THE NEW REQUIREMENTS OF ASCE 7-16 FOR SITE-SPECIFIC GROUND MOTIONS
(Interim Solution to an Identified Short-Coming in the Seismic Design Procedures of ASCE 7-10)

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Topics

• Background
  – Design Response Spectrum (Figure 11.4-1 of ASCE 7-16)
  – Earthquake Ground Motions and Response Spectra 101
  – Site-Specific Requirements of ASCE 7-10 (and ASCE 7-05)

• The Problem – Root Cause

• The Solution – Short-Term

• Investigations and Findings - FEMA-funded BSSC study

• Summary of New Requirements (ASCE 7-16)
  – Section 11.4.1 - Mapped Acceleration Parameters, $S_s$ and $S_1$
  – Section 11.4.3 - Site Coefficients, $F_a$ and $F_v$
  – Section 11.4.7 - Site Specific Ground Motion Procedures
  – Section 21.4 - Design Acceleration Parameters

• Impact on Design – Design Examples

• Conclusions
Background - Design Response Spectrum
(Figure 11.4-1, ASCE 7-05, ASCE 7-10 or ASCE 7-16 with annotation)

\[ S_{DS} = \frac{2}{3} \times S_{MS} = \frac{2}{3} \times F_a \times S_s \]

\[ S_{D1} = \frac{2}{3} \times S_{M1} = \frac{2}{3} \times F_v \times S_1 \]

\[ C_s = \frac{S_{DS}}{(R/I_e)} \quad T \leq T_s \]

\[ C_s = \frac{S_{D1}}{T(R/I_e)} \quad T_s < T \leq T_L \]

\[ T_s = \frac{S_{D1}}{S_{DS}} \]

Kircher Presentation – The New Requirements of ASCE 7-16 for Site-Specific Ground Motions
### Background – Site Coefficients ($F_a$ and $F_v$)  
(Tables 11.2-1 and 11.2-2, ASCE 7-05 and ASCE 7-10)

#### VALUES OF SITE COEFFICIENT $F_a$  

<table>
<thead>
<tr>
<th>SITE CLASS</th>
<th>$S_e \leq 0.25$</th>
<th>$S_e = 0.50$</th>
<th>$S_e = 0.75$</th>
<th>$S_e = 1.00$</th>
<th>$S_e \geq 1.25$</th>
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<tr>
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<td>0.8</td>
<td>0.8</td>
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<td>0.8</td>
</tr>
<tr>
<td>B</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>C</td>
<td>1.2</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>1.0</td>
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<td>1.4</td>
<td>1.2</td>
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<td>1.0</td>
</tr>
<tr>
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<td>1.7</td>
<td>1.2</td>
<td>0.9</td>
<td>0.9</td>
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<tr>
<td>F</td>
<td>Note b</td>
<td>Note b</td>
<td>Note b</td>
<td>Note b</td>
<td>Note b</td>
</tr>
</tbody>
</table>

*a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at short period, $S_e$.  

b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

#### VALUES OF SITE COEFFICIENT $F_v$  

<table>
<thead>
<tr>
<th>SITE CLASS</th>
<th>$S_t \leq 0.1$</th>
<th>$S_t = 0.2$</th>
<th>$S_t = 0.3$</th>
<th>$S_t = 0.4$</th>
<th>$S_t \geq 0.5$</th>
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</thead>
<tbody>
<tr>
<td>A</td>
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<tr>
<td>B</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
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<tr>
<td>C</td>
<td>1.7</td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.3</td>
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<tr>
<td>D</td>
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</tbody>
</table>

*a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at 1-second period, $S_t$.  

b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.
Site Classification and Shear Wave Velocity ($v_{s,30}$) Criteria  
(Table 20.3-1 of ASCE 7-05, ASCE 7-10 and ASCE 7-16)

<table>
<thead>
<tr>
<th>Site Class</th>
<th>$v_s$</th>
<th>$N$ or $N_{ch}$</th>
<th>$s_u$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Hard rock</td>
<td>$&gt;5,000$ ft/s</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>B. Rock</td>
<td>2,500 to 5,000 ft/s</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>C. Very dense soil and soft rock</td>
<td>1,200 to 2,500 ft/s</td>
<td>$&gt;50$</td>
<td>$&gt;2,000$ psf</td>
</tr>
<tr>
<td>D. Stiff soil</td>
<td>600 to 1,200 ft/s</td>
<td>15 to 50</td>
<td>1,000 to 2,000 psf</td>
</tr>
<tr>
<td>E. Soft clay soil</td>
<td>$&lt;600$ ft/s</td>
<td>$&lt;15$</td>
<td>$&lt;1,000$ psf</td>
</tr>
</tbody>
</table>
| Any profile with more than 10 ft of soil having the following characteristics:  
  — Plasticity index $PI > 20$,  
  — Moisture content $w \geq 40\%$,  
  — Undrained shear strength $s_u < 500$ psf |
| F. Soils requiring site response analysis in accordance with Section 21.1 | See Section 20.3.1 |
Background - Map of $T_L$ Regions (and Relationship to Earthquake Magnitude) (Chapter 22, ASCE 7-05, ASCE 7-10 and ASCE 7-16)

<table>
<thead>
<tr>
<th>$M$</th>
<th>$T_c$ (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0 – 6.5</td>
<td>4</td>
</tr>
<tr>
<td>6.5 – 7.0</td>
<td>6</td>
</tr>
<tr>
<td>7.0 – 7.5</td>
<td>8</td>
</tr>
<tr>
<td>7.5 – 8.0</td>
<td>12</td>
</tr>
<tr>
<td>8.0 – 8.5</td>
<td>16</td>
</tr>
<tr>
<td>8.5 – 9.0+</td>
<td>20</td>
</tr>
</tbody>
</table>

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

• Earthquake Ground Motions 101
  – Earthquake Ground Motion Records
  – Earthquake Ground Motion Response Spectra
  – Earthquake Ground Motion Predictive Equations (GMPEs)

• Site-Specific Seismic Hazard Analysis – ASCE 7-10
  – When Required (or Permitted)? - Section 11.4.7
  – Risk-Targeted $MCE_R$ Ground Motions – Section 21.2
    • Probabilistic $MCE_R$ Ground Motions
    • Deterministic $MCE_R$ Ground Motions
  – Design Response Spectrum – Section 21.3
  – Design Acceleration Parameters – Section 21.4
Earthquake Ground Motion Characterization

- **Ground Motion Time Histories**
  - Acceleration (including PGA)
  - Velocity (including PGV)
  - Displacement (including PGD)

- **Elastic Response Spectra**
  - Peak response of a collection of linear single-degree-of-freedom systems with 5% viscous damping
  - “Smooth” spectra used for design (to represent many different possible ground motion time histories)
Figure 2-15a: Distribution of ground motions for selected strong-motion stations: north component of acceleration. Time histories are plotted close to the associated site. Time and amplitude scales are shown to the right. Shaded areas represent alluvial basins and valleys.
Example Variability of Recorded Ground Motions – 1994 Northridge Earthquake

Figure 2-16 Maximum horizontal acceleration versus distance for the Northridge earthquake. Distance is from the surface projection of the aftershock zone, as defined by Joyner and Boore (1988). Largest of the two horizontal components is plotted. Bold line is the median curve of Joyner and Boore (1988) for a M6.7 earthquake. Light lines indicate ±1 and ±2 standard deviations. Circles indicate CSMIP stations; triangles indicate USGS stations.
A Couple of Ground Motion Response and Design Spectra References

Newmark & Hall (EERI 1982)  Housner & Jennings (EERI 1982)
Example Smooth Design Spectra based on Response Spectra of 1971 San Fernando Eq. Ground Motion Record (Housner & Jennings, EERI 1982)

Smooth Design Spectra
(0%, 2%, 5%, 10%, 20% Damping)

Response Spectra
(0%, 2%, 5%, 10%, 20% Damping)
Example Early Design Spectra for Different Site Conditions
(Fig. 24, Seed & Idriss, EERI 1982, from Seed, Ugas Lymer, BSSA 66:1, 1976)
Example Design Spectra - Deterministic MCE$_R$ Ground Motions (ASCE 7-16)

PEER NGA West2 GMPEs (M7.0 at $R_x = 6$ km, Site Class boundaries)
Example Design Spectra - Deterministic MCE\(_R\) Ground Motions (ASCE 7-16) PEER NGA West2 GMPEs (M7.0 at \(R_x = 6\) km, Site Class boundaries)

- Site Class AB - vs,30 = 5,000 fps
- Site Class BC - vs,30 = 2,500 fps
- Site Class CD - vs,30 = 1,200 fps
- Site Class DE - vs,30 = 600 fps

\[ SV\ (\text{in/s}) = \left( \frac{386.4}{2\pi} \right) T \times SA(g) \]
\[ SD\ (\text{in}) = \left( \frac{386.4}{4\pi^2} \right) T^2 \times SA\ (g) \]
\[ SD\ (\text{in}) = 9.8 \times T^2 \times SA\ (g) \]
Example Design Spectra - Deterministic MCE_R Ground Motions (ASCE 7-16)
PEER NGA West2 GMPEs (M7.0 at R_x = 6 km, Site Class boundaries)
Example Design Spectra - Deterministic MCE\textsubscript{R} Ground Motions (ASCE 7-16) PEER NGA West2 GMPEs (M7.0 at R\textsubscript{x} = 6 km, Site Class boundaries)
PEER NGA Ground Motion Predictive Equations (GMPEs)
(the equations formerly known as attenuation functions)

- West 1/West 2 GMPEs are based on statistical analysis of response spectra of earthquake records of PEER NGA West1/West2 databases
- Multiple GMPEs developed for each seismic region (and PEER project):
  - Four West1 GMPEs – AS08, BA08, CB08 and CY08
  - Five West2 GMPEs – ASK14, BSSA14, CB14, CY14 and I14
- Response Spectral Acceleration (g) is “predicted” as a function:
  - Earthquake magnitude (M)
  - Distance from the site to fault rupture plane (Rₓ, Rₑ and RJB)
  - Site conditions defined in terms of site shear wave velocity (vₛ,30)
  - Fault type (strike-slip/normal, reverse/trust)
  - Fault geometry (ZTOR, W and Dip angle)
  - Basin depth terms (Z₁.₀ and Z₂.₅)
- Response “predicted” for 20 Periods from T = 0.01 (s) to T = 10 (s)
- Spectra may be calculated using PEER NGA GMPE spreadsheets:
  - West1 (Al Atik 2009) - average of 3 GMPEs (ASCE 7-10 WUS sites)
  - West2 (Seyhan 2014) – average of 4 GMPEs (ASCE 7-16 WUS sites)
Definitions of Distance from Site to Fault Rupture Plane and Fault Parameters of the PEER NGA West 1 and West2 GMPEs

(a) Strike slip faulting

(b) Reverse or normal faulting, hanging-wall site
Recent and Relevant Special Issues of *Earthquake Spectra*

PEER NGA – West2 Project

2014 National Seismic Hazard Maps

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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)
Response spectral acceleration at four periods for strike-slip faults. All amplitudes adjusted to $V_{30} = 760\text{ m/s}$ using soil amplification factors of BSSA14 (from Figure 5, “NGA-West2 Equations for Predicting PGA, PGV, and 5% Damped PSA for Shallow Crustal Earthquakes,” Boore et al., *Earthquake Spectra*, Vol. 30, No. 3 August 2014)
Example Comparison of Deterministic MCE\textsubscript{R} Ground Motions
NGA West1 and NGA West2 GMPEs (M7.0 at R\textsubscript{x} = 6 km, Site Class boundaries)

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

West2 is 27\% greater than West1 at 0.3s
\(v_{s,30} = 1,200 \text{ fps}\)

West2 is 45\% greater than West1 at 0.5s
\(v_{s,30} = 600 \text{ fps}\)
New data shake quake strategy – Analysis of foreign disasters may allow state to ease strict building codes – Sacramento Bee (June 24, 2007)

“Deierlein, deputy director of the Pacific Earthquake Engineering Center at UC Berkeley, is among dozens of consultants, professors and government scientists who toiled to understand implications of data from Taiwan, Turkey and other recent deadly quakes.

The result was a set of five “attenuation” equations that can be used to predict how much a given quake, in a given spot, will make different types of ground shudder miles away.

For much of California, that means 10 percent to 35 percent less shaking, said Youssef Bozorgnia, associate director of the quake research center at Berkeley.

‘We are so proud of these’ equations, Bozorgnia said, because they could reduce construction costs by hundreds of millions of dollars in much of coastal California, where new or retrofitted buildings would not need to be as robust.”
Seismic Code Development “Yo-Yo” Dilemma

• Earth Science. The underlying earth science of earthquakes is rapidly evolving and will necessarily change as research advances our understanding of earthquake ground motions.

• Seismic Codes. Building owners and other stakeholders assume that seismic codes reflect “settled science” and that the seismic criteria required for building design only change when there is a compelling reason (e.g., discovery of a new active fault).

• Seismic Design Criteria Yo-Yo. Up and down changes to seismic design criteria (each code cycle) erode stakeholder confidence in seismic codes and the underlying earth science they are based on.
Site-Specific Requirements ASCE 7-10

• Section 11.4.7 – Site-Specific Ground Motion Procedures:
  – Chapter 21 procedures are permitted for any structure
  – Section 21.1 procedures are required for structures on Site Class F sites (i.e., soil failure)
  – Section 21.2 procedures are required for isolated or damped structures when $S_1 \geq 0.6$ g

• Section 21.1 - Site Response Analysis
  – Development of surface $MCE_R$ ground motions from bedrock $MCE_R$ ground motions using dynamic models of the site soil conditions

• Section 21.2 – Risk-Targeted Maximum Considered Earthquake (MCE$_R$) Ground Motion Hazard Analysis
  – Section 21.2.1 – Probabilistic MCE$_R$ Ground Motions
  – Section 21.2.2 – Deterministic MCE$_R$ Ground Motions
  – Section 21.2.3 – Site-Specific MCE$_R$ Ground Motions
Site-Specific Requirements ASCE 7-10 (cont.)

- Section 21.3 – Design Response Spectrum
  - Two-thirds of $MCE_R$ at each period
  - Not less than 80 percent of the Design Spectrum of Section 11.4.5 at each period (i.e., “safety net”)

- Section 21.4 – Design Acceleration Parameters ($S_{DS}$ and $S_{D1}$)
  - Short-period Design Acceleration Parameter, $S_{DS}$
    - Based on response spectral acceleration at $T = 0.2s$ (i.e., same basis as that of the design value maps of Chapter 22), but
    - Not less than 90% of peak acceleration response (i.e., at any short period)
  - 1-Second Design Acceleration Parameter, $S_{D1}$
    - Based on response spectral acceleration at $T = 1.0s$ (i.e., same basis as that of the design value maps of Chapter 22), but
    - Not less than 100% of 2 x response spectral acceleration at $T = 2.0s$ (i.e., since site spectrum may be greater than $1/T$)
Illustration of the Criteria of Section 21.4 of ASCE 7-10
Site Class DE, M8 at R = 8.5 km (PEER NGA-West1 Relations)

ELF “Design Spectrum”
\[ C_s x \left( \frac{R}{I_e} \right) = \min[S_{DS}, \frac{S_{D1}}{T}] \]

\[ S_{D1} = \max(S_a[T=1.0s], 2 \times S_a[T=2.0s]) \]

\[ S_{DS} = \max(S_a[T=0.2s], 0.9 \times S_a[T = \text{all}]) \]
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” - ASCE 7-16 w/o New Site-Specific Requirements
M7.0 earthquake ground motions at $R_X = 6.5$ km, Site Class C
Example ELF “Design Spectrum” - ASCE 7-16 w/o New Site-Specific Requirements
M7.0 earthquake ground motions at $R_x = 6.5$ km, Site Class D
Example ELF “Design Spectrum” - ASCE 7-16 w/o New Site-Specific Requirements
M7.0 earthquake ground motions at R_x = 6.5 km, Site Class E
Short-Term Solution (ASCE 7-16)

• BSSC PUC Considered Two Options:
  – Re-formulate seismic parameters to eliminate potential non-conservatism in ELF (and MRSA) seismic forces
  – Require site-specific analysis when ELF (and MRSA) seismic forces could be potentially non-conservative

• FEMA-funded BSSC study performed by Kircher & Associates that developed the technical approach and basis for proposing changes to current seismic criteria
  – Developed new values of re-formulated parameters (Option 1)
  – Developed criteria for requiring site-specific analysis (Option 2)
    • Developed conservative values of current seismic parameters for design using ELF (and MRSA) methods in lieu of site-specific analysis
Study Acknowledgments

• FEMA-funded 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”

• 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)
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 site effects embedded directly in ground motion design values maps)
- Challenges:
  - Non-WUS sites? - GMPEs are not available for all U.S. regions
  - 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?
Summary of New Requirements – ASCE 7-16

• New Site-Specific Requirements
  – Section 11.4.7 - Site Specific Ground Motion Procedures – Site-specific ground motions are now required for all buildings at certain sites (e.g., not just isolated/damped structures at high seismic sites)
  – Section 21.4 - Design Acceleration Parameters (S_{DS} and S_{D1}) – More appropriate rules are now required for developing design acceleration parameters from site-specific design spectra
  – Other site-specific requirements of Chapter 21 – No Changes

• Other New Ground Motion-Related Requirements
  – Section 11.4.1 - Mapped Acceleration Parameters, S_{s} and S_{1} (Chapter 22) – based on USGS 2014 update of NSHMP maps
  – Section 11.4.3 - Site Coefficients – No changes to Site Class definitions, but values of F_{a} (Table 11.4-1) and F_{v} (Tables 11.4-2) modified based on PEER NGA-West2 Project research
New Design Values Maps of $MCE_R$ Ground Motion Parameters, $S_s$ and $S_1$
(Chapter 22 of ASCE 7-16)

- New (updated) science, but not new (site-specific) $MCE_R$ methods:
  - Design values maps of $MCE_R$ ground motion parameters, $S_s$ and $S_1$, are based on the site-specific $MCE_R$ methods of Chapter 21 of ASCE 7-16 (but these methods did not change substantially from those of ASCE 7-10)

- New (updated) Science – Design values are based on the USGS updates of the National Seismic Hazard Maps:
  - National Seismic Hazard Maps provide updated estimates of 2% in 50-year uniform hazard spectra (UHS) of median (RotD50) ground motions
  - The design values of ASCE 7-10 were derived from the 2009 update of the NSHMP maps (USGS OFR 2008-1128)
  - The design values of ASCE 7-16 were derived from the 2014 update of the NSHMP maps (USGS OFR 2014-1091)
New Values of the Site Coefficient, $F_a$ (Table 11.4-1 of ASCE7-16)
(showing as proposed changes to ASCE 7-10)

Table 11.4-1 Site Coefficient, $F_a$

<table>
<thead>
<tr>
<th>Site Class</th>
<th>Mapped Risk-Targeted Maximum Considered Earthquake (MCE$_R$) Spectral Response Acceleration Parameter at Short Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S_s \leq 0.25$</td>
</tr>
<tr>
<td>A</td>
<td>0.8</td>
</tr>
<tr>
<td>B</td>
<td>1.0 0.9</td>
</tr>
<tr>
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<td>2.5 2.4</td>
</tr>
<tr>
<td>F</td>
<td></td>
</tr>
</tbody>
</table>

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) and Site Class D is no longer the “default” site class (since Site Class C amplification is greater in some cases).
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, $F_v$

<table>
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<tr>
<th>Site Class</th>
<th>$S_1 \leq 0.1$</th>
<th>$S_1 = 0.2$</th>
<th>$S_1 = 0.3$</th>
<th>$S_1 = 0.4$</th>
<th>$S_1 = 0.5$</th>
<th>$S_1 \geq 0.6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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<td>1.0 0.8</td>
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<tr>
<td>C</td>
<td>1.7 1.5</td>
<td>1.6 1.5</td>
<td>1.5</td>
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<td>1.3 1.5</td>
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<tr>
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<td>2.0 2.2</td>
<td>1.8 2.0</td>
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<tr>
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<td>3.5 4.2</td>
<td>3.2 3.3</td>
<td>2.8</td>
<td>2.4</td>
<td>2.4 2.2</td>
<td>2.0</td>
</tr>
<tr>
<td>F</td>
<td>See Section 11.4.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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).
New Site-Specific Requirements of Section 21.4 of ASCE 7-16

- Section 21.4 – Improved derivation of design acceleration parameters $S_{DS}$ and $S_{D1}$ from a site-specific design spectrum:
  
  - Base $S_{DS}$ on 90 percent of the peak acceleration of the site-specific design spectrum (periods of 0.2s to 1s) – ignore 100 percent of the value at 0.2s
    
    Consistently define domain of constant acceleration in terms of 90 percent of peak acceleration response regardless of the period of peak response (within the range 0.2s to 1s).
  
  - Base $S_{D1}$ on 100 percent of $T_x$ site-specific design spectrum at the period of peak velocity response (periods 1s to 5s)
    
    Extend period range from 1s to 5s for Site Class D and E sites to avoid underestimating response in the domain of constant velocity for soil sites
Illustration of the New Requirements of Section 21.4 of ASCE 7-16
Site Class DE, M8 at R = 8.5 km (PEER NGA-West1 Relations)

ELF “Design Spectrum”
\[ C_s \times \left( \frac{R}{I_e} \right) = \min[S_{DS}, S_{D1}/T] \]

\[ S_{D1} = \max(T \times S_a[1s \leq T \leq 5s]) \]

\[ S_{DS} = \max(0.9 \times S_a[T \geq 0.2s]) \]
New Site-Specific Requirements of Section 11.4.7 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 procedure is used for design.
Impact on Design - Example Values of the Design Coefficient ($C_s$)

- Two Structural Systems:
  - 4-Story Steel Special Moment Frame Building
  - 20-Story Steel Special Moment Frame Building

- Three Site Conditions (each system) – Site Class C, D and E

- One Set of Seismic Parameters (for all examples) – $S_s = 1.5 \, g$, $S_1 = 0.6 \, g$

- Four Sets of ELF Design Criteria (for each example):
  - ASCE 7-10 – Current design requirements of ASCE 7-10
  - ASCE 7-16 w/008 – New design requirements of ASCE 7-16 including the new site-specific requirements of Section 11.4.7
  - ASCE 7-16 w/NSC – What if ASCE 7-16 had adopted the new site coefficients, but not the new requirements of Section 11.4.7?
  - ASCE 7-16 w/SSAF - What if ASCE 7-16 had adopted the new site coefficients and (proposed) new spectrum shape adjustment factors (SSAFs) to modify the frequency content of the Design Spectrum?
Example Comparison of the Design Coefficient ($C_s$)
4-Story Steel Special Moment Frame Building - Site Class C

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel</th>
<th>Site Class</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>MF</td>
<td>$S_s$</td>
<td>1.50</td>
</tr>
<tr>
<td>Detailing</td>
<td>Special</td>
<td>$S_f$</td>
<td>0.60</td>
</tr>
<tr>
<td>Floors</td>
<td>4</td>
<td>$T_L$ (s)</td>
<td>12</td>
</tr>
<tr>
<td>Height (ft)</td>
<td>45</td>
<td>SDC</td>
<td>D</td>
</tr>
<tr>
<td>$T_a$ (s)</td>
<td>0.59</td>
<td>R</td>
<td>8</td>
</tr>
</tbody>
</table>

**Design Coefficient, $C_s$ (g)**

- **ASCE 7-10**: Design Value at $T$
- **ASCE 7-16 w/NSC**: Design Value at $T$
- **ASCE 7-16 w/008**: Design Value at $T$
- **ASCE 7-16 w/SSAF**: Design Value at $T$
**Example Comparison of the Design Coefficient ($C_s$)**

4-Story Steel Special Moment Frame Building - Site Class D

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel</th>
<th>Site Class</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>MF</td>
<td>$S_s$</td>
<td>1.50</td>
</tr>
<tr>
<td>Detailing</td>
<td>Special</td>
<td>$S_f$</td>
<td>0.60</td>
</tr>
<tr>
<td>Floors</td>
<td>4</td>
<td>$T_L$ (s)</td>
<td>12</td>
</tr>
<tr>
<td>Height (ft)</td>
<td>45</td>
<td>SDC</td>
<td>D</td>
</tr>
<tr>
<td>$T_a$ (s)</td>
<td>0.59</td>
<td>$R$</td>
<td>8</td>
</tr>
</tbody>
</table>

### Graphical Representation

- **ASCE 7-10**: Design Value at $T$ (red square)
- **ASCE 7-16 w/NSC**: Design Value at $T$ (blue triangle)
- **ASCE 7-16 w/008**: Design Value at $T$ (black circle)
- **ASCE 7-16 w/SSAF**: Design Value at $T$ (green diamond)
Example Comparison of the Design Coefficient (C_s) for 4-Story Steel Special Moment Frame Building - Site Class E

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel</th>
<th>Site Class</th>
<th>( S_s )</th>
<th>( S_1 )</th>
<th>( T_a ) (s)</th>
<th>( T_L ) (s)</th>
<th>Height (ft)</th>
<th>SDC</th>
<th>( R )</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>MF</td>
<td>( S_s )</td>
<td>1.50</td>
<td>0.60</td>
<td>0.59</td>
<td>12</td>
<td>45</td>
<td>D</td>
<td>8</td>
</tr>
<tr>
<td>Detailing</td>
<td>Special</td>
<td>( S_1 )</td>
<td>0.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Design Coefficient, \( C_s \) vs. Period (seconds)

- Red: ASCE 7-10
- Blue: ASCE 7-16 w/NSC
- Blue Diamond: Design Value at T
- Green: ASCE 7-16 w/SSAF
- Green Triangle: Design Value at T
- Black: ASCE 7-16 w/008
- Black Diamond: Design Value at T

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Example Comparison of the Design Coefficient ($C_s$)
20-Story Steel Special Moment Frame Building - Site Class C

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel</th>
<th>Site Class</th>
<th>$C_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>MF</td>
<td>$S_s$</td>
<td>1.50</td>
</tr>
<tr>
<td>Detailing</td>
<td>Special</td>
<td>$S_1$</td>
<td>0.60</td>
</tr>
<tr>
<td>Floors</td>
<td>20</td>
<td>$T_L$ (s)</td>
<td>12</td>
</tr>
<tr>
<td>Height</td>
<td>212</td>
<td>SDC</td>
<td>D</td>
</tr>
<tr>
<td>$T_a$ (s)</td>
<td>2.03</td>
<td>R</td>
<td>8</td>
</tr>
</tbody>
</table>

Graph showing the comparison of design coefficients at different periods for ASCE 7-10, ASCE 7-16 w/NSC, and ASCE 7-16 w/008.

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Example Comparison of the Design Coefficient ($C_s$)
20-Story Steel Special Moment Frame Building - Site Class D

Design Coefficient, $C_s (g)$

<table>
<thead>
<tr>
<th>Period (seconds)</th>
<th>Design Value at T</th>
<th>ASCE 7-10</th>
<th>ASCE 7-16 w/NSC</th>
<th>ASCE 7-16 w/008</th>
<th>ASCE 7-16 w/SSAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td></td>
<td></td>
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<tr>
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</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel</th>
<th>Site Class</th>
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<tbody>
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<td>$S_f$</td>
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<td>Floors</td>
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<td>12</td>
</tr>
<tr>
<td>Height (ft)</td>
<td>212</td>
<td>SDC</td>
<td>D</td>
</tr>
<tr>
<td>$T_a$ (s)</td>
<td>2.03</td>
<td>$R$</td>
<td>8</td>
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</tbody>
</table>

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

02/14/2016 2016 ASCE Short Course SC10
Example Comparison of the Design Coefficient ($C_s$) for 20-Story Steel Special Moment Frame Building - Site Class E

Site-Specific Analysis Required ($T_a > T_s$)

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel</th>
<th>Site Class</th>
<th>$E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
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<tr>
<td>Detailing</td>
<td>Special</td>
<td>$S_f$</td>
<td>0.60</td>
</tr>
<tr>
<td>Floors</td>
<td>20</td>
<td>$T_L (s)$</td>
<td>12</td>
</tr>
<tr>
<td>Height (ft)</td>
<td>212</td>
<td>SDC</td>
<td>D</td>
</tr>
<tr>
<td>$T_a (s)$</td>
<td>2.03</td>
<td>$R$</td>
<td>8</td>
</tr>
</tbody>
</table>

Period (seconds)

Design Coefficient, $C_s (g)$

ASCE 7-10
- Design Value at $T$

ASCE 7-16 w/NSC
- Design Value at $T$

ASCE 7-16 w/008
- Design Value at $T$

ASCE 7-16 w/SSAF
- Design Value at $T$
Conclusions

- **New Building Design.** The new site-specific requirements (and exceptions) of Section 11.4.7 of ASCE 7-16 will have a significant impact on the design of new tall flexible buildings at Site Class D and E sites (e.g., 50 percent increase in design forces).

- **Existing Building Safety.** Implications for existing buildings (??).

- **Temporary Solution.** The new site-specific design requirements of Section 11.4.7 of ASCE 7-16 provide a short-term solution that can and should be replaced by a more appropriate long-term solution in the next Code cycle (ASCE 7-22).

- **Multi-Period Design Spectra.** 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 would directly incorporate site, basin and other effects that influence the shape (i.e., frequency content) of the design spectrum.