NEW ASCE 7-16 REQUIREMENTS AND LIMITATIONS OF FOR SITE-SPECIFIC GROUND MOTIONS

2016 COSMOS Annual Meeting – Current Ground Motion Design Values Maps – Issues and Solutions

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USGS science for a changing world

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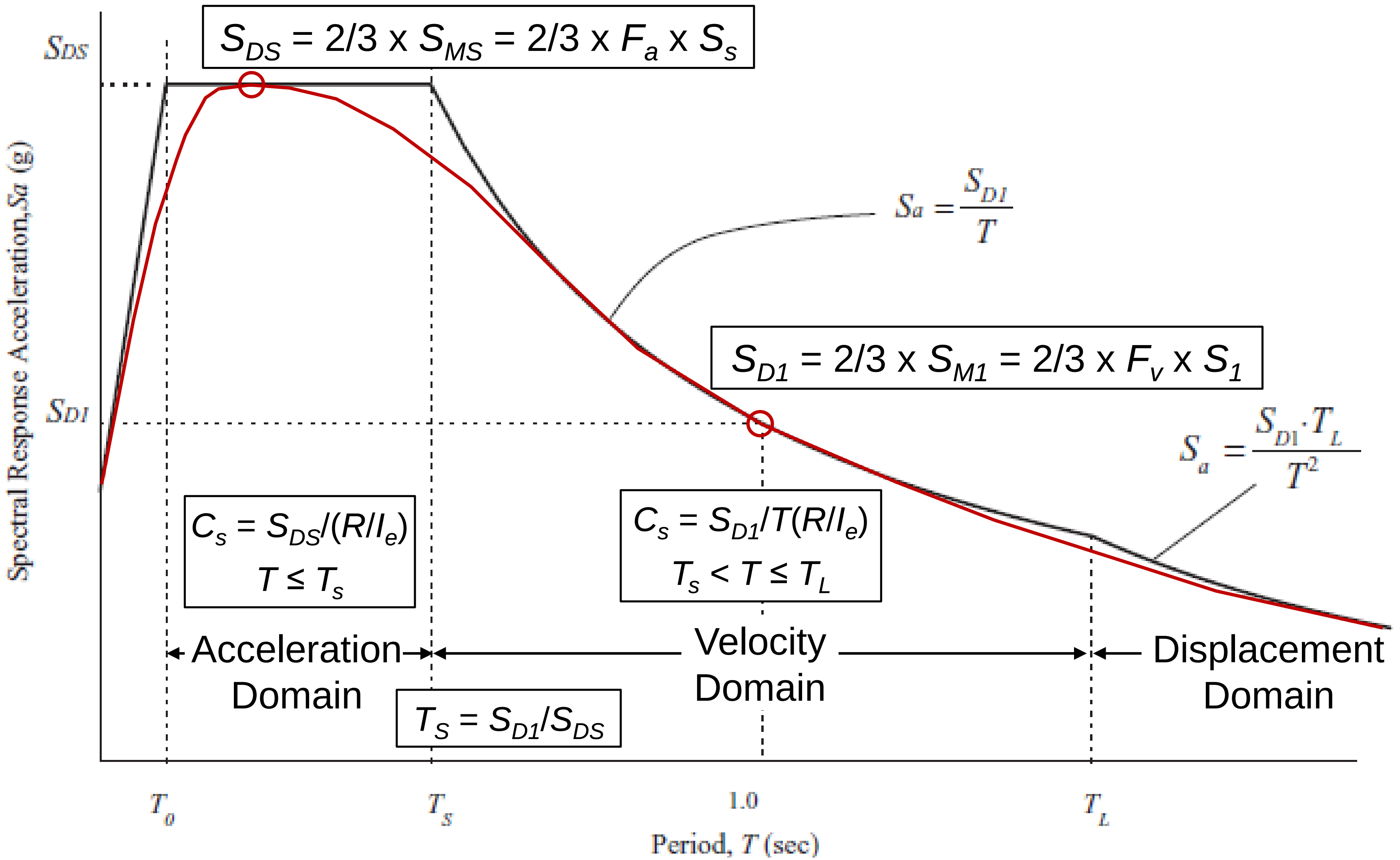
Building Seismic Safety Council

Topics

- Summary of New Requirements of ASCE 7-16
  - **Section 11.4 Site Coefficients (Supplement No. 1)**
  - Section 11.4.7 Site Specific Ground Motion Procedures
  - **Section 21.2.2 Deterministic MCE_R Floor (Supplement No. 1)**
  - **Section 21.3 Lower-Bound Limits (Supplement No. 1)**
  - Section 21.4 Design Acceleration Parameters
- Background
  - The Problem (root cause of the new requirements)
  - Long-Term Solution (ASCE 7-22)
  - Short-Term Solution Options and Related Studies (ASCE 7-16)
- Example Calculation of Site-Specific Ground Motions
  - **New ASCE 7-16 Chapter 21 Requirements (Supplement No. 1)**
- Conclusion

Design Response Spectrum
(Figure 11.4-1, ASCE 7-16 with annotation)



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

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 11.4.7		
F	See Section 11.4.7					

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 classes 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).

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

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

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 11.4.7				
F	See Section 11.4.7					

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 ≥ 0.2 w/Exceptions

Site-Specific analysis required for Site Class E sites where S_1 ≥ 0.2 w/o Exception

Existing Site-Specific Requirements of Section 11.4.7 (i.e., ASCE 7-10 and ASCE 7-16)

- Site-specific ground motion procedures are <u>permitted</u> for any structure
- Site-specific ground motion procedures <u>required</u> for:
  - Section 21.1 procedures are required for structures on Site Class F sites
  - Section 21.2 procedures are required for isolated or damped structures when $S_1 \geq 0.6$ g
- Chapter 21 – Site-Specific Ground Motion Procedures (sections):
  - Section 21.1 – Site Response Analysis
  - Section 21.2 - Risk-Targeted MCE_R Ground Motion Hazard Analysis
    - Section 21.2.1 - Probabilistic MCE_R Ground Motions
    - **Section 21.1.2 - Deterministic MCE_R Ground Motions**
    - Section 21.2.3 – Site-Specific MCE_R
  - **Section 21.3 – Design Response Spectrum**
  - Section 21.4 – Design Acceleration Parameters
  - Section 21.5 – MCE_G Peak Ground Acceleration

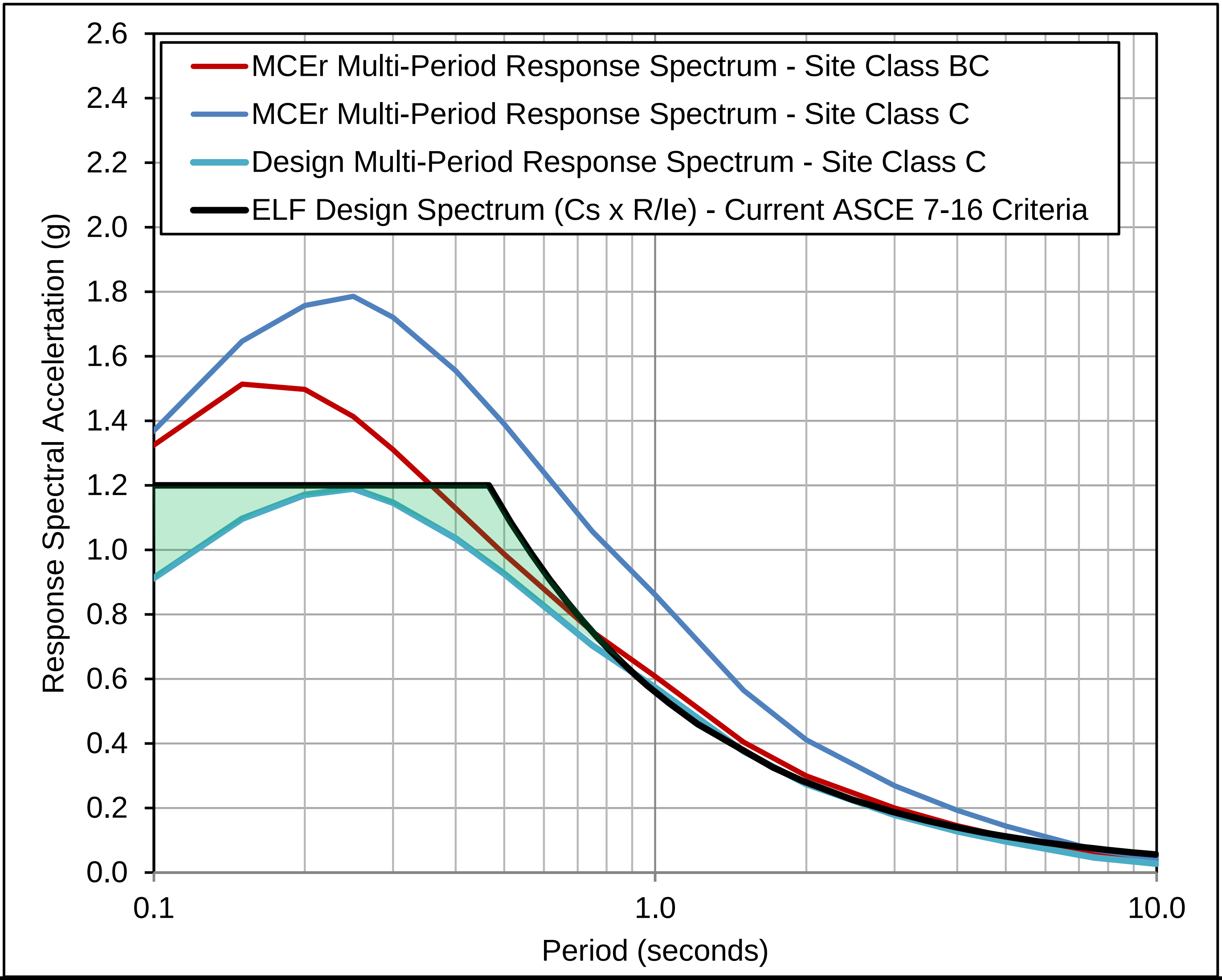
New Requirements for Site-Specific Analysis - Section 11.4.7

- 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
  - 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.

Root Cause of the "Problem"

- Section 11.4 of ASCE 7-10 (ASCE 7-16) - 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
  - 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 (e.g., soil sites whose seismic hazard is dominated by large magnitude events)

Example ELF “Design Spectrum” based on ASCE 7-16 Seismic Criteria
M7.0 earthquake ground motions at R_X = 6.5 km, Site Class C



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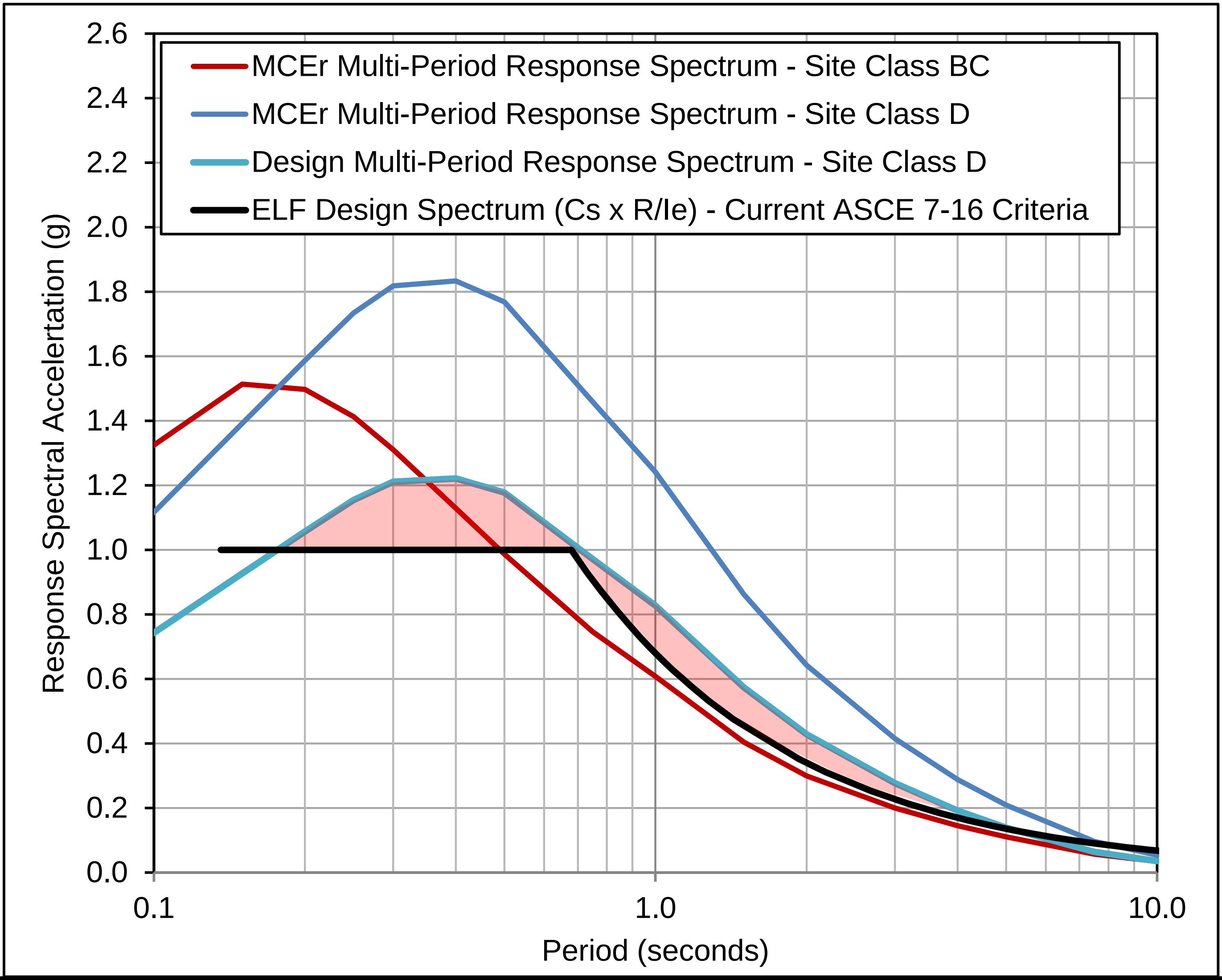
Example ELF "Design Spectrum" based on ASCE 7-16 Seismic Criteria
M7.0 earthquake ground motions at R_X = 6.5 km, Site Class D



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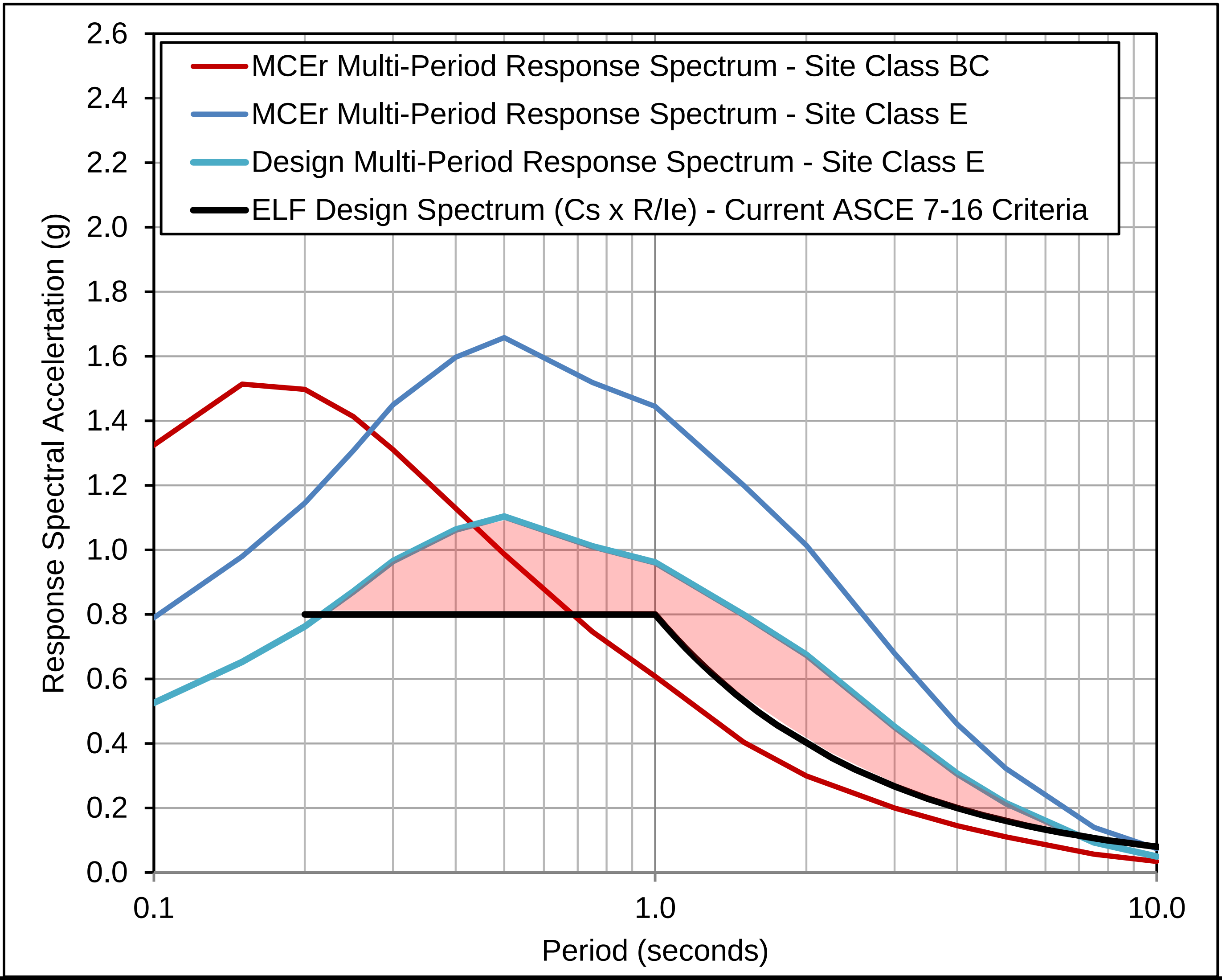
Example ELF "Design Spectrum" based on ASCE 7-16 Seismic Criteria
M7.0 earthquake ground motions at R_X = 6.5 km, Site Class E



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Long-Term Solution (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 (*Project 17*):
  - Development of new ground motion design values maps (by the USGS) for each new response period of interest
  - Development of new ground motion maps (by the USGS) with site effects embedded directly in ground motion design values (~~or new site factor tables developed for each new response period of interest~~)
  - Reworking of seismic design requirements and criteria of Chapter 11 (and other chapters) to accurately represent and properly incorporate new multi-period ground motions

Short-Term 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

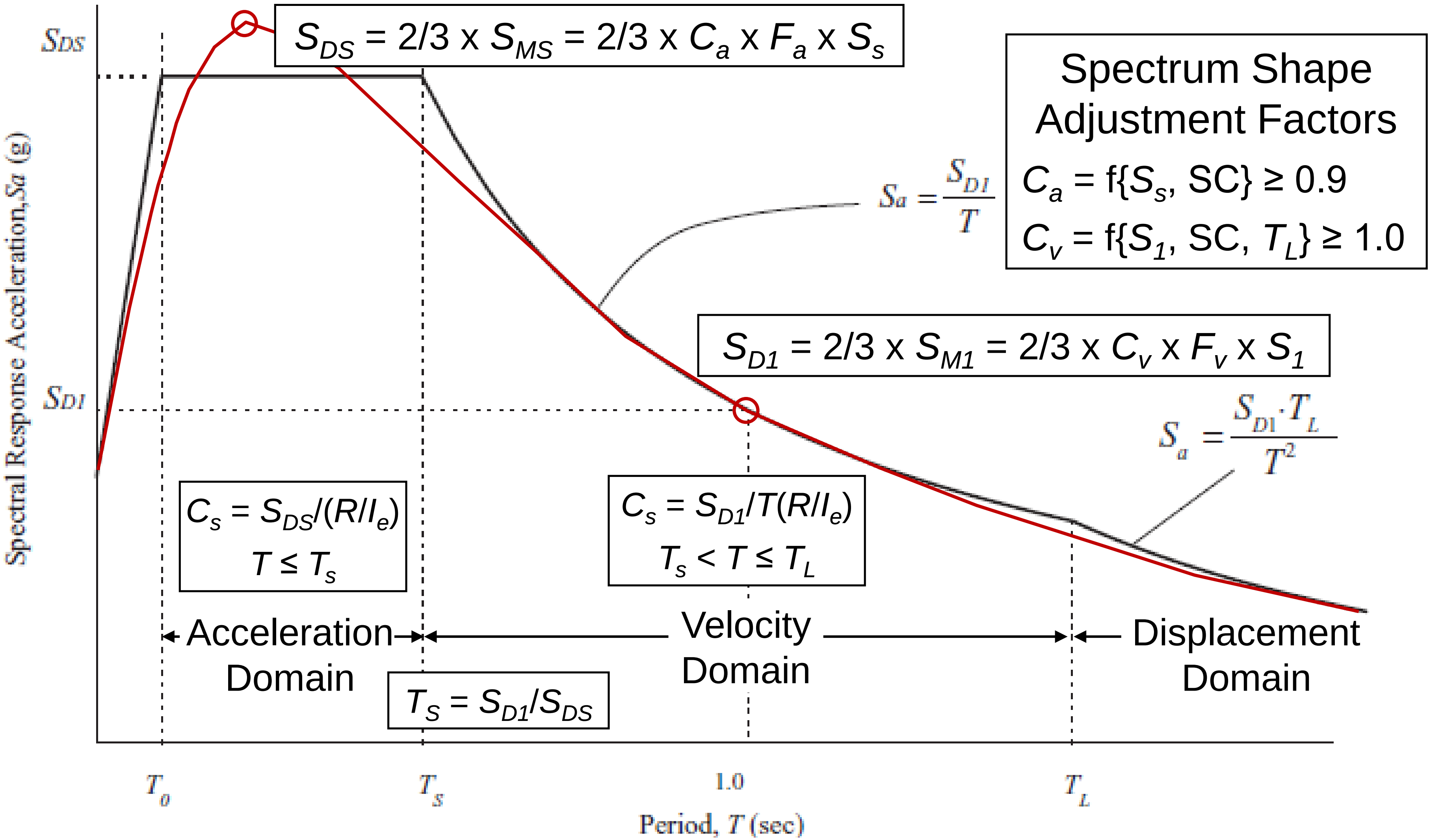
"C'mon, c'mon — it's either one or the other."

Short-Term Solution Homework (ASCE 7-16)

- Perform a study to develop the technical approach and basis for proposing changes to current seismic criteria
  - Develop new values of re-formulated parameters (Option 1)
  - Develop criteria for requiring site-specific analysis (Option 2)
    - Develop conservative values of current seismic parameters for design using ELF (and MRSA) methods in lieu of site-specific analysis
- Study report available from NIBS:
  - Kircher, C. A. (2015). "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://c.ymcdn.com/sites/www.nibs.org/resource/resmgr/BSSC2/Seismic_Factor_Study.pdf

Option 1 - Spectrum Shape Adjustment Factor Reformulation

(Figure 11.4-1 annotated to show proposed C_a and C_v factors of PUC Proposal IT11-006)



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Tentative Re-Formulation of Seismic Parameters

- Add two new "spectrum shape adjustment" factors, C_a and C_v, to Eqs. 11.4-1 and 11.4-2 of Section 11.4.3 which would define values of S_{MS} and S_{M1}, as follows:

$$S_{MS} = \underline{C_a} F_a S_S \qquad (11.4\text{-}1)$$

$$S_{M1} = \underline{C_v} F_v S_1 \qquad (11.4\text{-}2)$$

- Use the new values of seismic coefficients F_a and F_v
- Calculate values of spectrum shape adjustment factors C_a and C_v:

$$C_a = CF_a / F_{0.2} \qquad \text{(e.g., } F_{0.2} = F_a\text{)}$$

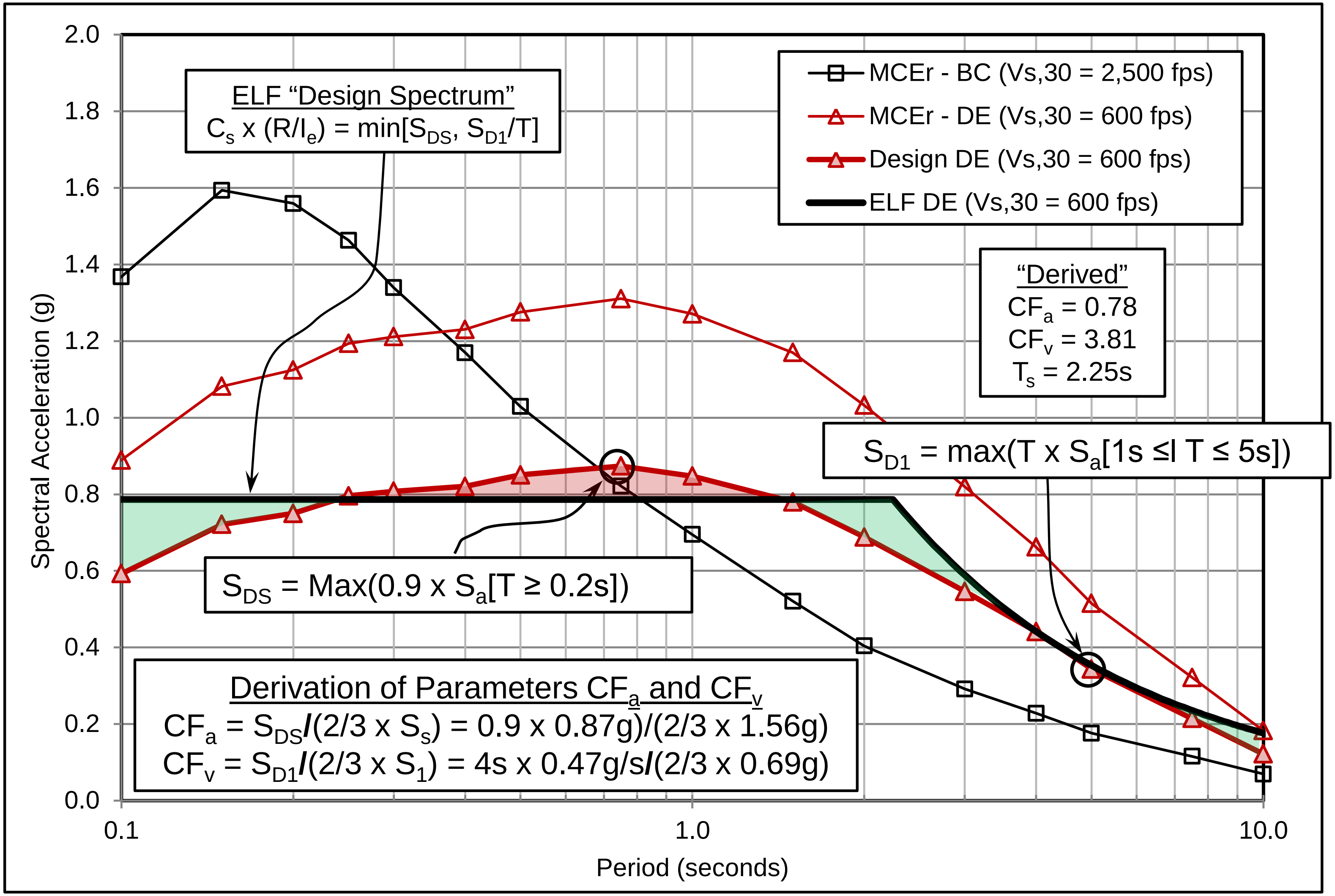
$$C_v = CF_v / F_{1.0} \qquad \text{(e.g., } F_{1.0} = F_v\text{)}$$

- Derive values of the parameters CF_a and CF_v from representative "target" MCE_R spectra using the new criteria of Section 21.4:

$$CF_a = 0.9 \max\{S_{aM}[T \geq 0.2\text{s}]\}/S_s$$

$$CF_v = 1.0 \max\{T \times S_{aM}[5\text{s} \geq T \geq 1\text{s}]\}/S_1$$

Example Derivation of Parameters, CF_a and CF_v using the New Criteria of Section 21.4 - Site Class DE, M8 at R = 8.5 km (NGA-West1 Relations)



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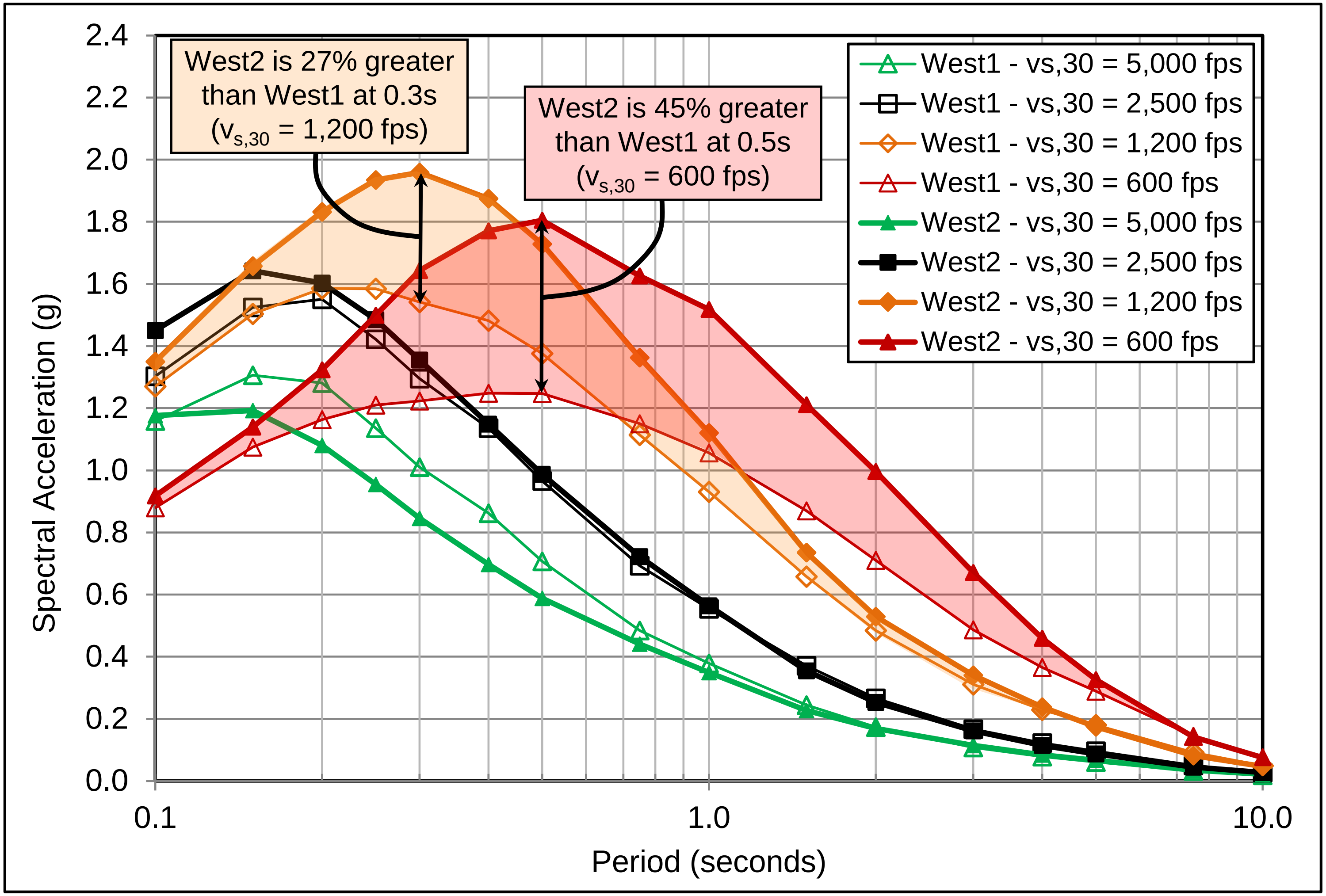
Example Comparison of Deterministic MCE_R Ground Motions
NGA West1 and NGA West2 GMPEs (M7.0 at R_x = 6 km, Site Class boundaries)



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

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.

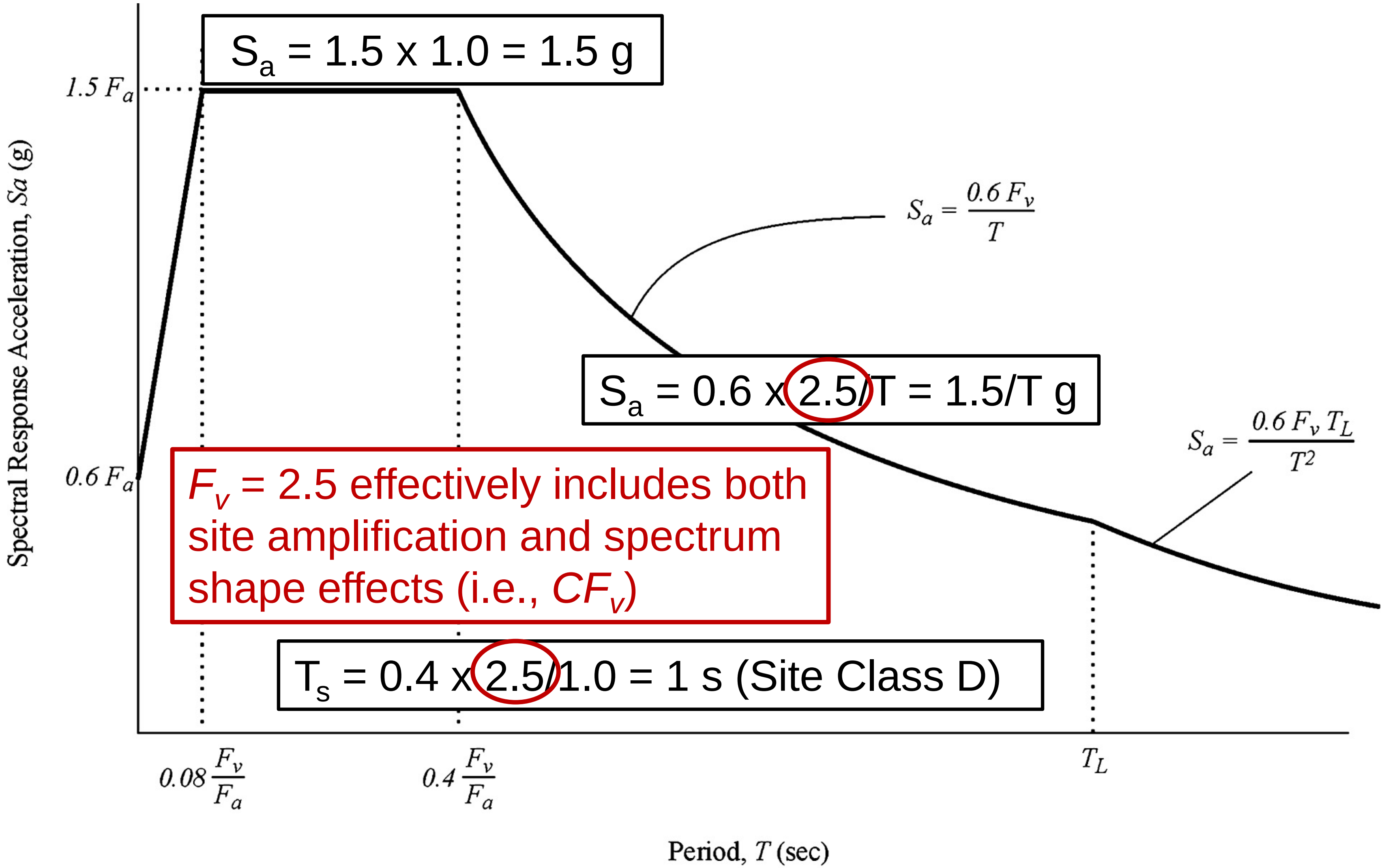
~~For the purposes of this standard, the~~ **ordinates of the deterministic ground motion response spectrum shall not be taken as lower than the corresponding ordinates of the response spectrum determined in accordance with Fig. 21.2-1**~~, where F_a and F_v are determined using Tables 11.4-1 and 11.4-2,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



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, <u>where F_a and F_v are determined as follows:</u>

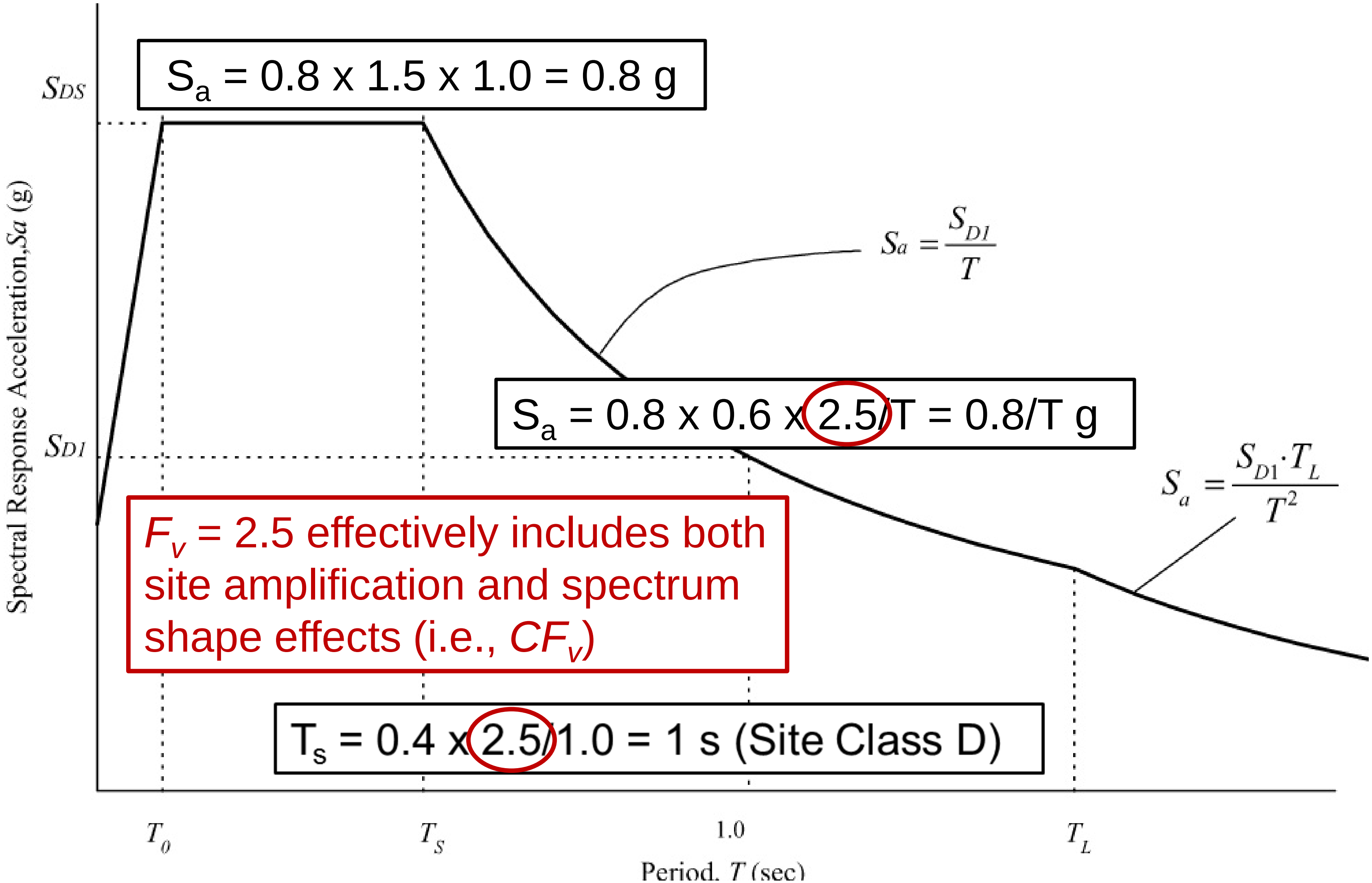
(i) <u>for Site Class A, B, and C: F_a and F_v are determined using Tables 11.4-1 and 11.4-2, respectively;</u>

(ii) <u>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</u>

(iii) <u>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 $S_1 > 0.1$.</u>

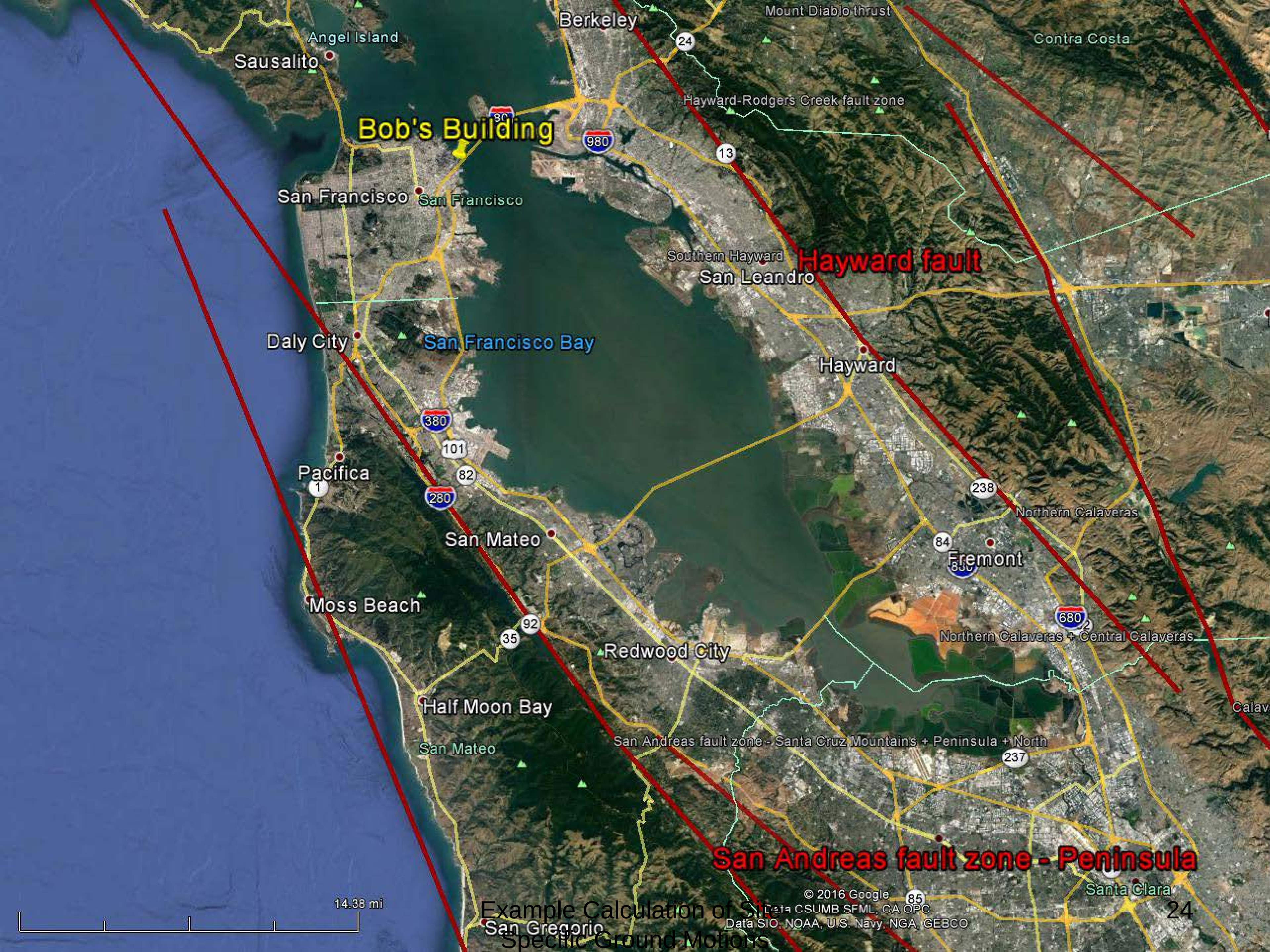
For sites classified as Site Class F requiring site-specific analysis in accordance with Section 11.4.7, the design spectral response acceleration at any period shall not be less than 80 percent of S_a determined for Site Class E in accordance with Section 11.4.5.

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 – Chapter 21 Calculation of Site-Specific Ground Motions – San Francisco Site ("Bob's Building")

- Site Location: San Francisco – SoMa District
  - Deterministic earthquake – Magnitude M8.0 on the San Andreas, R_x = 13.7 km
- Site Class D Site Conditions (assume three different values of $v_{s,30}$):
  - Center of Site Class D ($v_{s,30}$ = 870 fps)
  - Boundaries - Site Class CD ($v_{s,30}$ = 1,200 fps) and Site Class DE ($v_{s,30}$ = 600 fps)
- Site Coefficients:
  - ASCE 7-16 (Tables 11.4-1 and 11.4-2): $F_a = 1.2$, $F_v = 1.7$
  - Derived from Peer NGA West2 GMPEs (e.g., T5-9 and T5-13, Kircher, 2015) :
    - Site Class CD ($v_{s,30}$ = 1,200 fps): $F_{0.2} = 1.16$, $F_{1.0} = 1.99$
    - Site Class D ($v_{s,30}$ = 870 fps): $F_{0.2} = 1.05$, $F_{1.0} = 2.38$
    - Site Class DE ($v_{s,30}$ = 600 fps): $F_{0.2} = 0.85$, $F_{1.0} = 2.69$
- USGS RotD100 Ground Motion Data (2015 NEHRP Provisions):
  - Probabilistic: $C_{RS}S_{SUH} = 0.935 \times 1.858 = 1.737$, $C_{R1}S_{1UH} = 0.916 \times 0.734 = 0.672$
  - Deterministic: $S_{SD} = 1.5$, $S_{1D} = 0.6$
- Design Values (2015 NEHRP Provisions):
  - MCE_R Ground Motions: $S_{MS} = 1.2 \times 1.5 = 1.8$, $S_{M1} = 1.7 \times 0.6 = 1.02$
  - Design Ground Motions: $S_{DS} = 2/3 \times 1.8 = 1.2$, $S_{D1} = 2/3 \times 1.02 = 0.68$


Bob's Building
Hayward fault
San Andreas fault zone - Peninsula
Mount Diablo thrust
Hayward-Rodgers Creek fault zone
Southern Hayward
Northern Calaveras
Northern Calaveras + Central Calaveras
San Andreas fault zone - Santa Cruz Mountains + Peninsula + North
Berkeley
Contra Costa
Angel Island
Sausalito
San Francisco
San Francisco
San Leandro
Daly City
San Francisco Bay
Hayward
Pacifica
San Mateo
Fremont
Moss Beach
Redwood City
Half Moon Bay
San Mateo
San Gregorio
Santa Clara
14.38 mi
© 2016 Google
Data CSUMB SFML, CA OPC
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

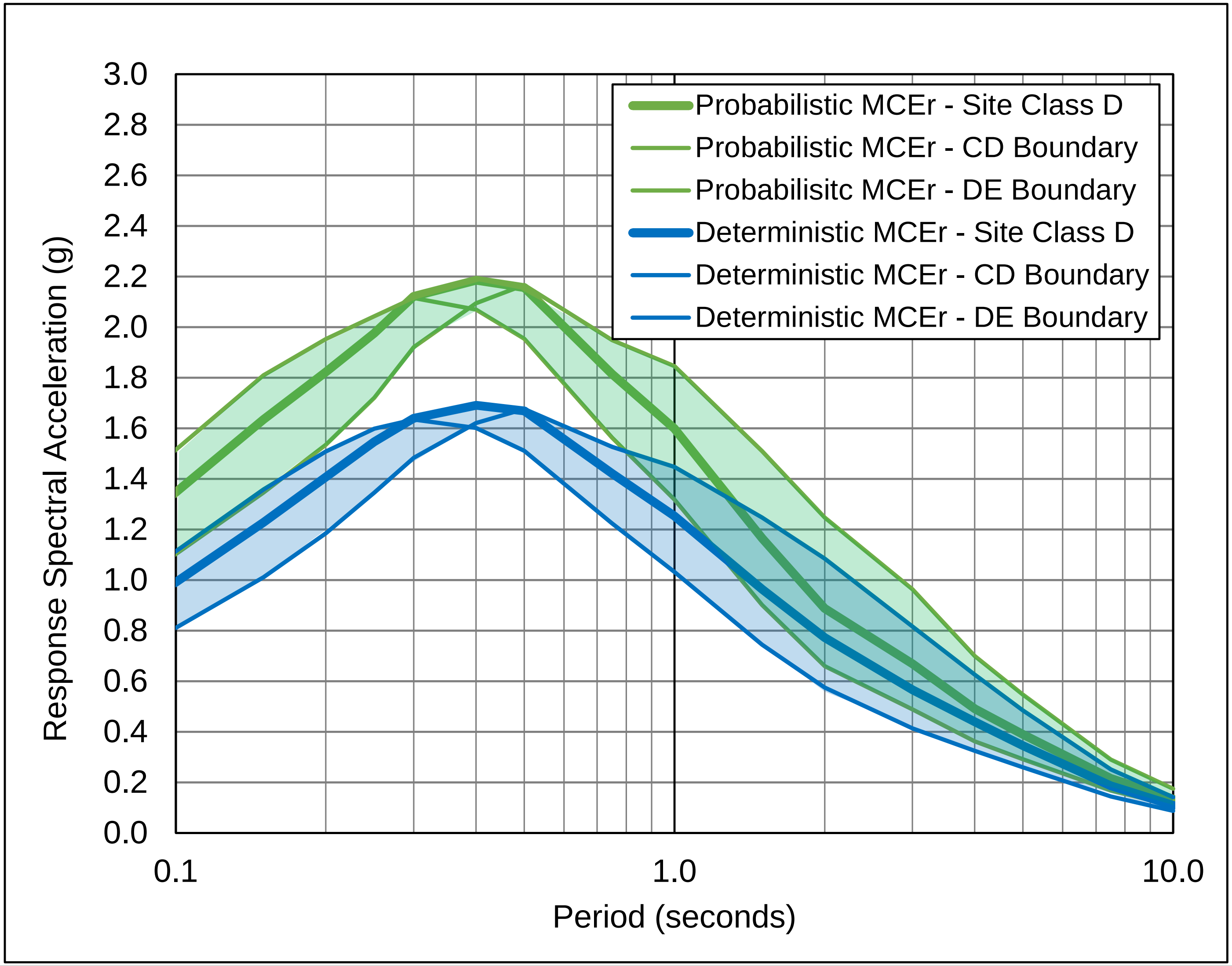
Example – Chapter 21 Calculation of Probabilistic MCE_R and Deterministic MCE_R Response Spectra for the Subject Site

- Probabilistic MCE_R Response Spectra:
  - Based on site-specific analysis anchored to USGS hazard:
  - 0.2 s response anchored to USGS value of $C_{RS}S_{SUH}$ = 1.737 (reference Site Class BC boundary) factored by $F_{0.2}$ = 1.16 (Site Class CD), $F_{0.2}$ = 1.05 (Site Class D) or $F_{0.2}$ = 0.85 (Site Class DE boundary)
  - 1.0 s response anchored to USGS value of $C_{R1}S_{1UH}$ = 0.672 (Site Class BC) factored by $F_{1.0}$ = 1.99 (Site Class CD boundary), $F_{1.0}$ = 2.38 (Site Class D) or $F_{1.0}$ = 2.69 (Site Class DE boundary)
- Deterministic MCE_R Response Spectra:
  - Governing characteristic earthquake: M8.0 on the SAF at R_x = 13.7 km
  - 84th Percentile RotD50 (median) ground motions based on Peer NGA West2 GMPEs - PEER spreadsheet - “Weighted Average of 2014 NGA West-2 GMPEs” (Seyhan 2014)
  - RotD100 (maximum) ground motions based RotD50 ground motions factored by 1.1 (at 0.2 s, or less), 1.3 (at 1.0 s) and 1.5 (at 5 s, or greater)
  - Same methods as those used by USGS to make design values maps

Summary Listing of Probabilistic MCE_R and Deterministic MCE_R Response Spectra for Site Class D (870 fps), Site Class CD Boundary (1,200 fps) and Site Class DE Boundary (600 fps) Site Conditions and the Deterministic MCE_R Lower Limit Response Spectrum (Section 21.2.2) and the 1.5 x 80 Percent Limit on the Design Response Spectrum (Section 21.3) for the Subject Site

T (s)	Deterministic MCE_R Floor (Sec. 21.2.2)	1.5 x 80% Design Limit (Sec. 21.3)	Deterministic MCE_R (West2 GMPEs)			Probabilisitc MCE_R (USGS est.)		
			CD	D	DE	CD	D	DE
			1,200 fps	870 fps	600 fps	1,200 fps	870 fps	600 fps
0.010	0.645	0.516	0.690	0.685	0.635	0.768	0.761	0.707
0.020	0.690	0.552	0.691	0.679	0.635	0.775	0.762	0.712
0.030	0.735	0.588	0.715	0.676	0.608	0.846	0.800	0.720
0.050	0.825	0.660	0.807	0.727	0.627	1.041	0.938	0.809
0.075	0.938	0.750	0.966	0.856	0.700	1.283	1.136	0.929
0.10	1.050	0.840	1.114	0.991	0.812	1.515	1.347	1.104
0.15	1.275	1.020	1.359	1.229	1.011	1.810	1.636	1.346
0.20	1.500	1.200	1.508	1.408	1.185	1.953	1.823	1.535
0.25	1.500	1.200	1.599	1.547	1.347	2.043	1.977	1.721
0.30	1.500	1.200	1.635	1.639	1.484	2.116	2.122	1.921
0.40	1.500	1.200	1.602	1.691	1.622	2.070	2.186	2.095
0.50	1.500	1.200	1.512	1.669	1.677	1.954	2.157	2.167
0.75	1.500	1.200	1.224	1.422	1.526	1.562	1.815	1.949
1.0	1.500	1.200	1.033	1.254	1.447	1.318	1.600	1.846
1.5	1.000	0.800	0.745	0.963	1.247	0.902	1.165	1.510
2.0	0.750	0.600	0.575	0.774	1.086	0.661	0.889	1.248
3.0	0.500	0.400	0.414	0.566	0.817	0.489	0.669	0.964
4.0	0.375	0.300	0.325	0.440	0.627	0.363	0.491	0.700
5.0	0.300	0.240	0.260	0.346	0.485	0.293	0.391	0.547
7.5	0.200	0.160	0.145	0.187	0.252	0.168	0.216	0.291
10.0	0.150	0.120	0.088	0.109	0.141	0.108	0.135	0.175

Comparison of Probabilistic MCE_R and Deterministic MCE_R Response Spectra for the Subject Site Showing the Variation in Response for Different Possible Values of $v_{s,30}$ of Site Class D Site Conditions



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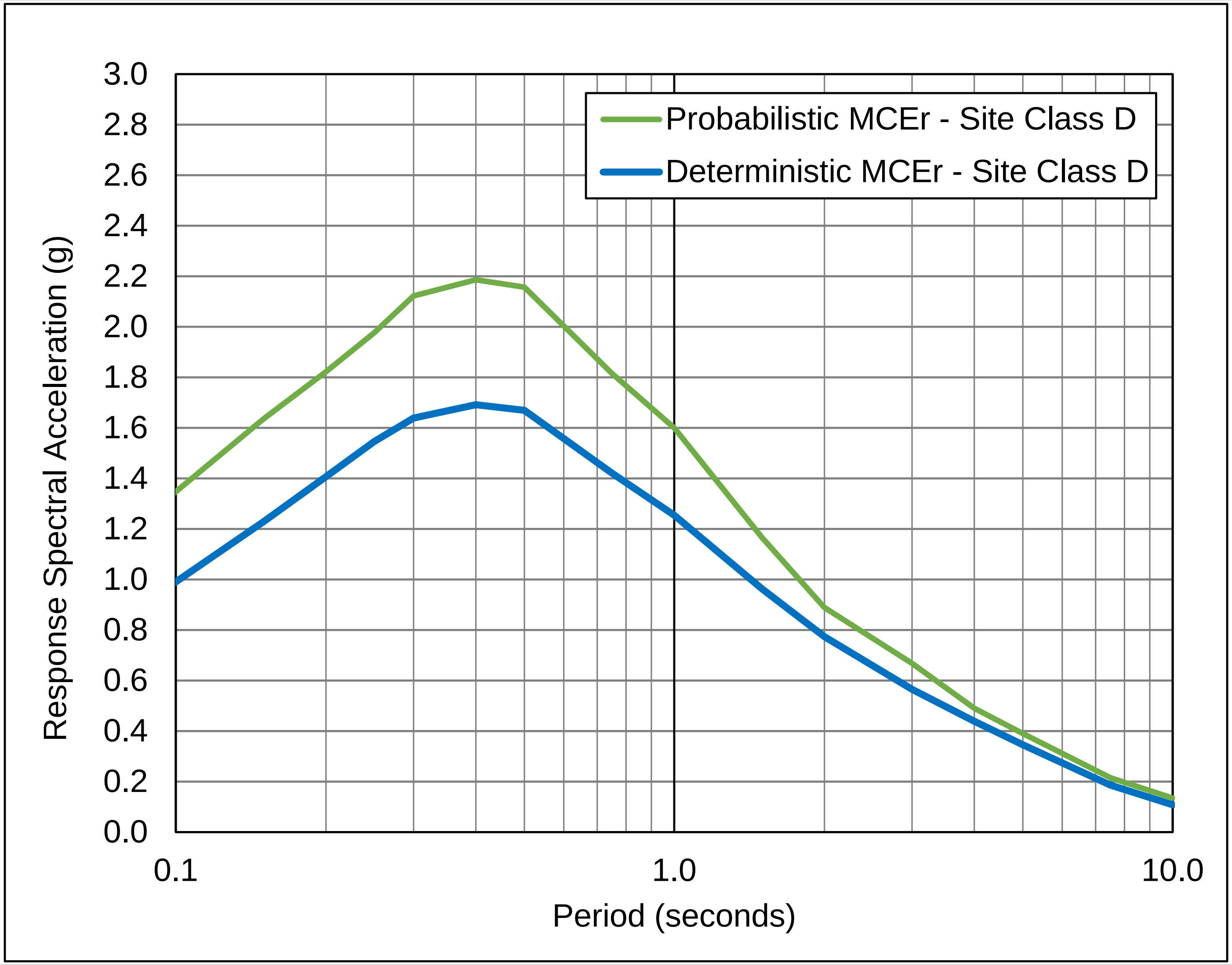
Probabilistic MCE_R and Deterministic MCE_R Response Spectra for the Subject Site Assuming Site Class D Site Conditions – $v_{s,30}$ = 870 fps



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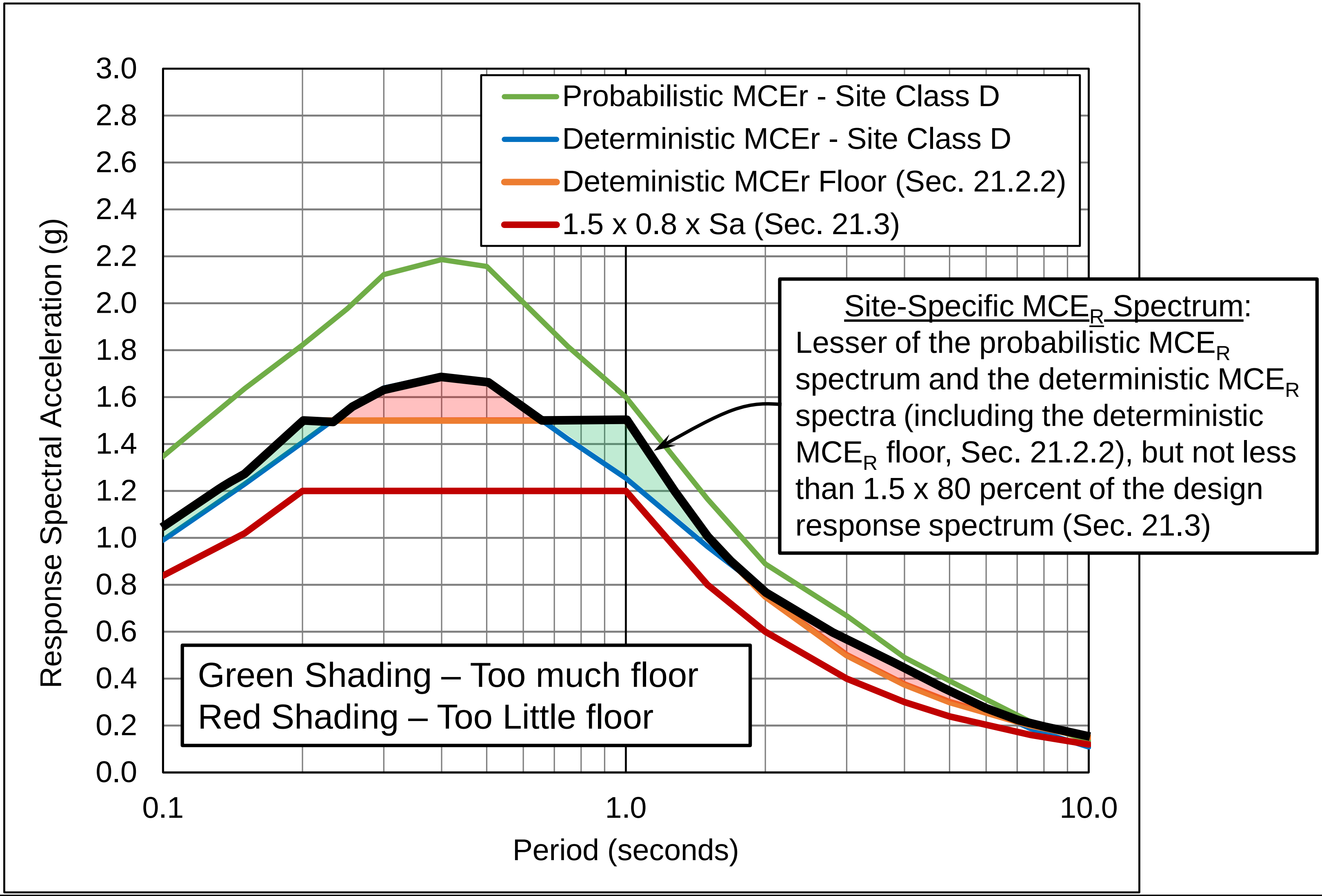
Development of Site-Specific MCE_R Ground Motions for the Subject Site Assuming Site Class D Site Conditions – $v_{s,30}$ = 870 fps



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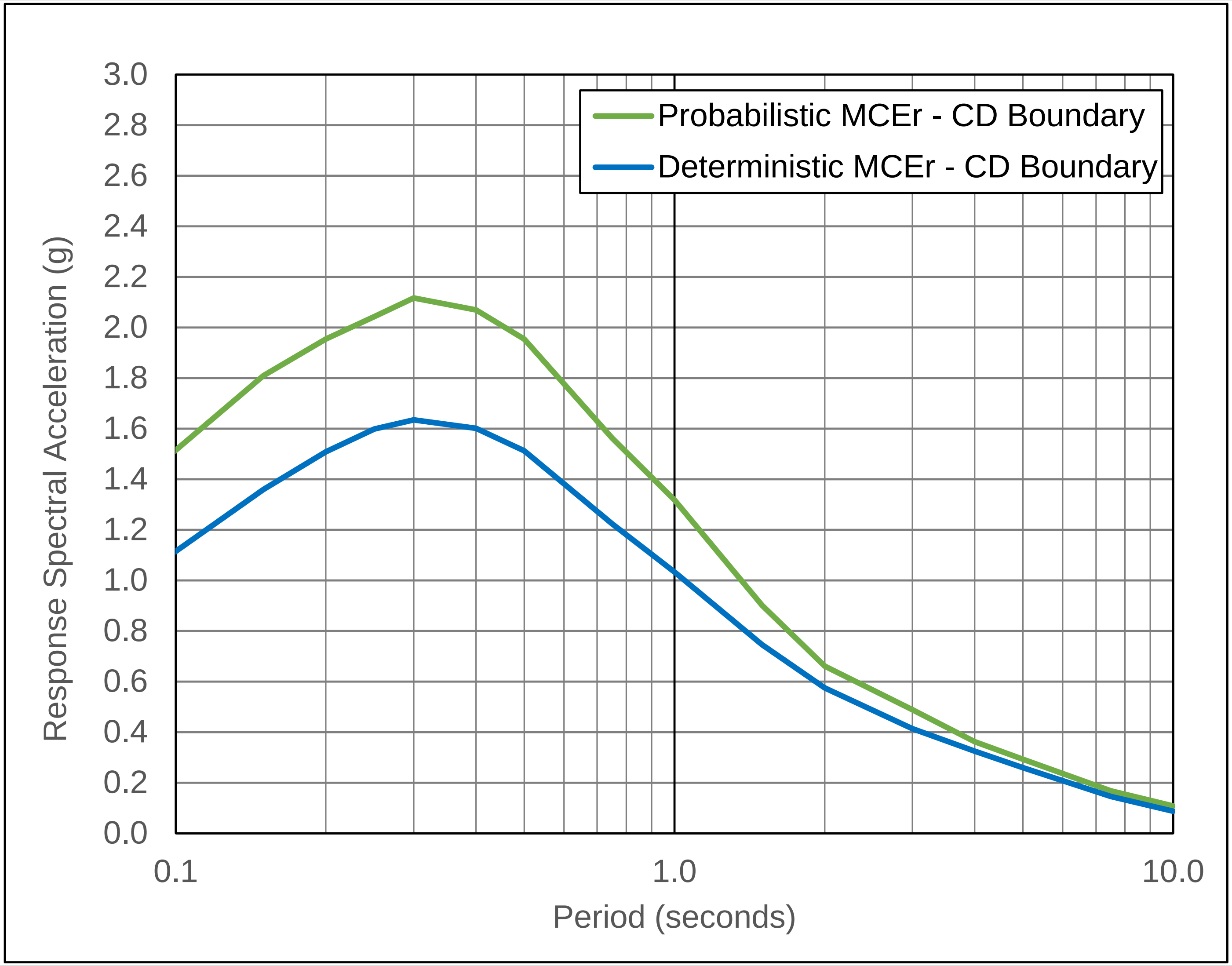
Probabilistic MCE_R and Deterministic MCE_R Response Spectra for the Subject Site Assuming Site Class CD Boundary Site Conditions – $v_{s,30}$ = 1,200 fps



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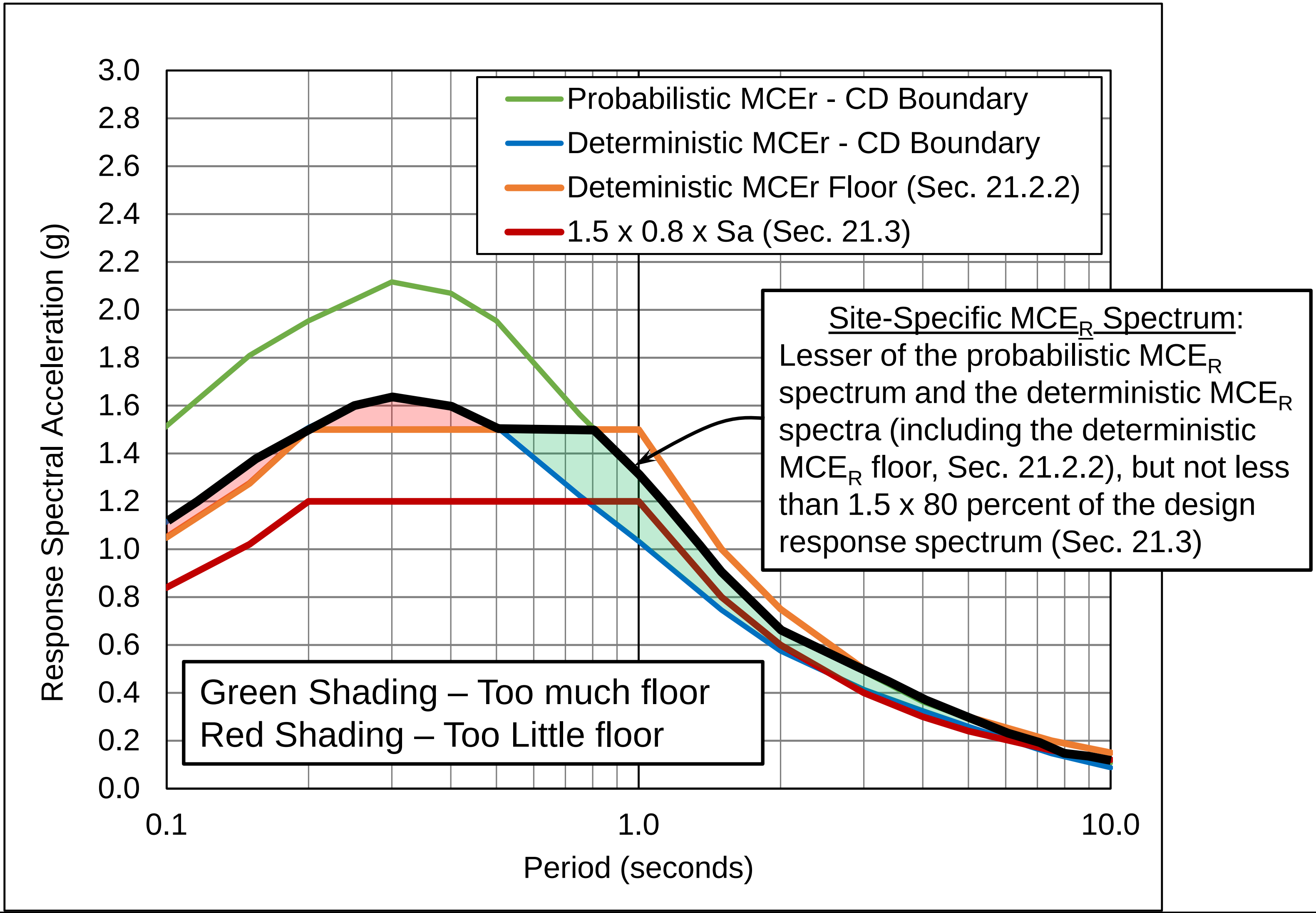
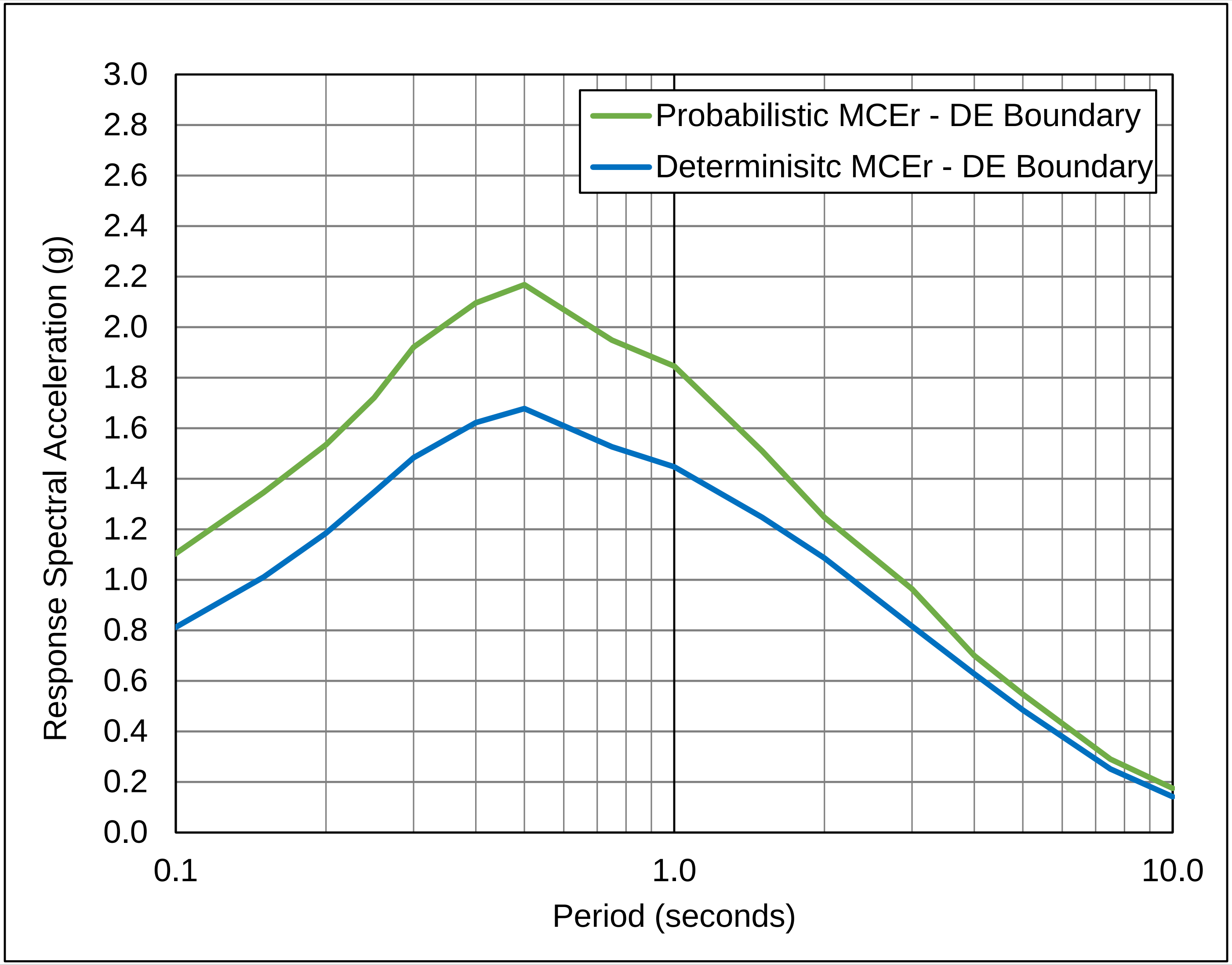
Development of Site-Specific MCE_R Ground Motions for the Subject Site Assuming Site Class CD Boundary Site Conditions – $v_{s,30}$ = 1,200 fps

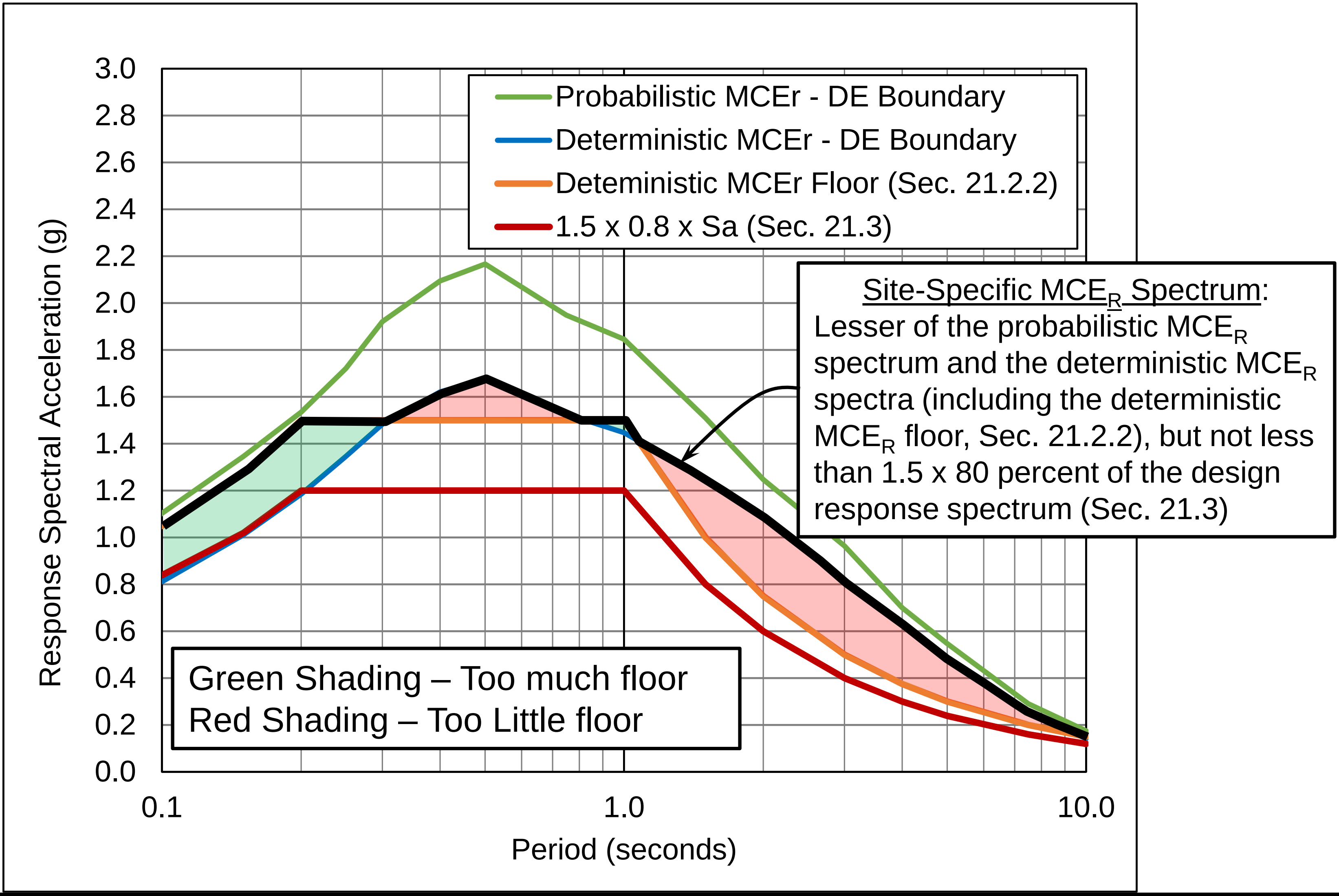


Probabilistic MCE_R and Deterministic MCE_R Response Spectra for the Subject Site Assuming Site Class DE Boundary Site Conditions – $v_{s,30}$ = 600 fps



Kircher Presentation – The New Requirements and Limitations of ASCE 7-16 for Site-Specific Ground Motions

Development of Site-Specific MCE_R Ground Motions for the Subject Site Assuming Site Class CD Boundary Site Conditions – $v_{s,30}$ = 600 fps



Kircher Presentation – The New Requirements and Limitations of ASCE 7-16 for Site-Specific Ground Motions

Summary and Conclusion

- The new requirements of ASCE 7-16 significantly increases the scope of site-specific analyses:
  – Now required for most sites with Site Class D or E site conditions (unless ELF/MRSA design is based on conservative values of design coefficients)
- The very new (Supplement No. 1) requirements of ASCE 7-16 clarify limits on the calculation of site-specific spectra:
  – Section 21.2.2 – Deterministic Floor criteria
  – Section 21.3 – Lower-bound (80%) criteria
- Future requirements of ASCE 7 (ASCE 7-22) will likely incorporate multi-period spectra precluding the need for overly broad requirements for site-specific analysis