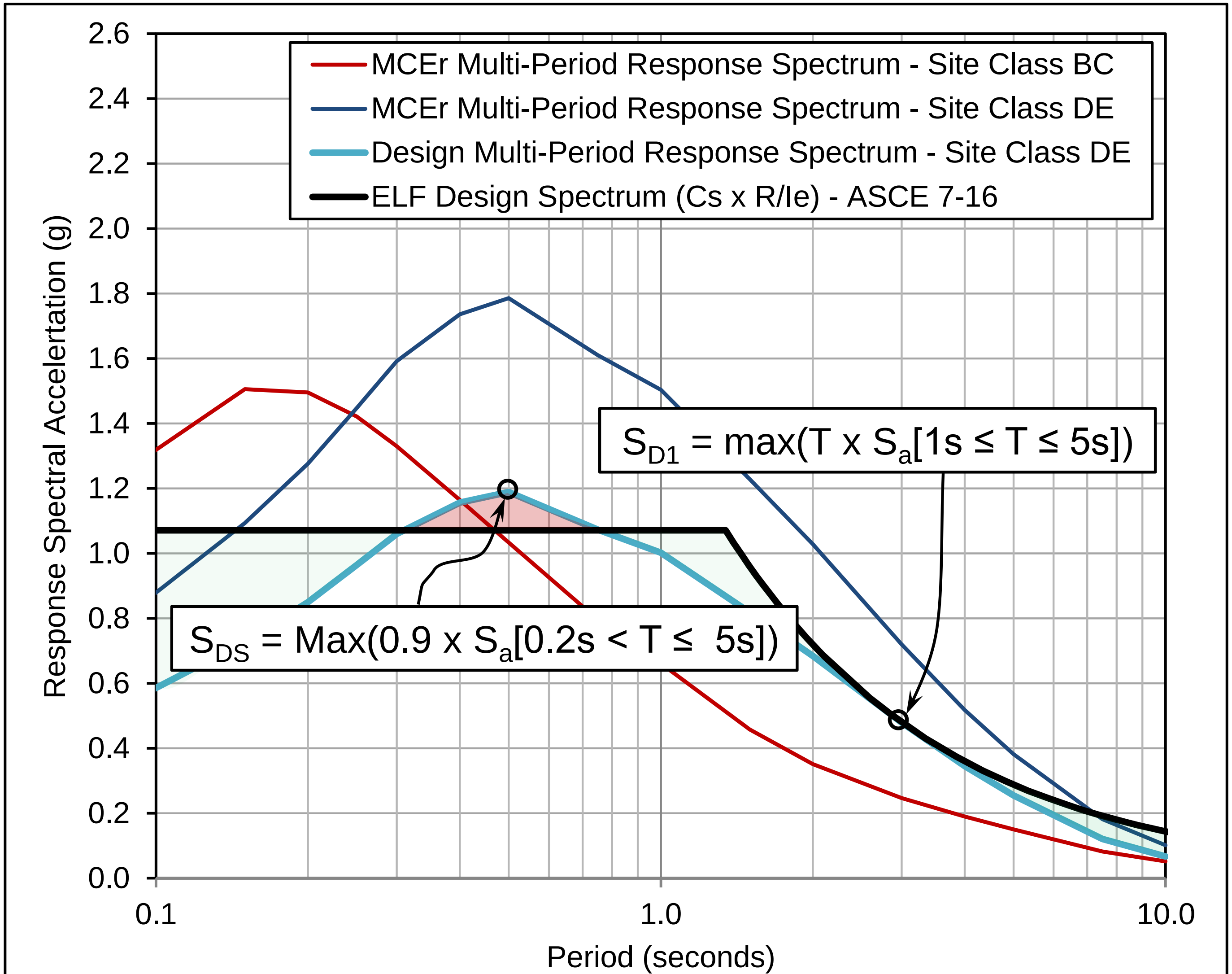
Example Values of S_{DS} and S_{D1} using the New Requirements of Sec. 21.4 (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class DE)

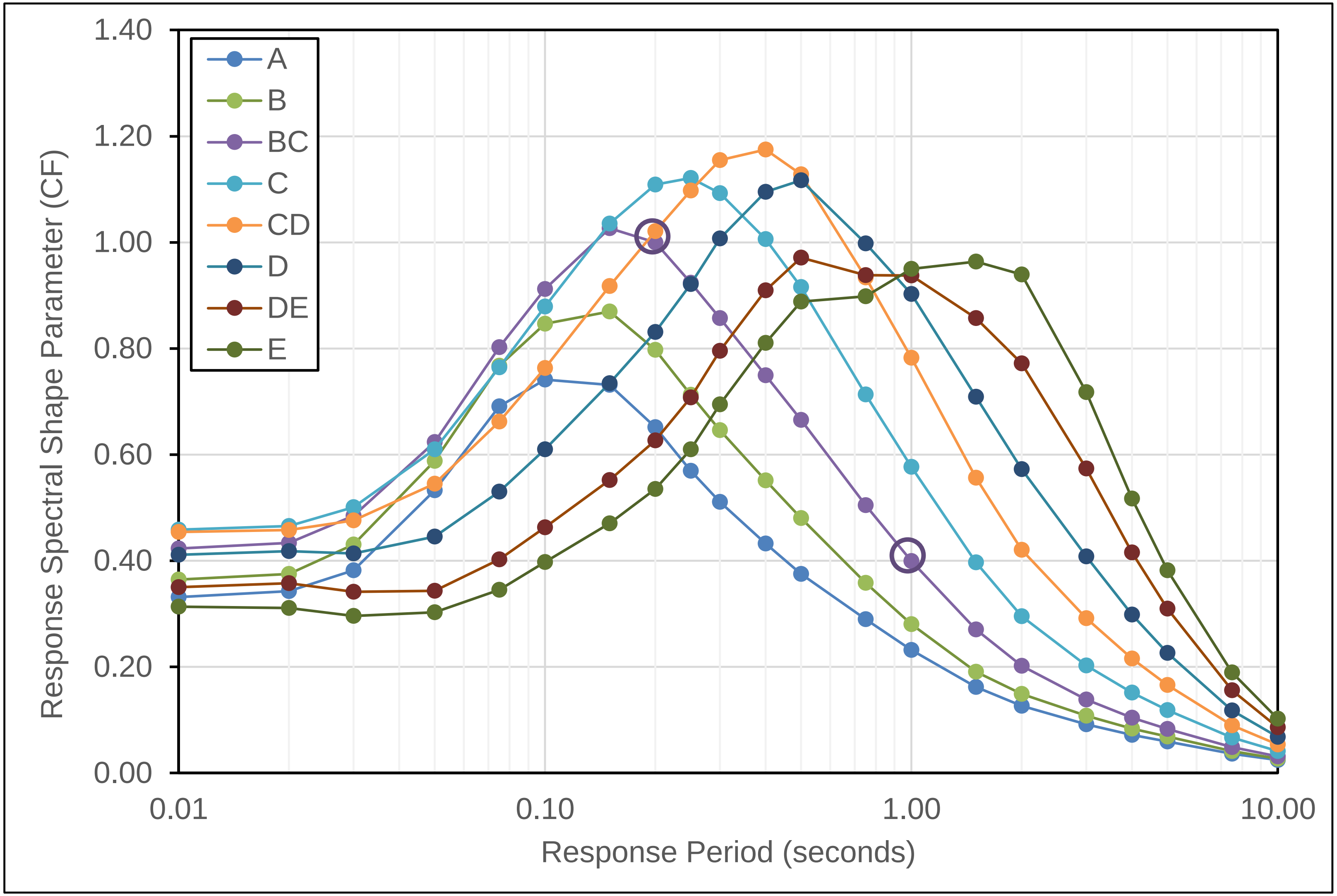


Example matrix of twenty-one response periods and nine site classes proposed as the standard format of multi-period response spectra

T (s)	Site Class							
	A	B	BC	C	CD	D	DE	E
0.010								
0.020								
0.030								
0.050								
0.075								
0.10								
0.15								
0.20			X					
0.25								
0.30								
0.40								
0.50								
0.75								
1.0			X					
1.5								
2.0								
3.0								
4.0								
5.0								
7.5								
10.0								

Notional MCE_R Multi-Period Spectral Shapes (normalized to S_S)

Derived from West 2 GMPEs M7.9, R_x = 21 km, ε_0 = 1.5 (S_S = 1.5, S_S/S_1 = 2.5)



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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

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					
	$S_S \le 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S = 1.25$	$S_S \ge 1.5$
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., $S_S \ge 1.0$)

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

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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

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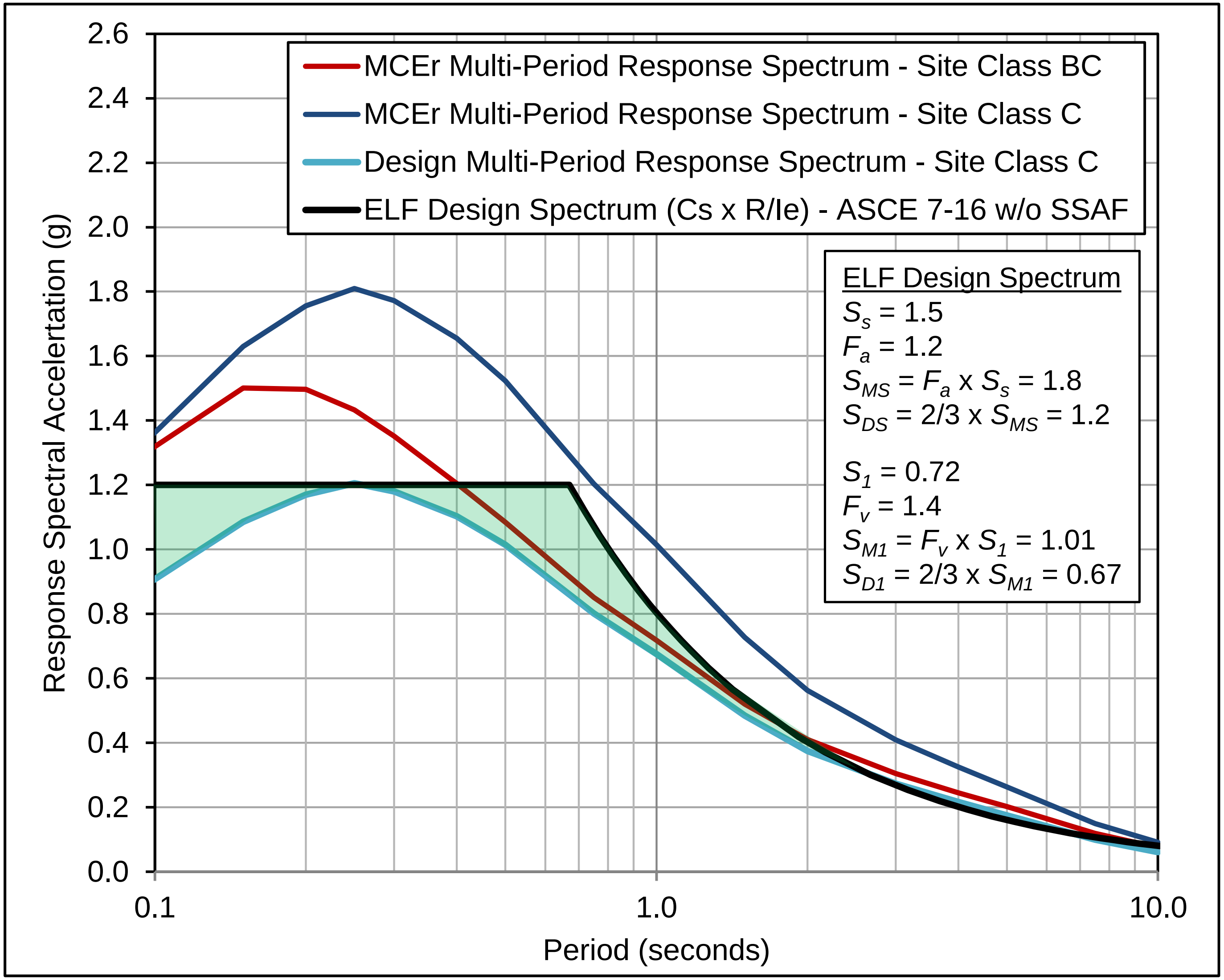
The "Problem" with ELF (MRSA) Methods

- 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>

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)



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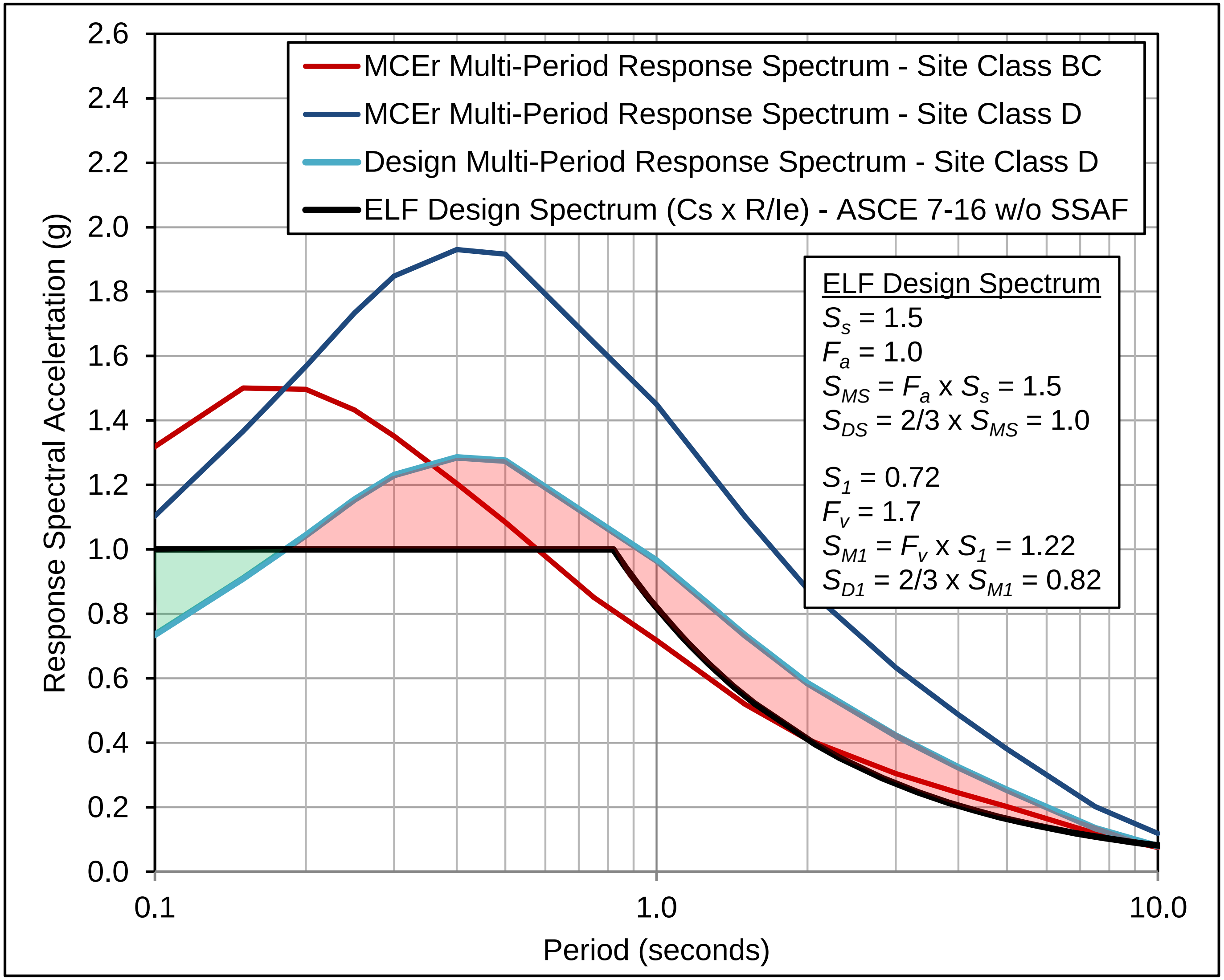
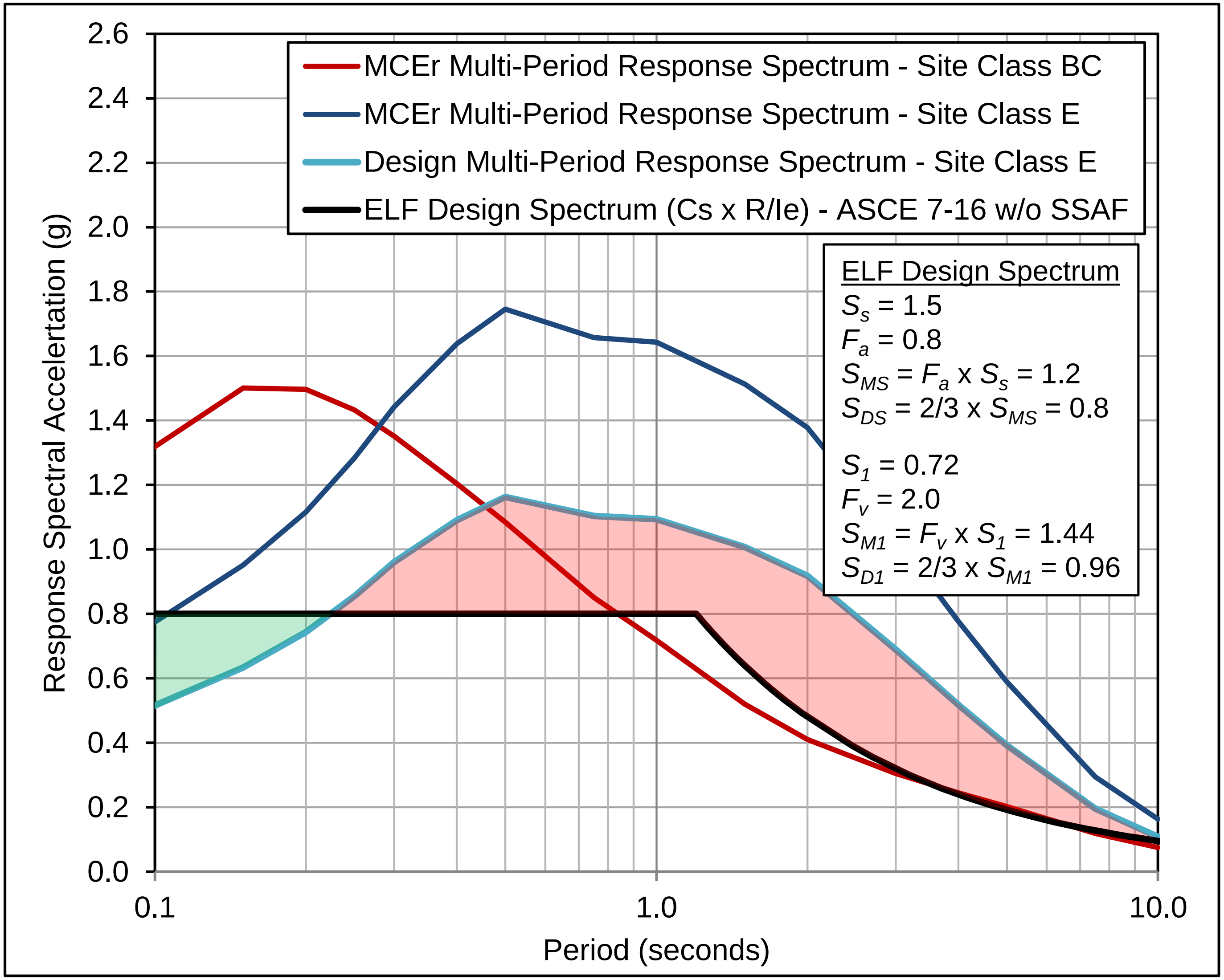
Example ELF "Design Spectrum" - ASCE 7-16 w/o New Site-Specific Requirements (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class D)



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)



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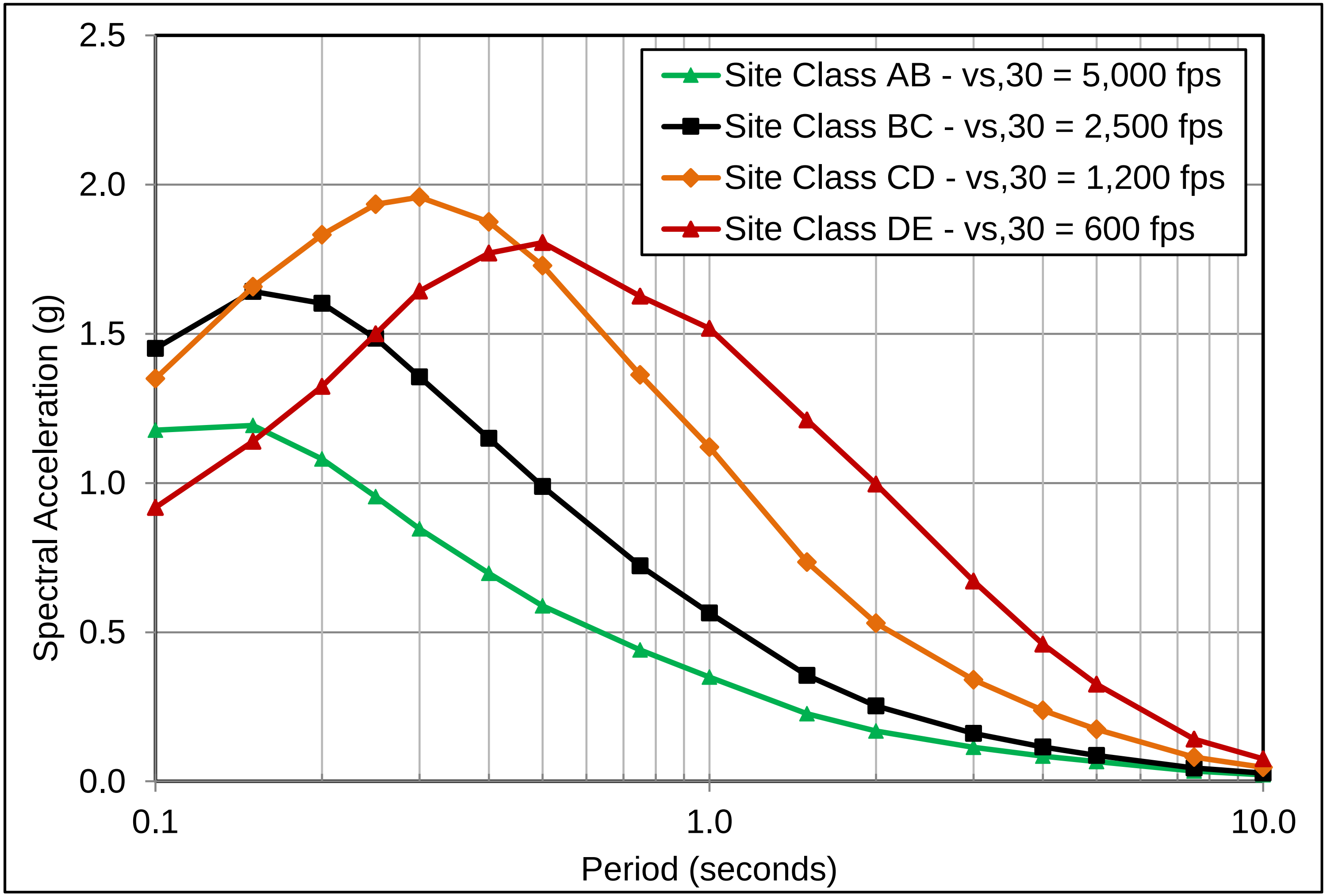
Example Deterministic MCE_R Ground Motions (ASCE 7-16)

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



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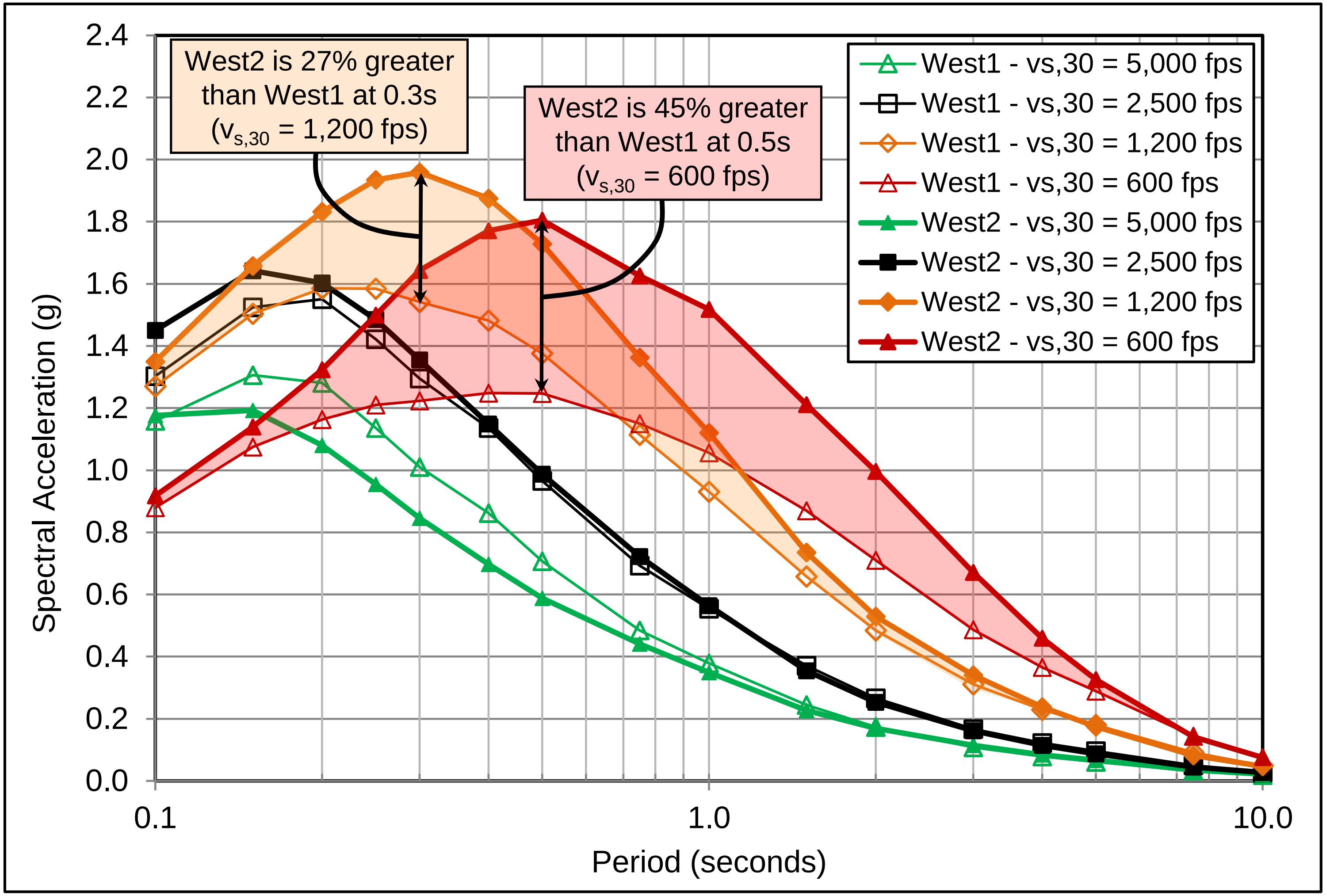
Example Comparison of Deterministic MCE_R Ground Motions

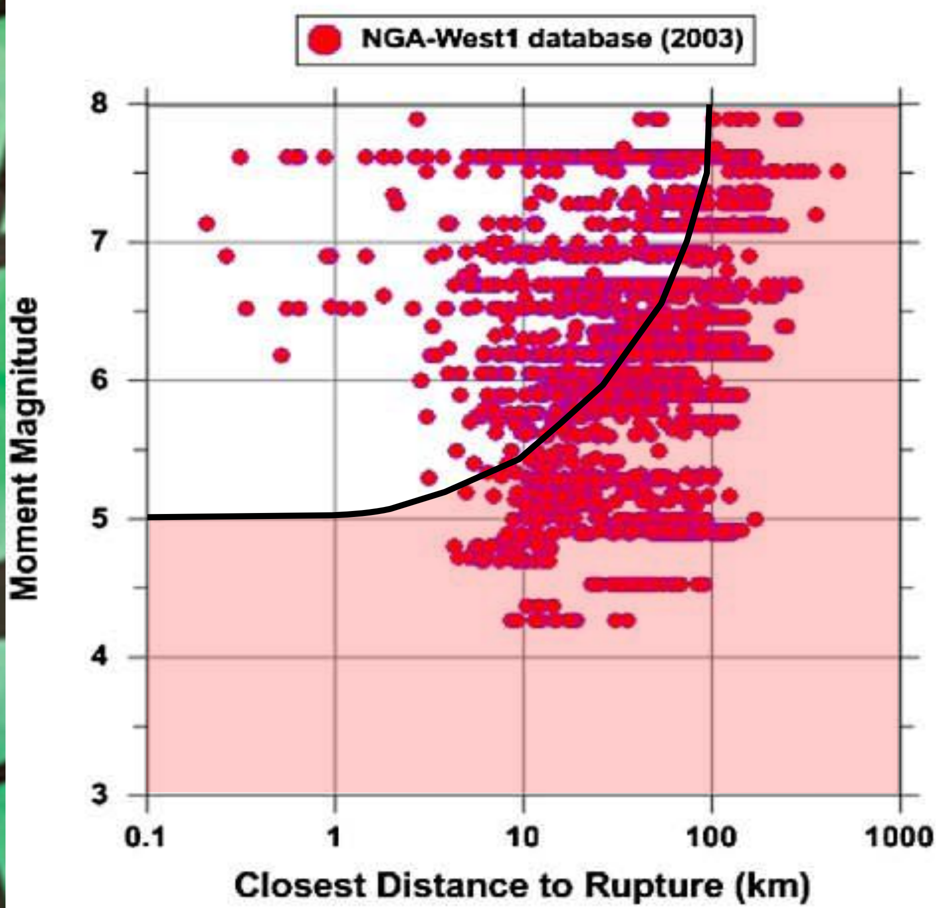
NGA-West1 and NGA-West2 GMPEs (M7.0 at R_x = 6 km, Site Class boundaries)



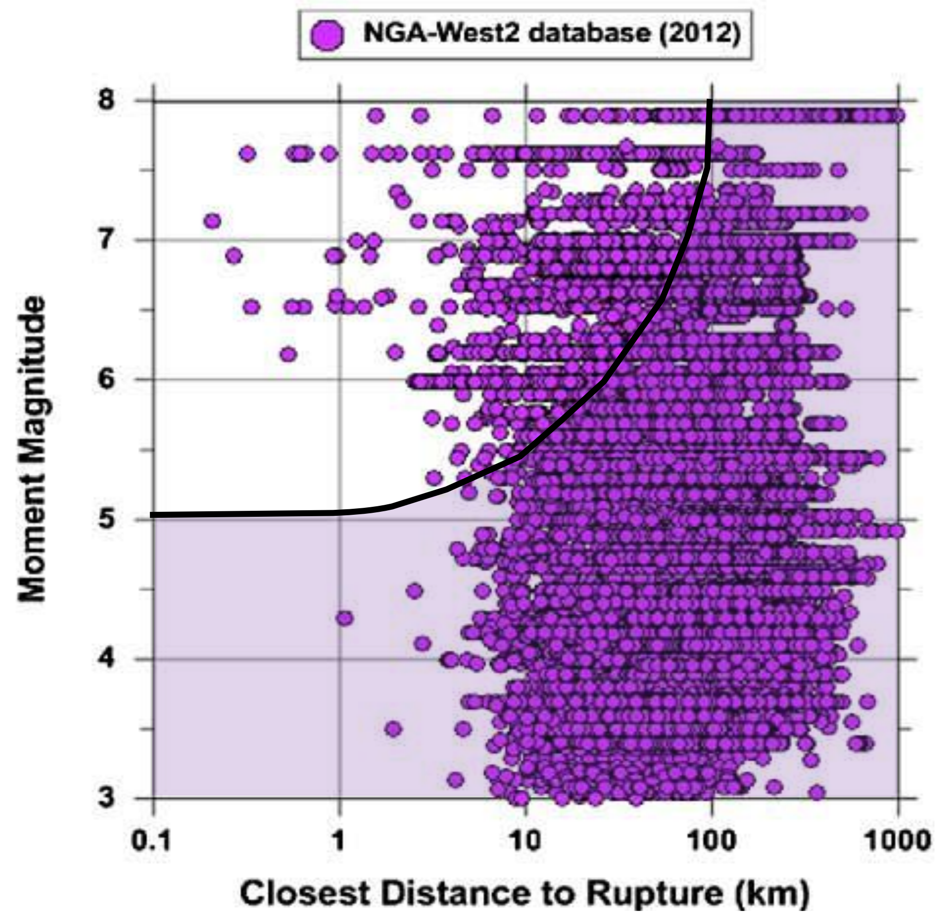
PEER NGA GMPE spreadsheet calc's: West1 based on Al Atik, 2009, West2 based on Seyhan, 2014)

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)



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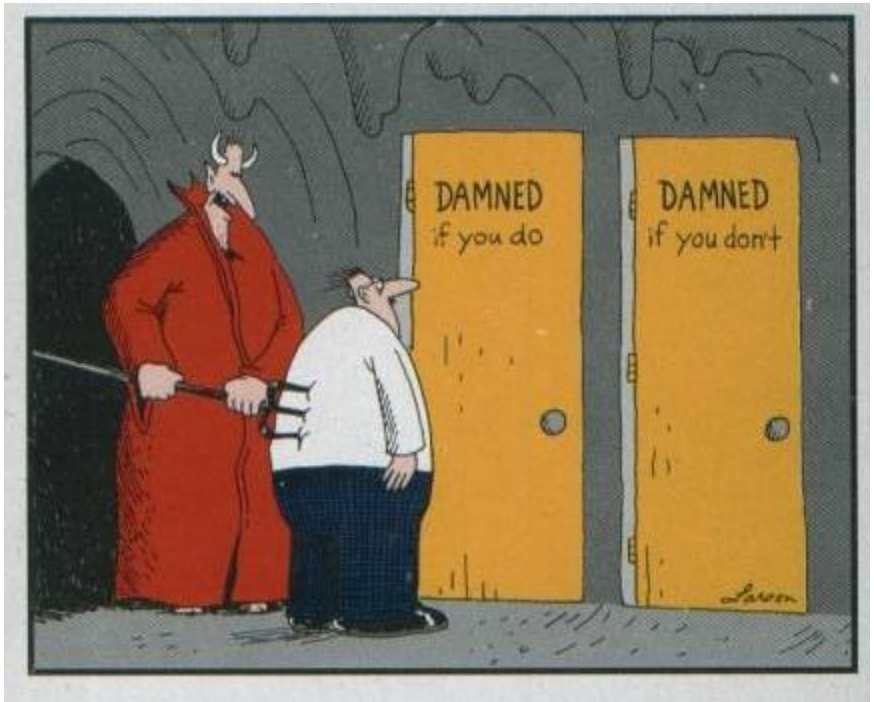
Interim Solution Options
(considered by the 2010 PUC)

- Option 1 - Re-formulate seismic parameters with *spectrum shape adjustment factors* 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)

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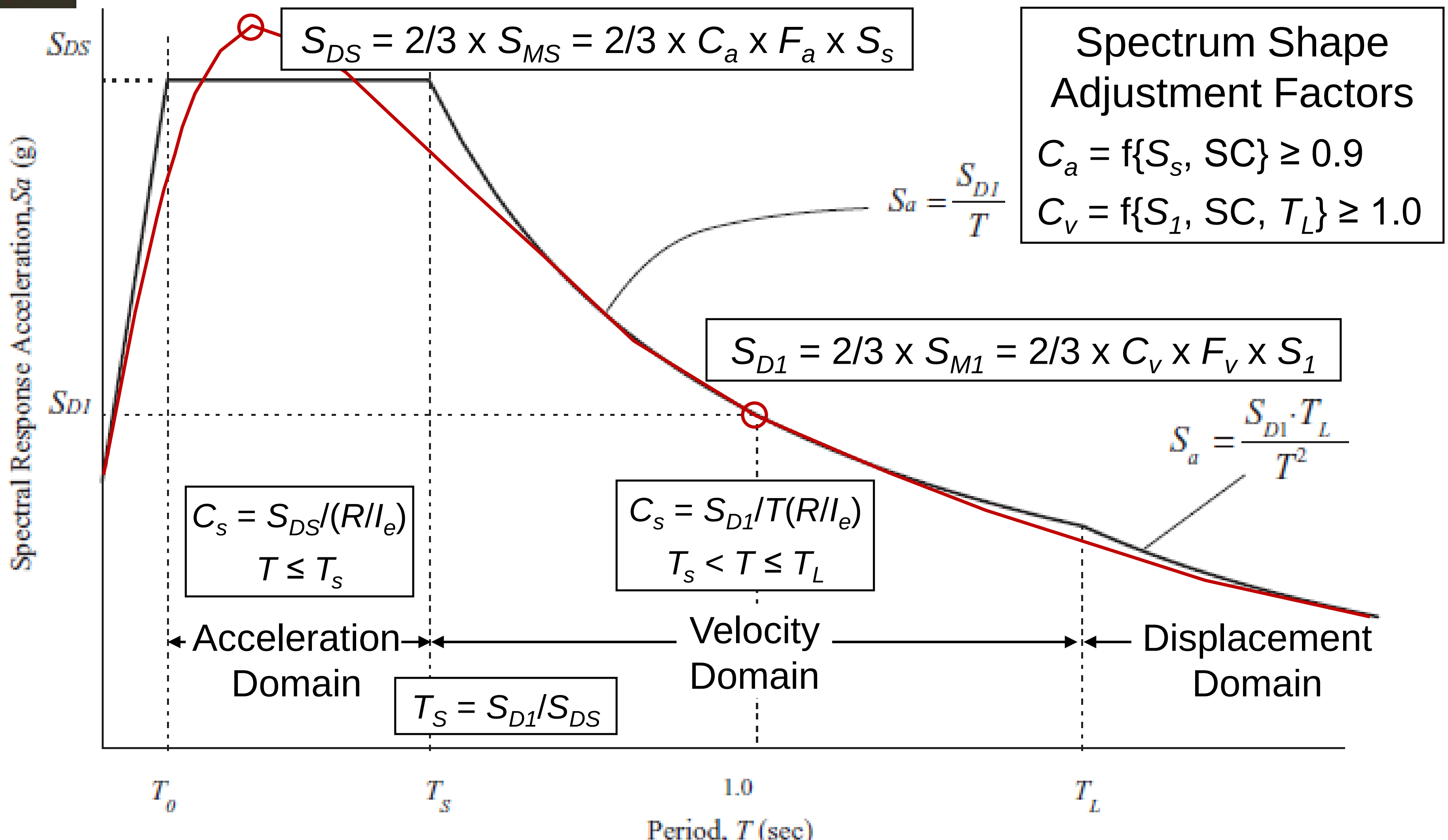
Option 1 - Spectrum Shape Adjustment Factor Reformulation

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



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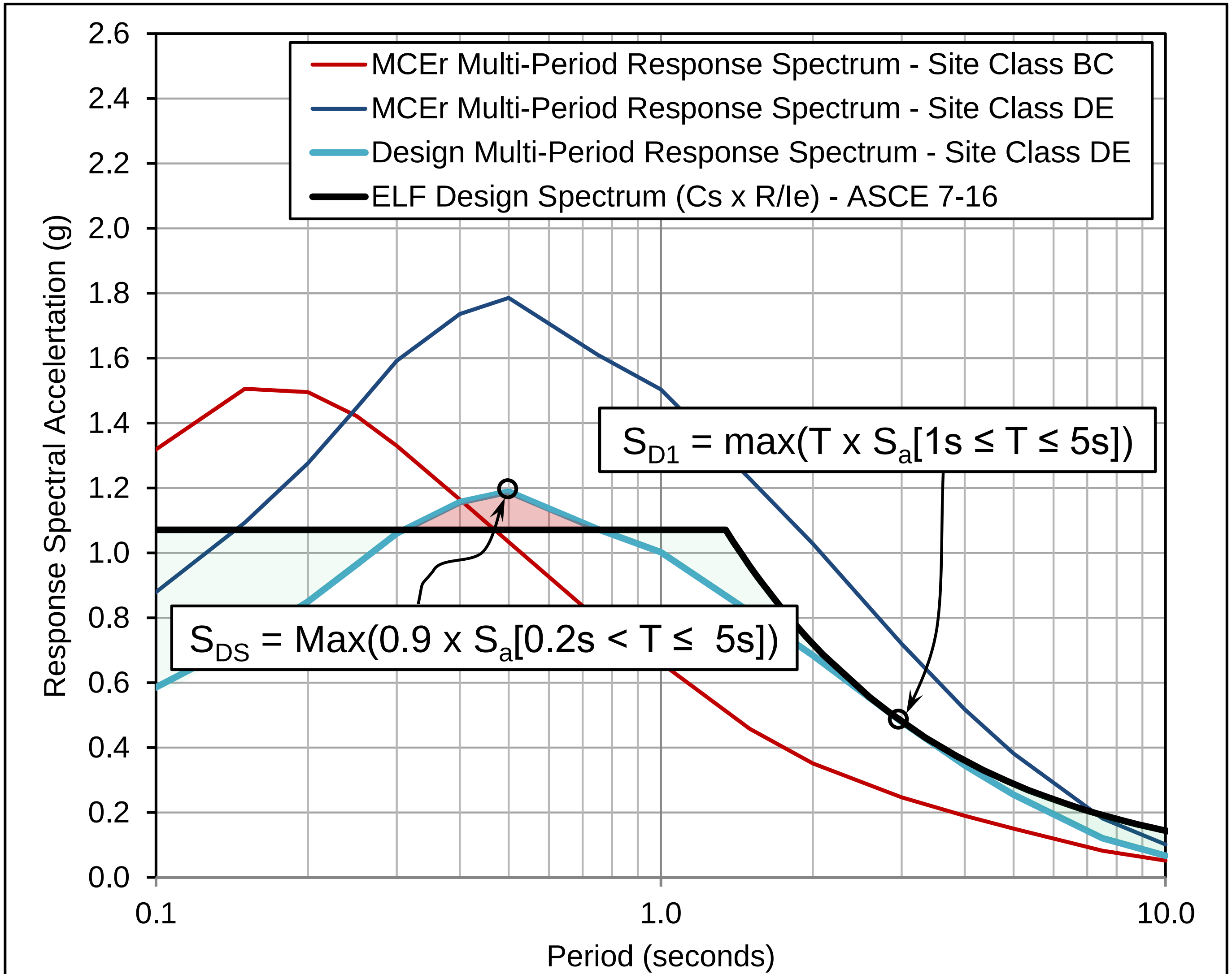
Example Values of S_{DS} and S_{D1} using the New Requirements of Sec. 21.4 (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class DE)



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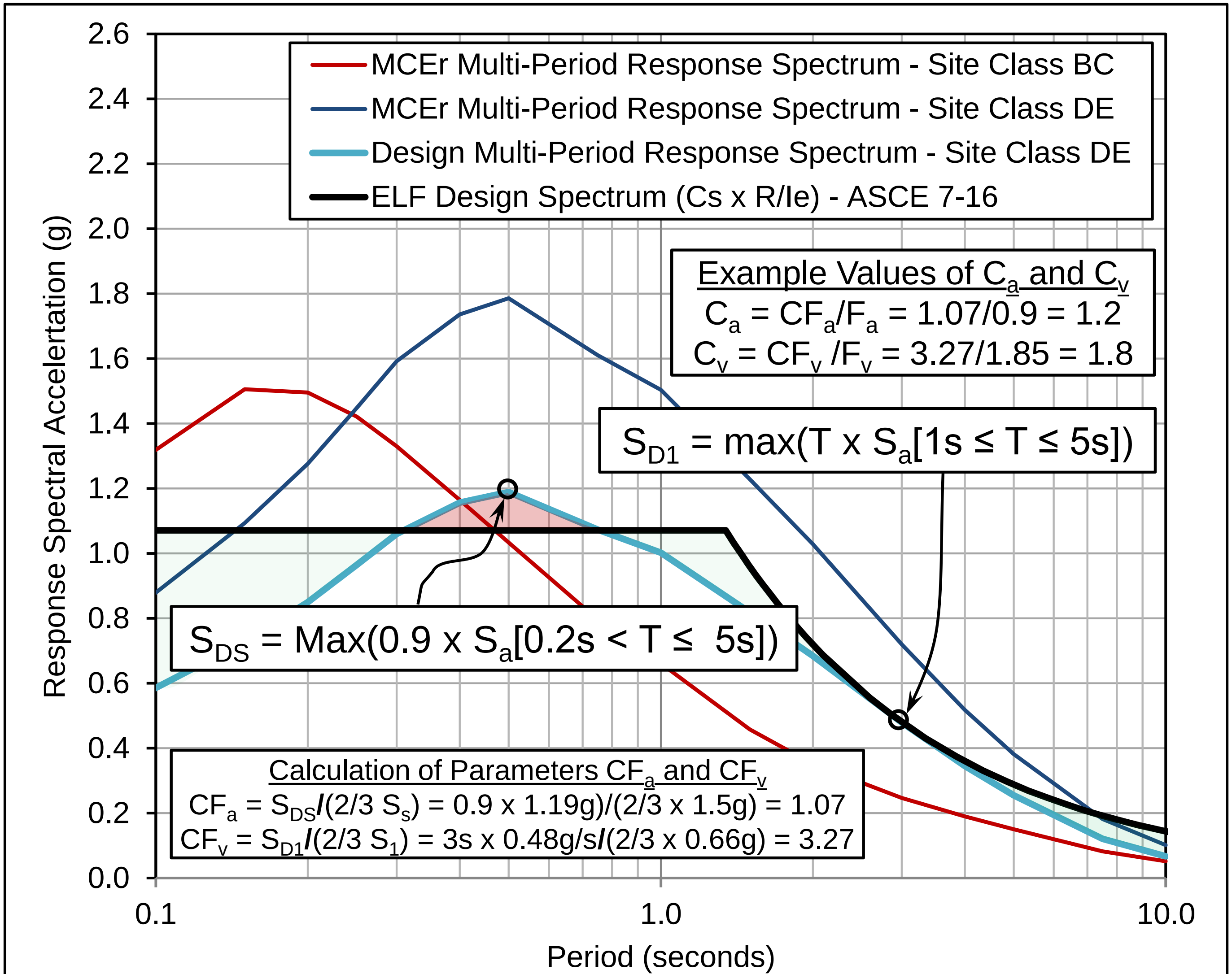
Example Calculation of Spectrum Shape Factors, C_a and C_v (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class DE)



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New Site-Specific Requirements of Section 11.4.7 of ASCE 7-16

- Site-specific ground motion procedures required 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.
- Exceptions 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 procedure is used for design.

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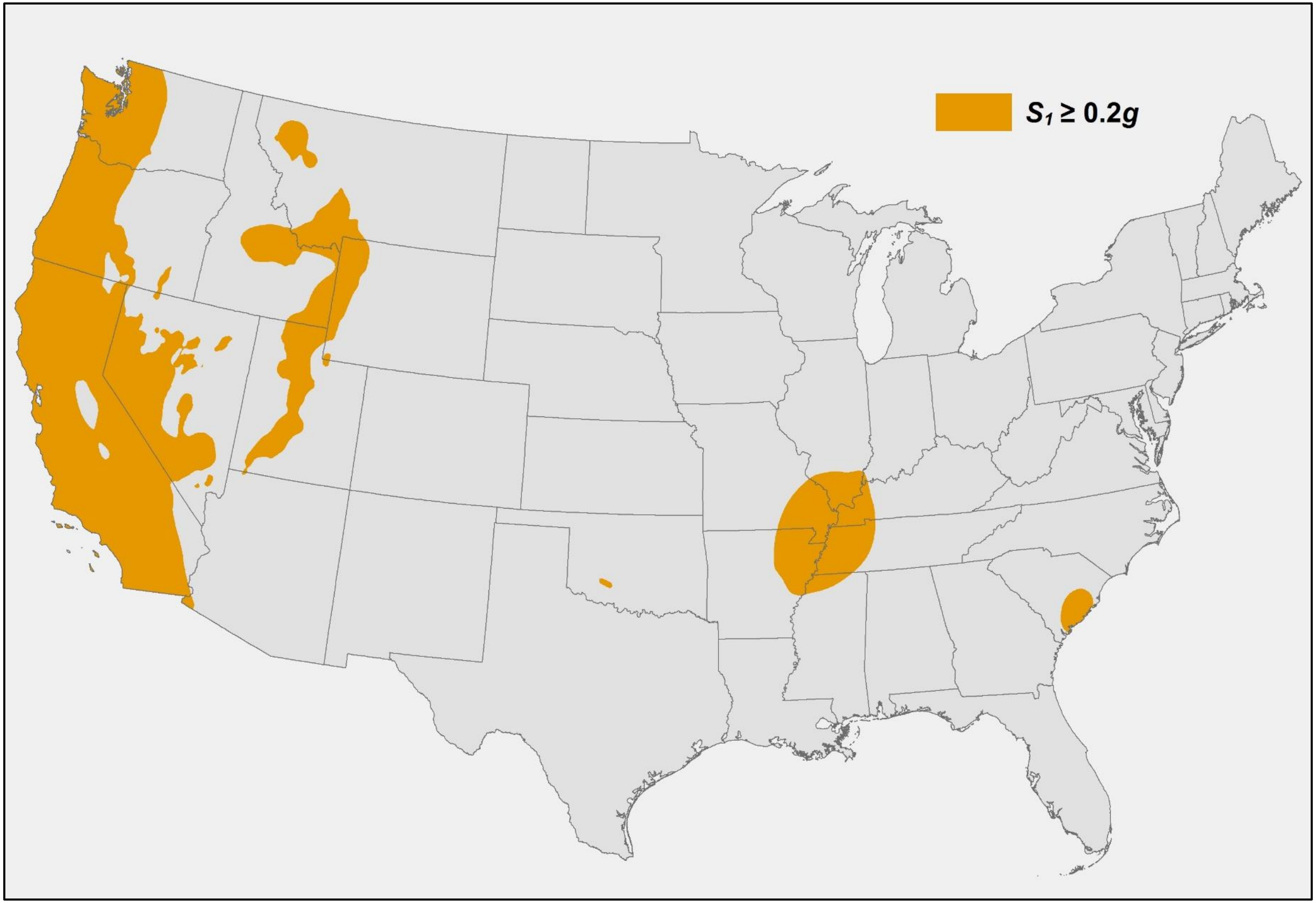
Conterminous United States Regions with $S_1 \geq 0.2g$



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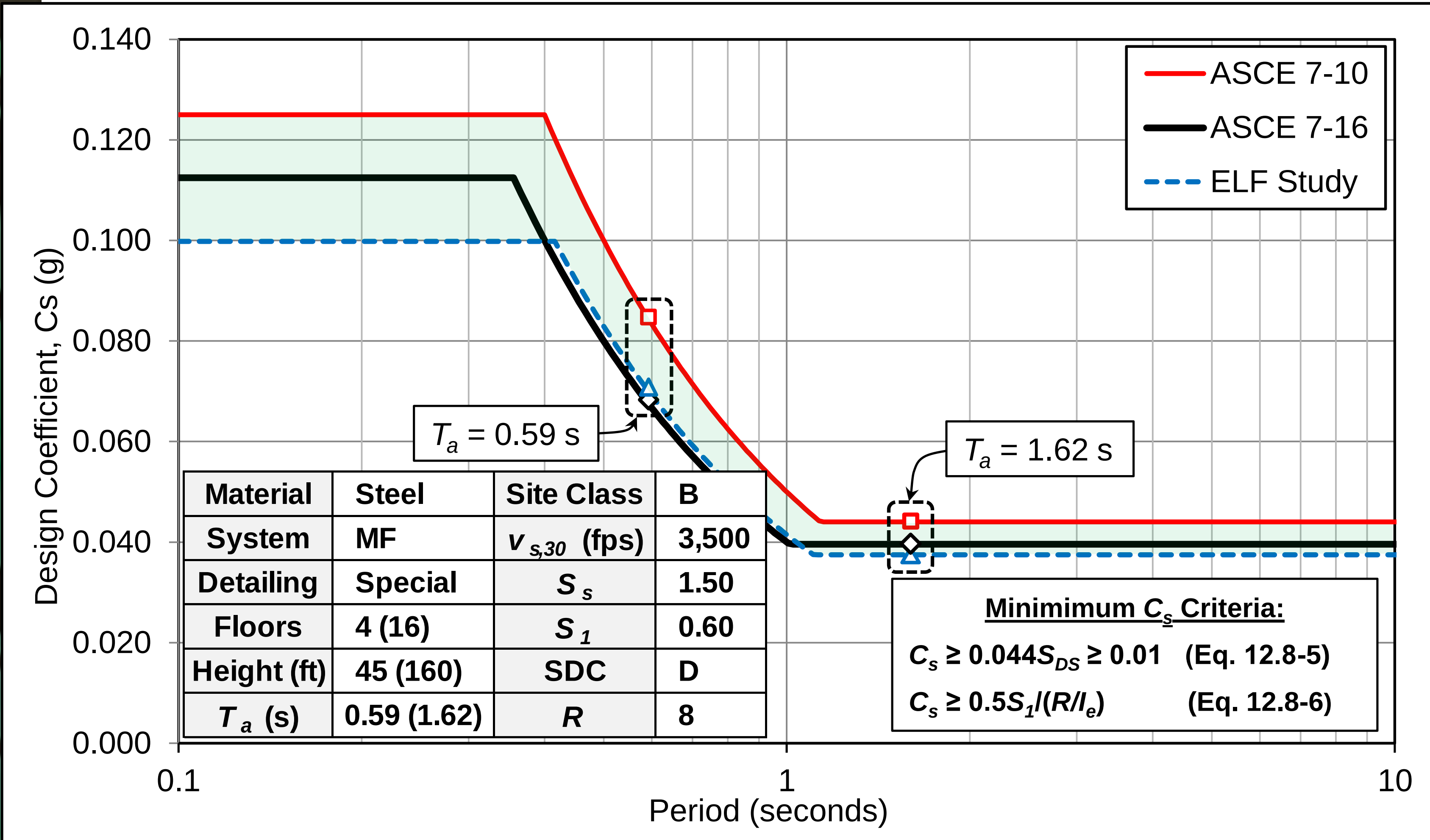
Example Values of the Design Coefficient (C_s)

- One (High Seismicity) Site - S_s = 1.5 g, S_1 – 0.6 g
- Two Structural (R/I_e = 8) 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)
- Four 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 and exceptions of Section 11.4.8**
  - ELF Study - What if ASCE 7-16 had adopted the spectrum shape adjustment factors (SSAFs)?

Example Comparison of the Design Coefficient (C_s)

4 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

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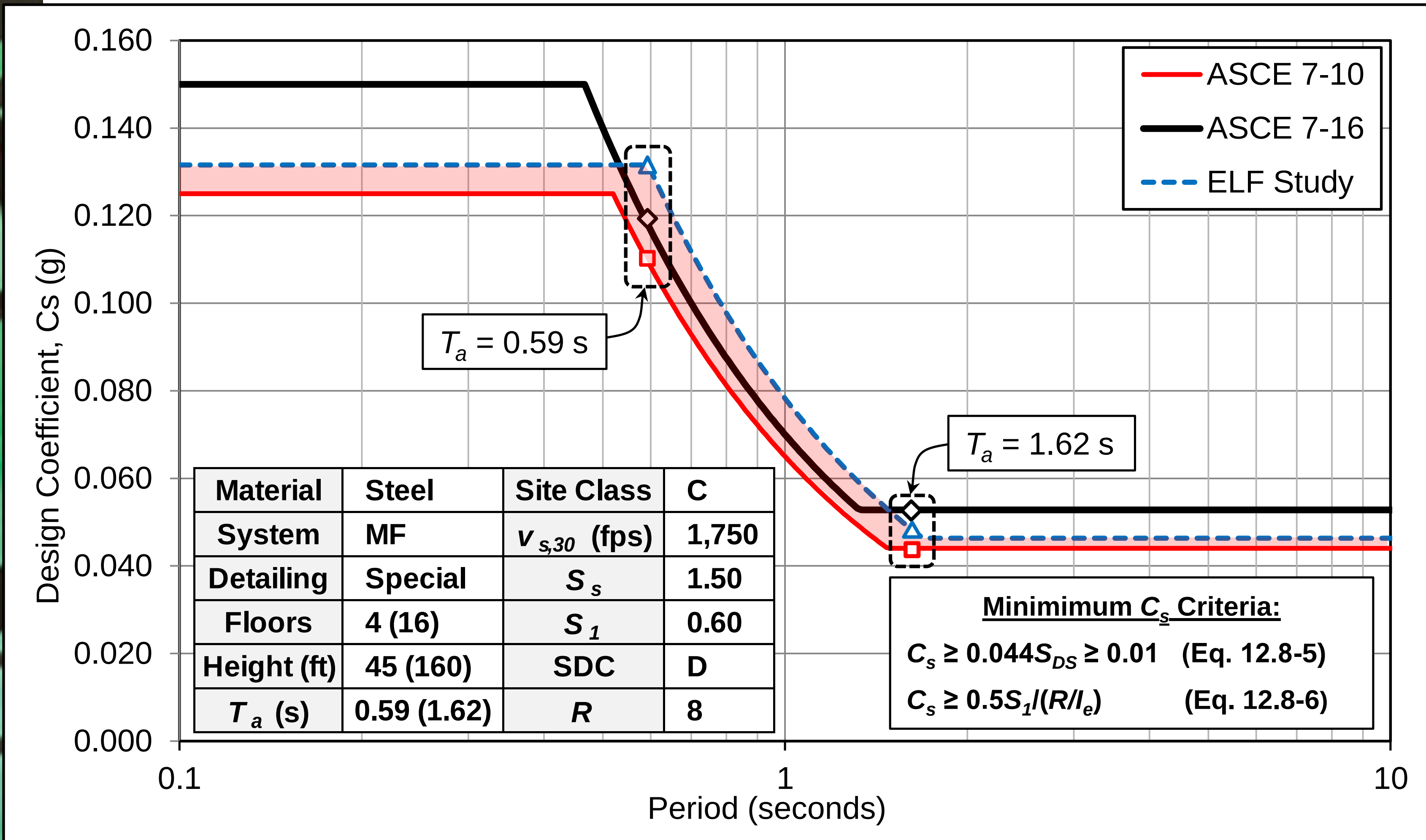
Example Comparison of the Design Coefficient (C_s)

4 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

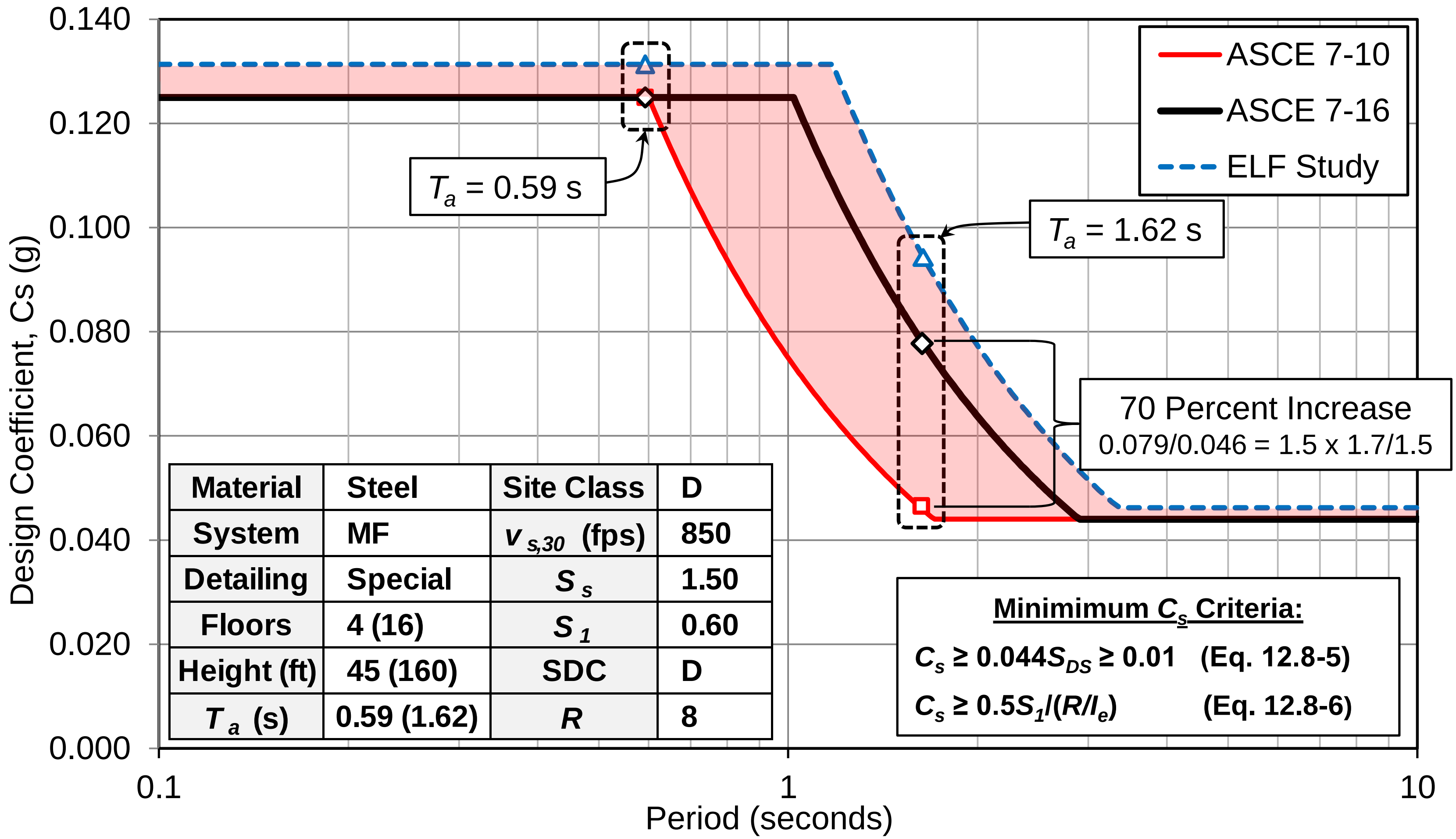
Minimum C_s Criteria:

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

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

Example Comparison of the Design Coefficient (C_s)

4 and 15-Story Steel Special Moment Frame Buildings - Site Class D



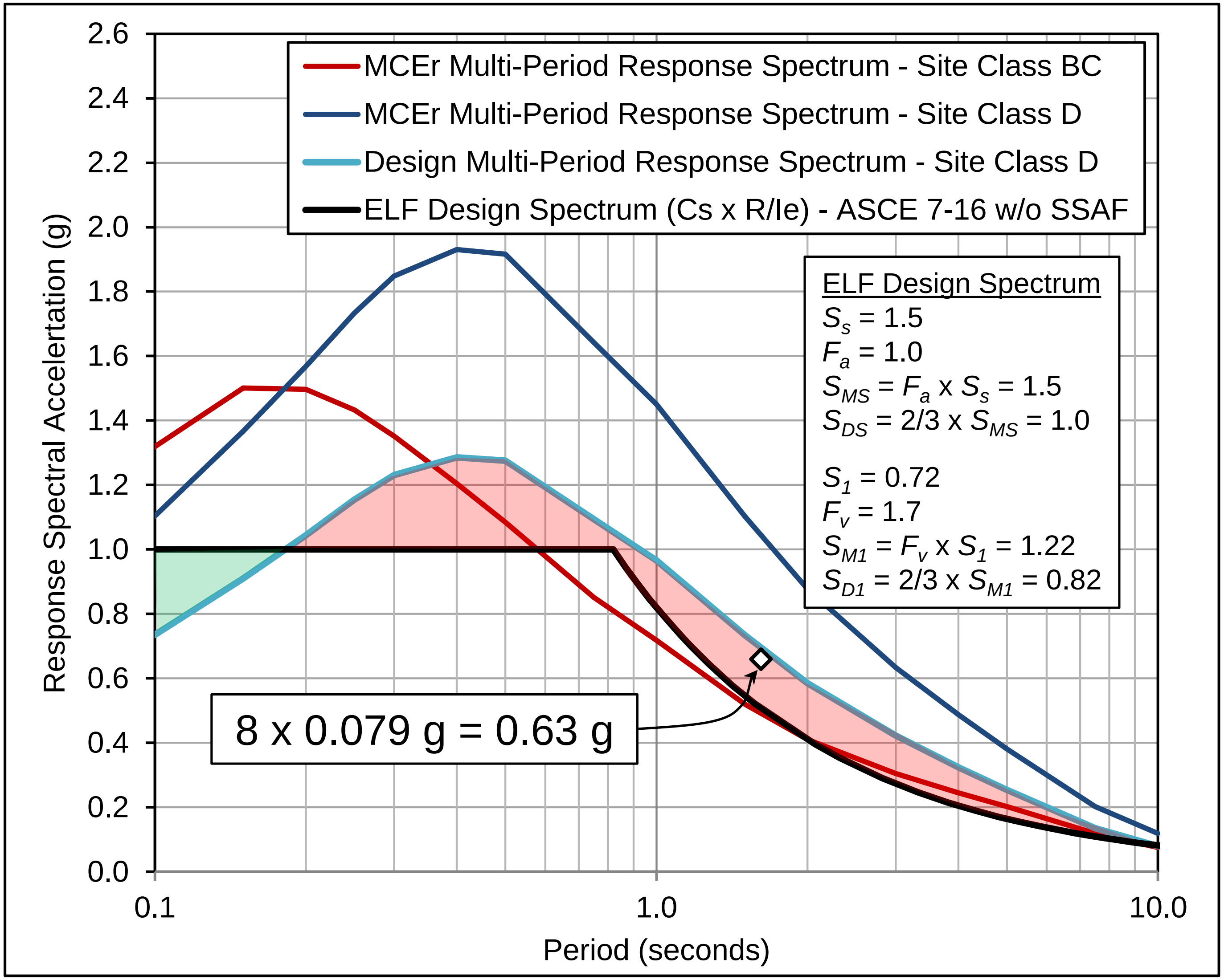
Material	Steel	Site Class	D
System	MF	$v_{s,30}$ (fps)	850
Detailing	Special	S_s	1.50
Floors	4 (16)	S_1	0.60
Height (ft)	45 (160)	SDC	D
T_a (s)	0.59 (1.62)	R	8

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 – C_s = 0.079 g (R = 8) and Multi-Period Design Spectrum (M8.0 earthquake ground motions at R_X = 9.9 km, Site Class D)



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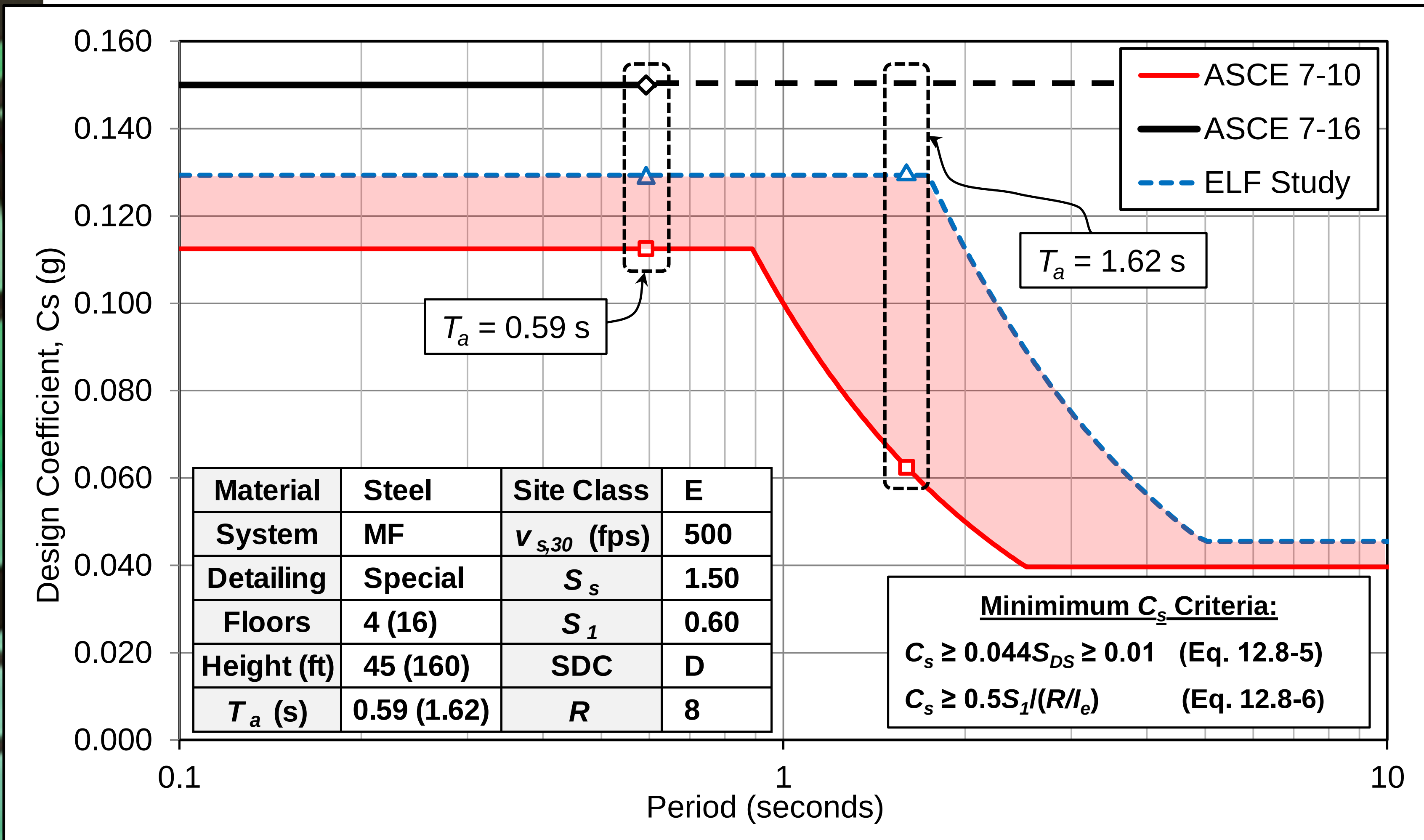
Example Comparison of the Design Coefficient (C_s)

4 and 15-Story Steel Special Moment Frame Buildings - Site Class E



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New ASCE 7-16 Requirements (not in the 2015 NEHRP Provisions) Section 21.2.2 Deterministic (MCE_R) Ground Motions

Section 21.2.2 Deterministic (*MCE_R*) Ground Motions. The deterministic spectral response acceleration at each period shall be calculated as an 84th-percentile 5% damped spectral response acceleration in the direction of maximum horizontal response computed at that period. The largest such acceleration calculated for the characteristic earthquakes on all known active faults within the region shall be used.

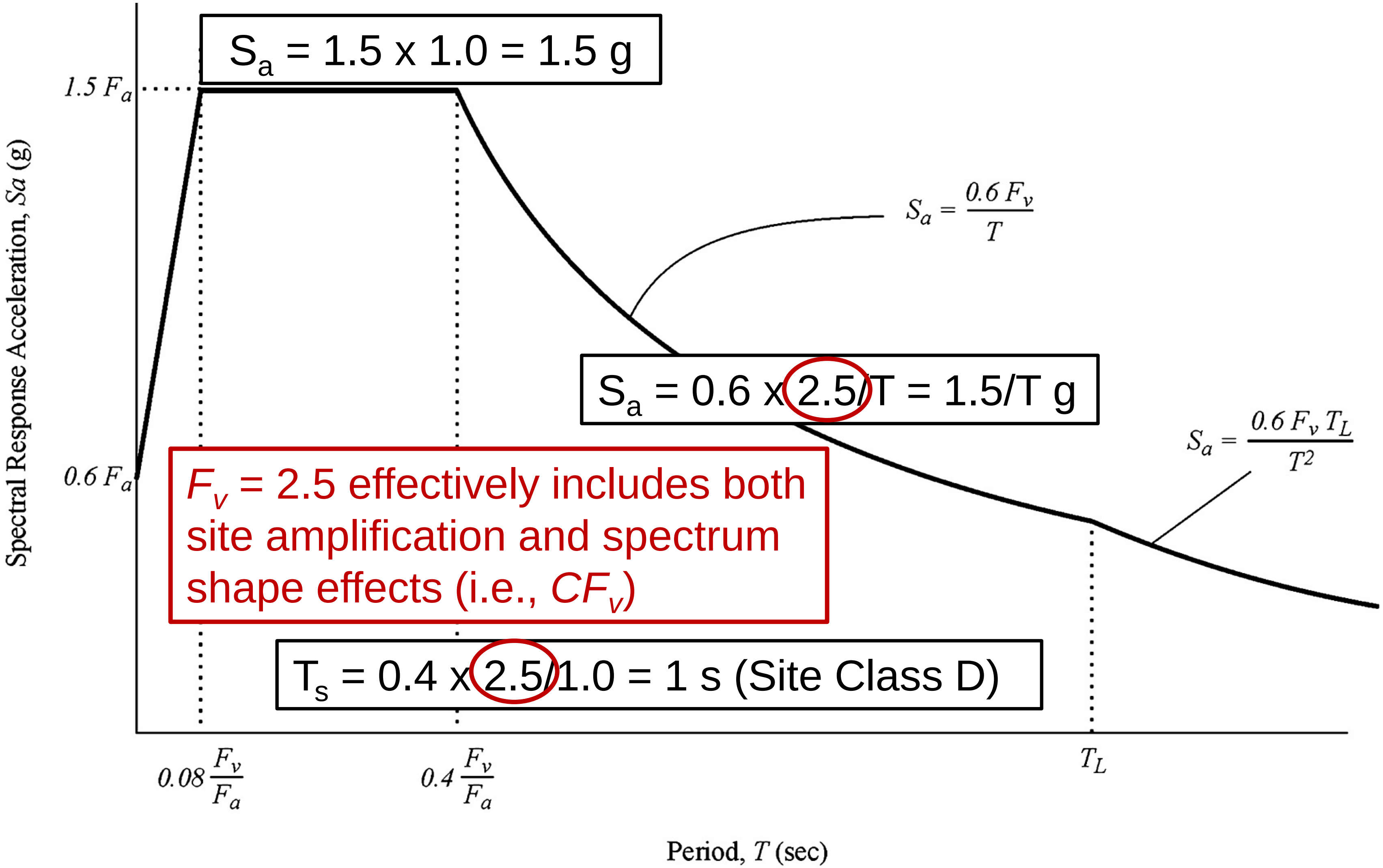
~~For the purposes of this standard, the~~ **ordinates of the deterministic ground motion response spectrum shall not be taken as lower than the corresponding ordinates of the response spectrum determined in accordance with Fig. 21.2-1**~~, where F_a and F_v are determined using Tables 11.4-1 and 11.4-2, respectively, with the value of S_S taken as 1.5 and the value of S_1 taken as 0.6~~. **For the purposes of calculating the ordinates.**

(i) for Site Classes A, B or C: F_a and F_v shall be determined using Tables 11.4-1 and 11.4-2, with the value of S_S taken as 1.5 and the value of S_1 taken as 0.6;

(ii) for Site Class D: F_a shall be taken as 1.0, and F_v shall be taken as 2.5; and

(iii) for Site Classes E and F: F_a shall be taken as 1.0, and F_v shall be taken as 4.0.

Figure 21.2-1 Deterministic Lower Limit on MCE_R Response Spectrum for Site Class D



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New ASCE 7-16 Requirements (not in the 2015 NEHRP Provisions)
Section 21.3 Design Response Spectrum

The design spectral response acceleration at any period shall be determined from Eq. 21.3-1.

$$S_a = 2/3\ S_{aM} \qquad (21.3\text{-}1)$$

where S_{aM} is the MCE spectral response acceleration obtained from Section 21.1 or 21.2.

The design spectral response acceleration at any period shall not be taken less than 80 percent of S_a determined in accordance with Section 11.4.5, where F_a and F_v are determined as follows:

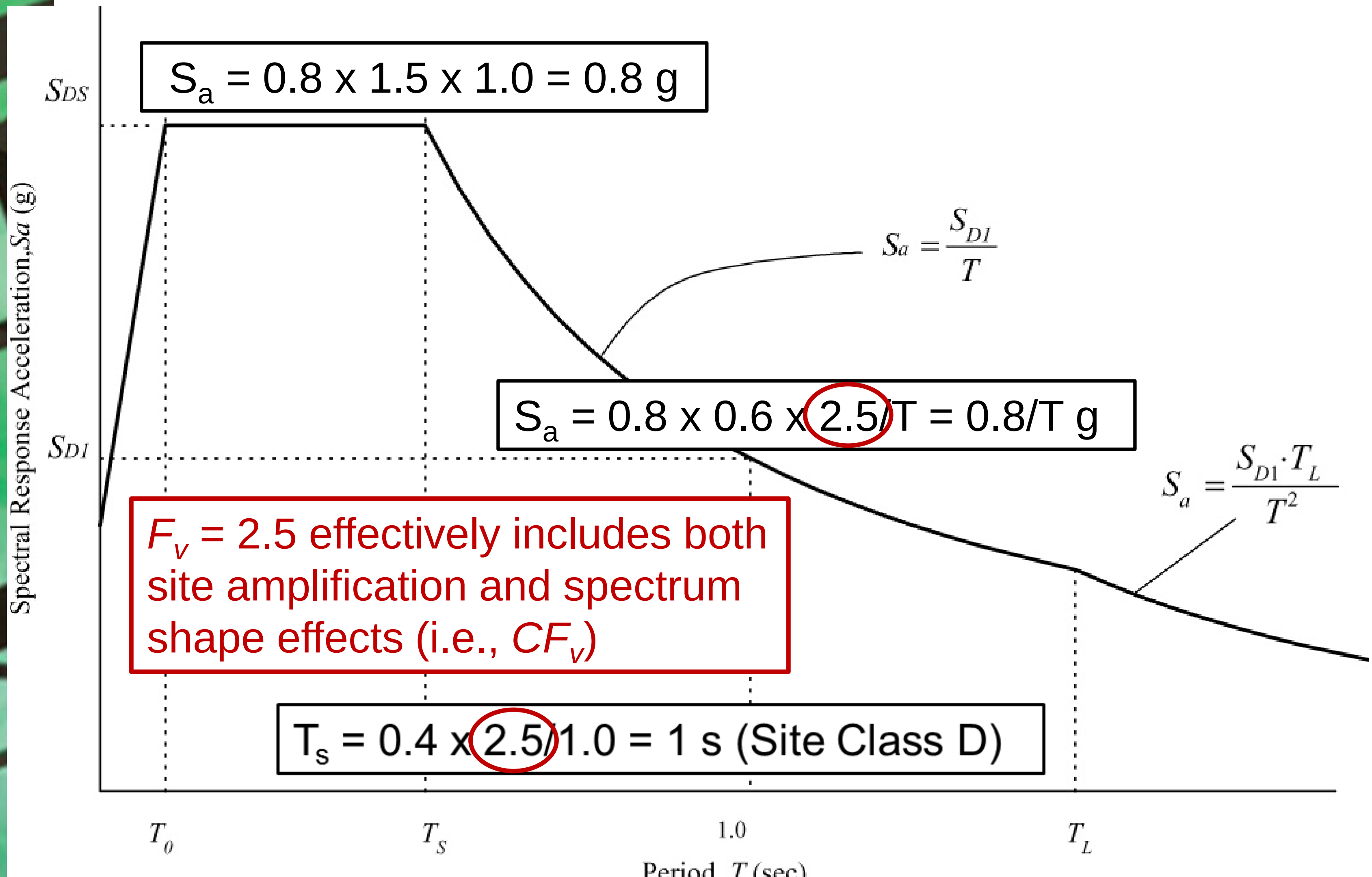
(i) for Site Class A, B, and C: F_a and F_v are determined using Tables 11.4-1 and 11.4-2, respectively;

(ii) for Site Class D: F_a is determined using Table 11.4-1, and F_v is taken as 2.4 for $S_1 < 0.2$ or 2.5 for $S_1 \geq 0.2$; and

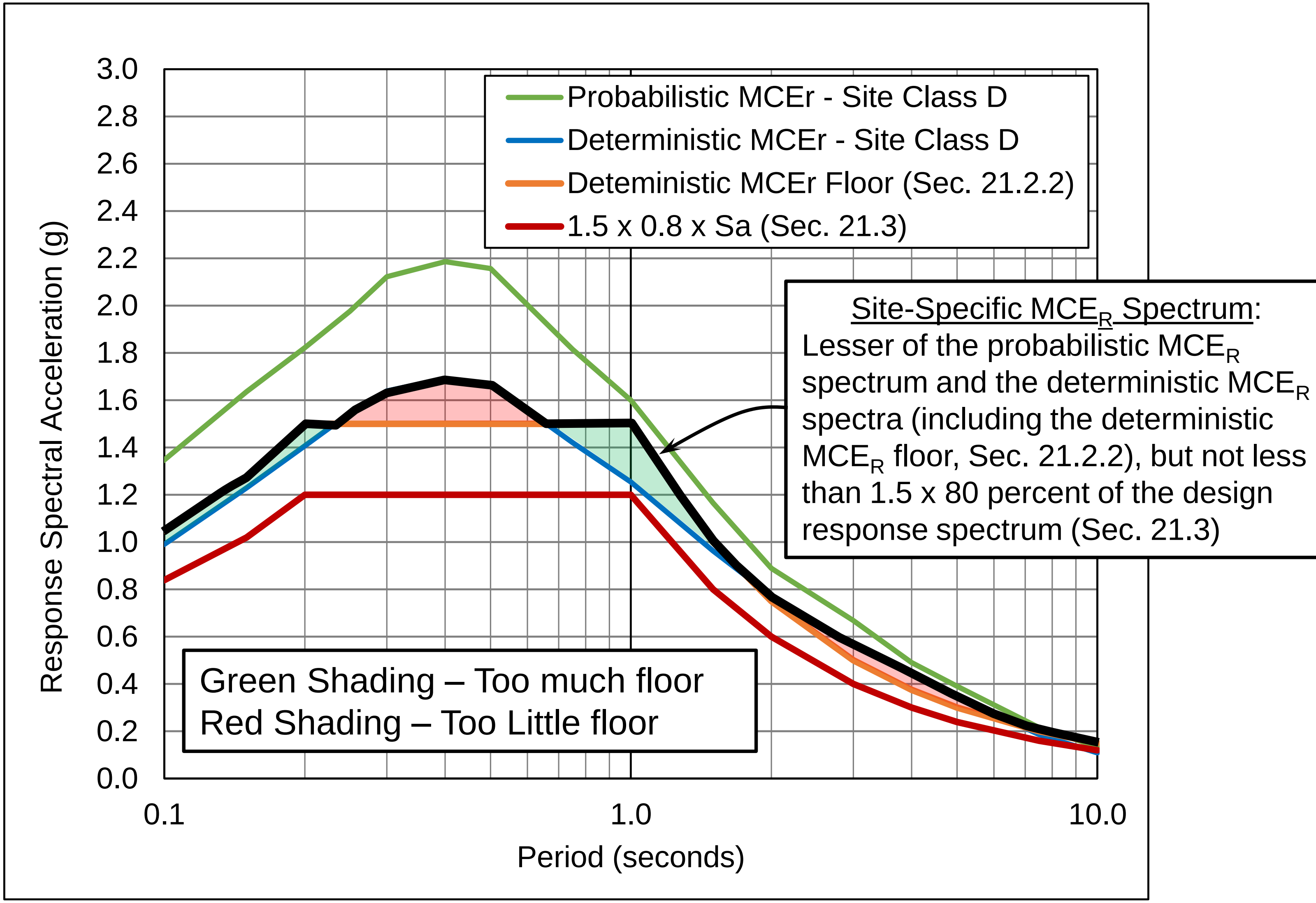
(iii) for Site Class E: F_a is determined using Table 11.4-1 for $S_S < 1.0$ or taken as 1.0 for $S_S \geq 1.0$, and F_v is taken as 4.2 for $S_1 \leq 0.1$ or 4.0 for $S_1 > 0.1$.

For sites classified as Site Class F requiring site-specific analysis in accordance with Section 11.4.7, the design spectral response acceleration at any period shall not be less than 80 percent of S_a determined for Site Class E in accordance with Section 11.4.5.

80 Percent of the Design Response Spectrum (Figure 11.4-1) for Site Class D and $S_s = 1.5$ and $S_1 = 0.6$



Example Development of Site-Specific MCE_R Ground Motions for a San Francisco Site Assuming Site Class D Site Conditions – $v_{s,30}$ = 870 fps



Example matrix of twenty-one response periods and nine site classes proposed as the standard format of multi-period response spectra

T (s)	Site Class							
	A	B	BC	C	CD	D	DE	E
0.010								
0.020								
0.030								
0.050								
0.075								
0.10								
0.15								
0.20								
0.25								
0.30								
0.40								
0.50								
0.75								
1.0								
1.5								
2.0								
3.0								
4.0								
5.0								
7.5								
10.0								

November 7, 2017 Meeting of the Project 17 Multi-Period Spectra Task Committee (MPS TC)

- MPS TC Attendance:
  - Charlie Kircher (Chair) - present
  - Nico Luco - present
  - Sanaz Rezaeian – present
  - C. B. Crouse - present
  - Jonathan Stewart – present (part time)
  - David Bonneville – by phone
  - John Hooper – present
- Topics Discussed:
  - Draft proposed changes to ASCE 7-16:
    - Chapter 11 – Design ground motions
    - Chapter 20 – Site Class definitions
    - Chapter 21 – Site-specific requirements
    - Chapter 22 – Ground motions parameter maps
  - Approach for developing multi-period spectra for all US sites

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Overview of Proposed Changes to ASCE 7-16

- Chapter 11 (Section 11.4)
  - Delete site coefficient tables assuming values of S_{MS} (S_{DS}) and S_{M1} (S_{D1}) developed by the USGS include site (and spectrum shape) effects
  - Revise to incorporate site-specific multi-period MCE_R and Design Response Spectra (developed by USGS and provided via a web-based app), but
  - Retain 2-Period definition of the Design Response Spectrum (Figure 11.4-1) defined by site-specific values of S_{DS}, S_{D1} and T_L (developed by USGS and provided via a web-based app) for sites w/o multi-period response spectra
  - Revise site-specific ground motion procedures (Section 11.4.7) to be the same as those of ASCE 7-10 (i.e., remove "band-aide")
- Chapter 20 (Table 20.3-1)
  - Revise definitions/criteria to include new site classes at boundaries
- Chapter 21 (Sections 21.2.2, Figure 21.2-1 and Section 21.3)
  - Revise Deterministic MCE_R floor (Section 21.2.2 ~~and Figure 21.2-1)~~
  - Revise 80% lower-bound limit (Section 21.3) to be based on multi-period design spectrum
- Chapter 22
  - Provide mapped values of S_{DS} and S_{D1} for "default site" conditions only (provide all mapped parameters/site conditions via a web-based app.)

Summary of Proposed Changes to Chapter 11 Seismic Design Criteria

- Section 11.3 – Symbols
  - Delete reference site-related terms (F_a, F_{PGA}, F_v, PGA, S_1 and S_S)
- Section 11.4 - Seismic Ground Motion Values
  - Define "Default Site Class" (when site properties not known)
  - Delete Tables 11.4-1 and 11.4-2 of site coefficients
  - Provide mapped values of S_{MS} and S_{M1} at USGS web site for User-specified site location and site conditions
  - Revise definition of Design Response Spectrum
  - Remove site-specific analysis requirements added to ASCE 7-16
- Section 11.6 - Seismic Design Category
  - ~~Replace S_1 with S_{M1} (for determining SDC E and F)~~
- Section 11.8 - Geologic Hazards/Geotechnical
  - Delete Table 11.8-1 of PGA site coefficients
  - Provide mapped values of PGA_M (for User-specified site data)
- Section 11.9 - Vertical Ground Motions
  - Revise basis (S_{MS} in lieu of S_S) and coefficients of Table 11.9-1

Summary of Proposed Changes to Chapter 20 Site Classification Procedure

- Section 20.1 – Site Classification
  - Add three new site classes to Table 20.3-1
- Section 20.3 – Site Class Definitions
  - Modify requirements based on F_a and F_v
  - Modify requirements to incorporate new site classes

Summary of Proposed Changes to Chapter 21 Site-Specific Ground Motion Procedures

- Section 21.2.1 – Probabilistic MCE_R Ground Motions
  - Delete Method 1 (based on risk coefficients)
- Section 21.2.2 – Deterministic MCE_R Ground Motions
  - Revise Deterministic Floor requirements ~~(delete Figure 21.2-1)~~
- Section 21.2.3 – Site-Specific MCE_R
  - Permit (multi-period) USGS MCE_R spectrum for site of interest
- Section 21.3 – Design Response Spectrum
  - Revise lower-bound limits on site-specific design response spectrum (e.g., not less than 67 percent of USGS MCE_R spectrum)
- Section 21.4 – Design Acceleration Parameters
  - Revise lower-bound limits on site-specific design parameters (e.g., not less 100 percent of the values of Chapter 11)
- Section 21.5 – MCE_G PGA
  - Delete deterministic PGA (base geomean PGA solely on probabilistic (2% in 50-yr) hazard

Summary of Proposed Changes to Chapter 22 Seismic Ground Motion and other Design Maps

- Replace maps of (reference site) MCE_R ground motion parameters S_S, S_1 and PGA with maps of MCE_R ground motion parameters S_{MS}, S_{M1} and PGA_M for "default site conditions" (Section 11.4.2.1):
  - "Where the soil properties are not known in sufficient detail to determine the site class, risk-targeted maximum considered earthquake (MCE_R) spectral response accelerations shall be based on the <u>more critical spectral response acceleration of Site Class C, Site Class CD, Site Class D and Site Class DE site conditions</u>, unless the authority having jurisdiction or geotechnical data determine that Site Class E or F soils are present at the site."
- Delete maps of risk coefficient parameters C_{RS} and C_{R1}