SITE-SPECIFIC SEISMIC ANALYSES

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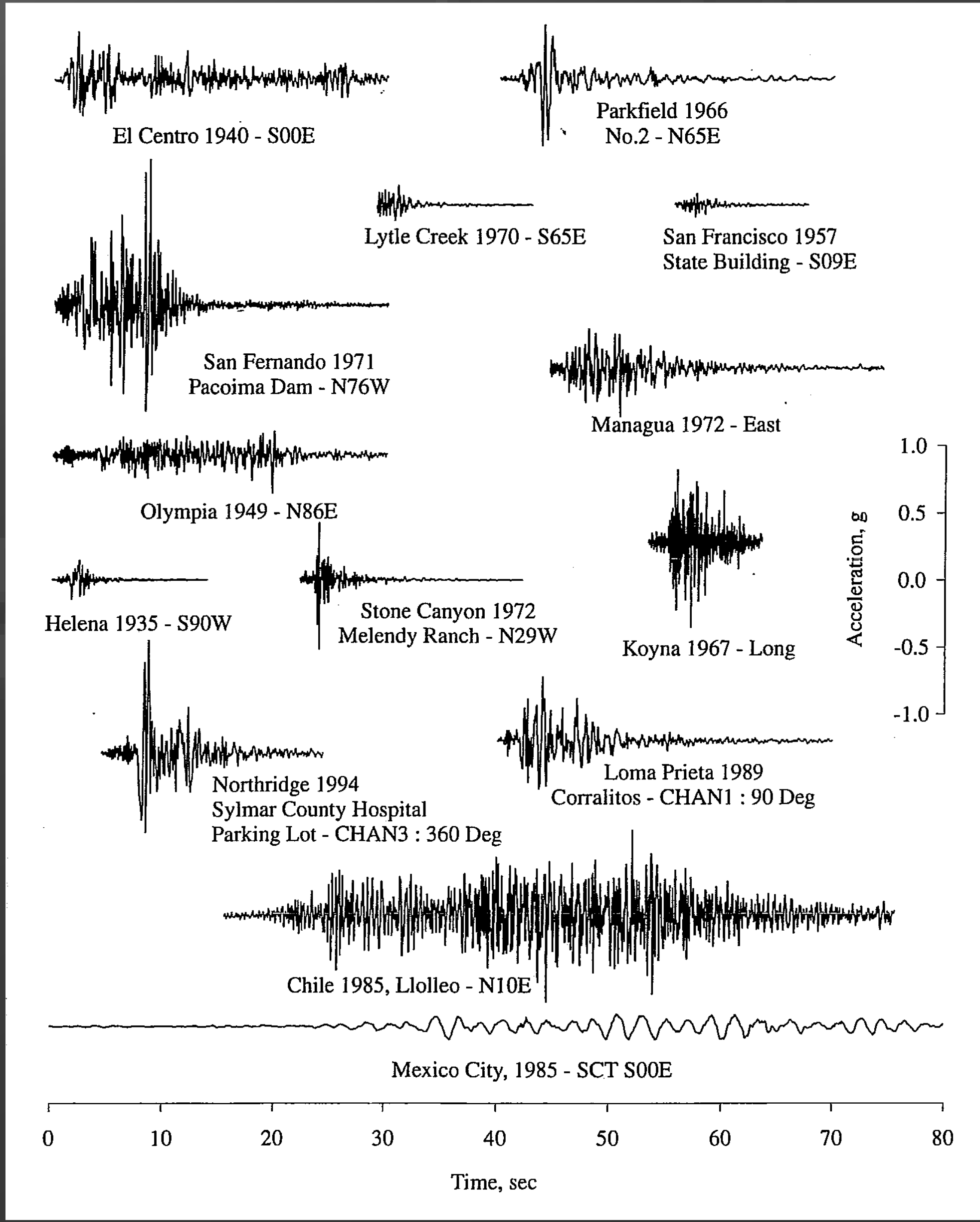
PRESENTATION OUTLINE

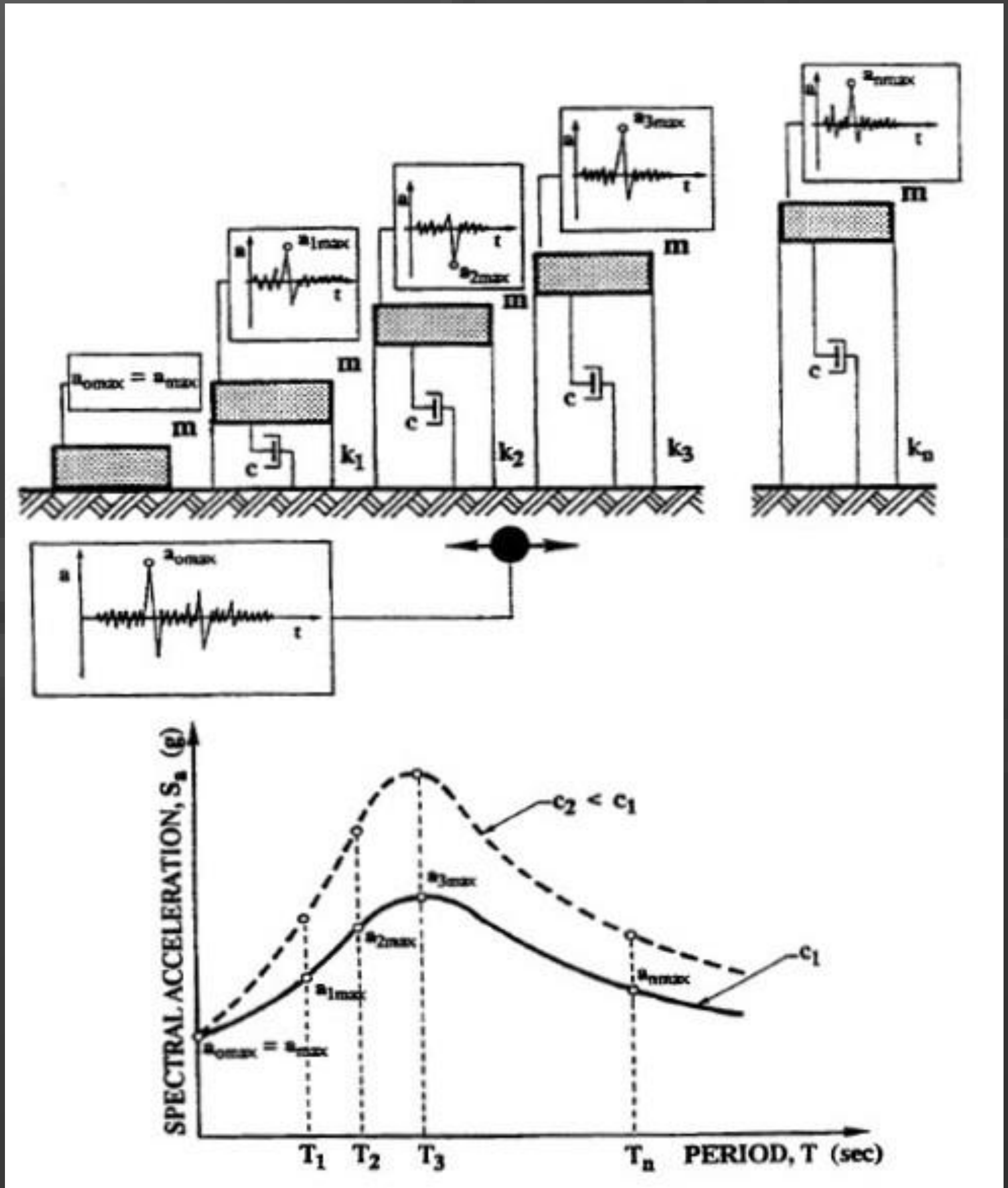
- Major concepts
- Why are site-specific seismic analyses needed?
- Types of site-specific analyses
  - Ground motion hazard analysis (GMHA)
  - Site response analysis (SRA)
- Example content of GMHA report
  - Overall steps of analysis
- Some issues regarding SRA
- Studies gone wrong and related thoughts
- Getting a good GMHA or SRA
- Self-assessment of qualifications for GMHA
- Personal plea for preparedness

EARTHQUAKE ACCELERATION TIME HISTORIES



- Amplitude
- Frequency content
- Duration

RESPONSE SPECTRA



$$F_{base} = k \times S_d$$
$$= m \times \omega^2 \times S_d$$
$$= m \times S_a$$

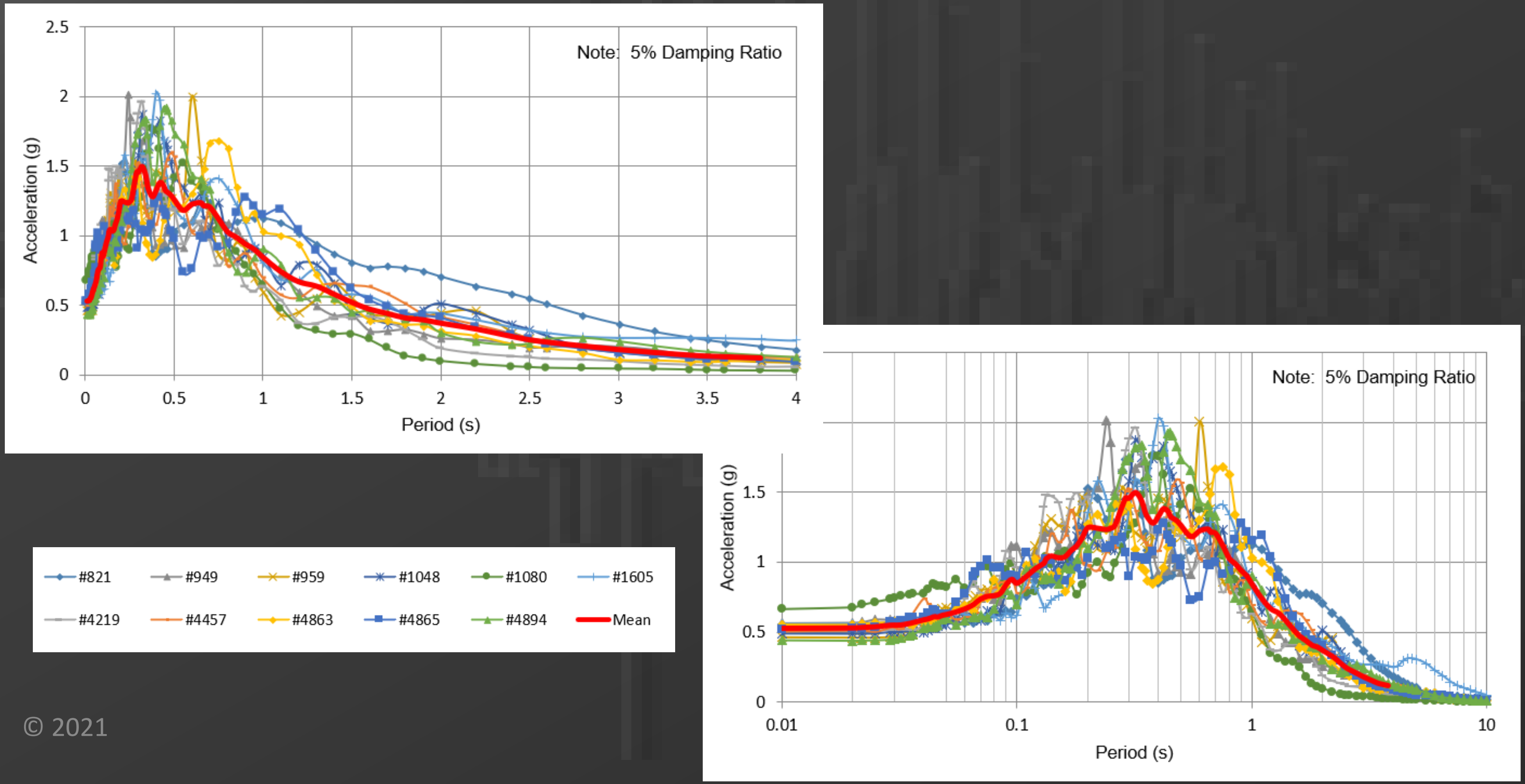
Note:

Spectrum = Singular

Spectra = Plural

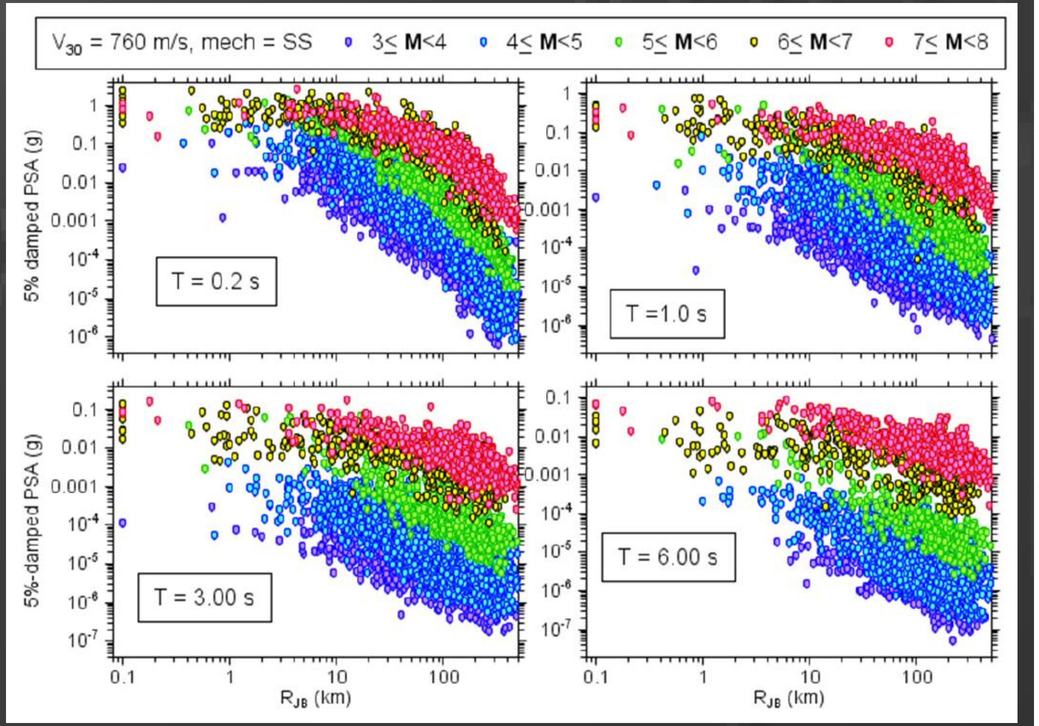
DESIGN RESPONSE SPECTRUM?

- Each spectrum is a unique description of an earthquake in terms of idealized structural response
- Composite of multiple (maybe scaled) spectra = basis of design?



RESPONSE SPECTRUM PREDICTION

- Comparing spectra from multiple earthquakes of similar magnitude, site distance, and site conditions reveals trends
  - Multi-variant regression to obtain Ground Motion Prediction Equations (GMPEs)



Boore et al. (2013)

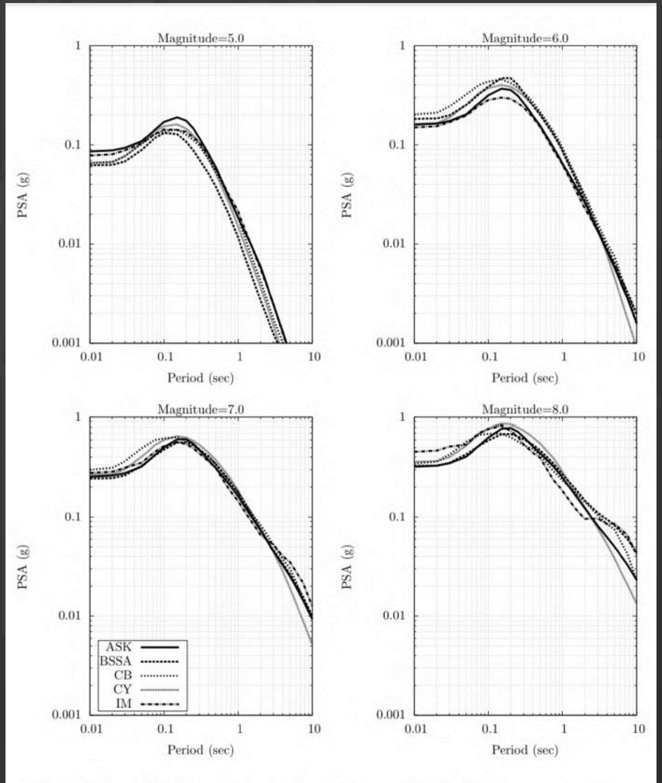
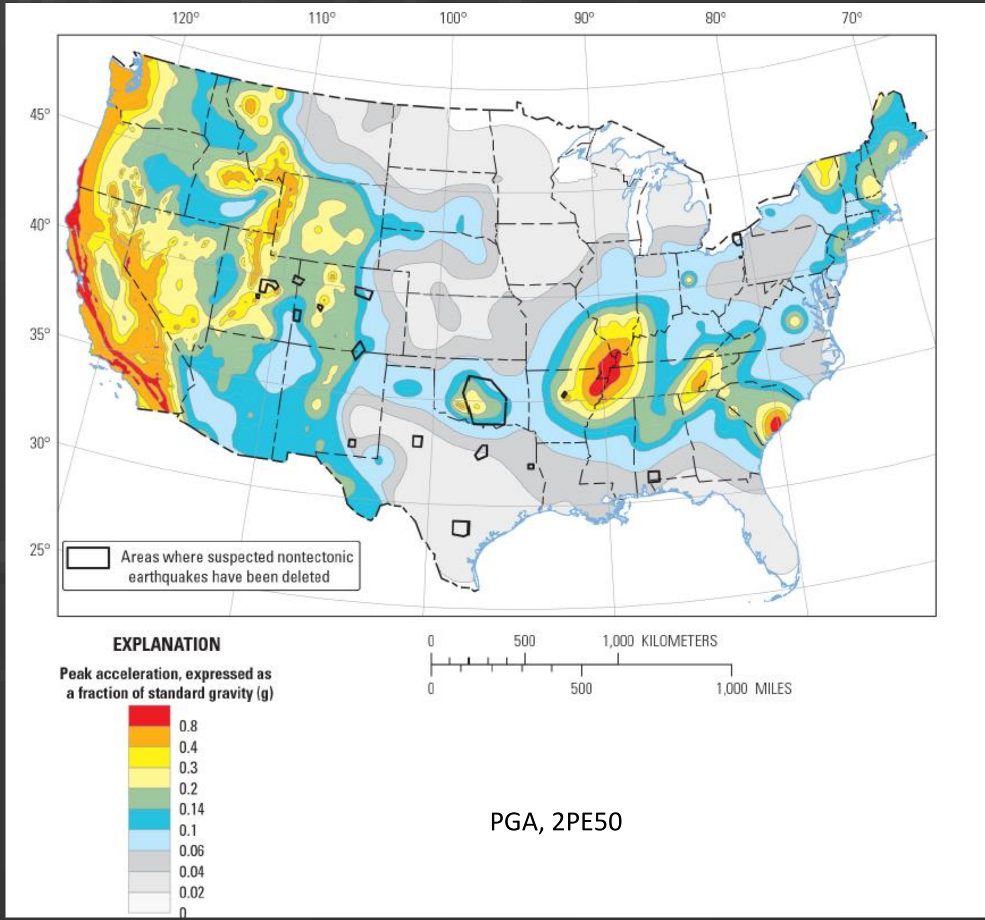


Figure 8: Comparison of median spectra for strike-slip earthquakes for VS30 = 760 m/sec at an RJB distance of 10 km.

Gregor et al. (2014)

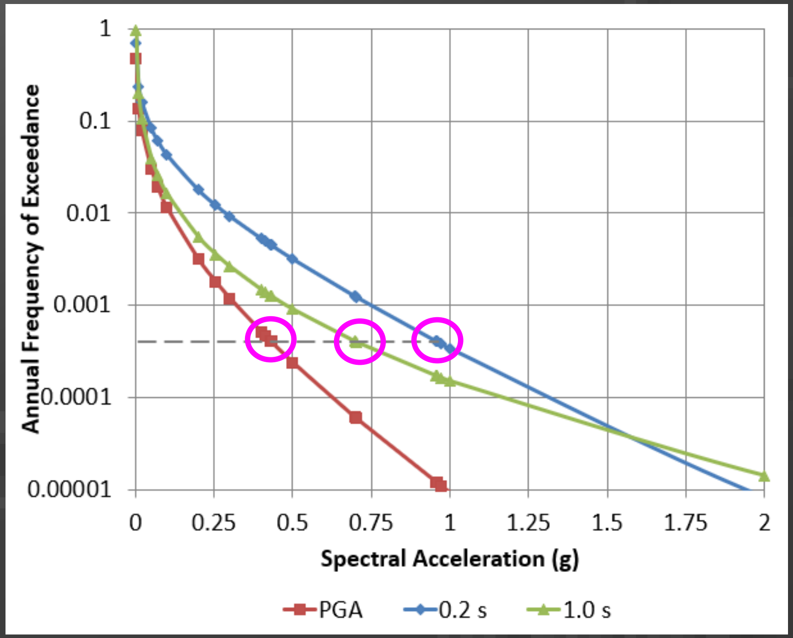
USGS NATIONAL SEISMIC HAZARD MAPPING PROJECT

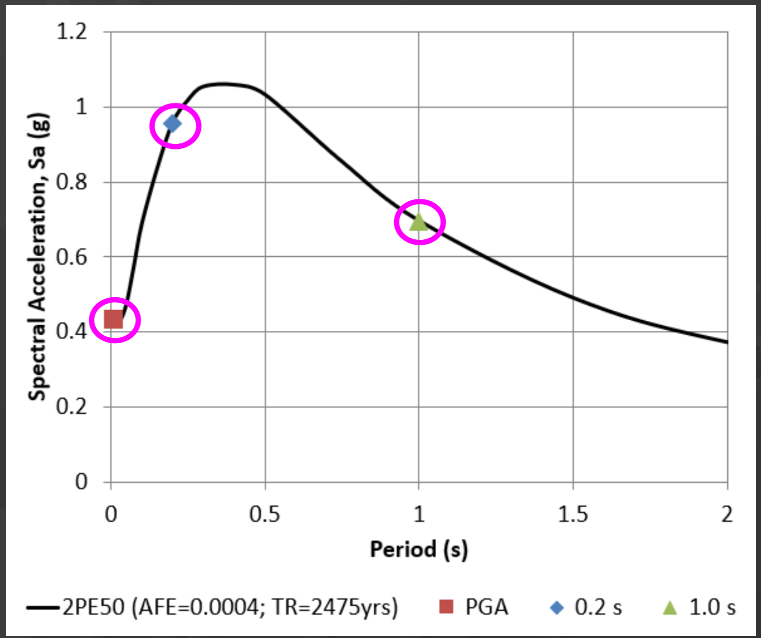
- Using probabilistic methods and a national seismic source database, USGS has used multiple GMPEs to calculate spectral accelerations corresponding to various probabilities of exceedance within certain times frames for the entire country



PGA, 2PE50

- Mapped accelerations assume "bedrock" site conditions
- Resulting spectra do not include certain effects not captured by GMPE
- Seismic source model is somewhat crude, but ok for first order, regional hazard assessment



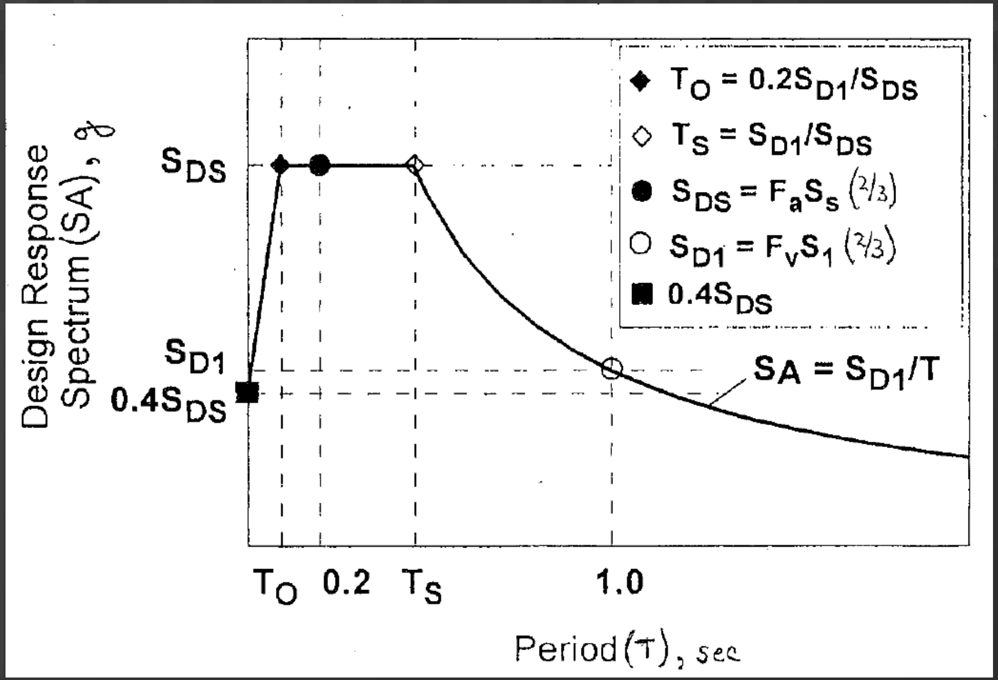


HAZARD CURVES AND RESPONSE SPECTRUM

- For building code purposes, USGS probabilistic values are combined with deterministic (scenario event) values and other considerations to obtain design values

SIMPLIFIED RESPONSE SPECTRUM

- Building/Design codes simplify the spectral shape such it that can (successfully?) be scaled with 3 or 4 parameters
  - Short-period spectral acceleration (S_s and/or PGA [from maps])
  - Mid-period spectral acceleration (S_1 [from maps])
  - Site Class (with S_s and S_1 it gives F_a and F_v [reflects site soil effects])

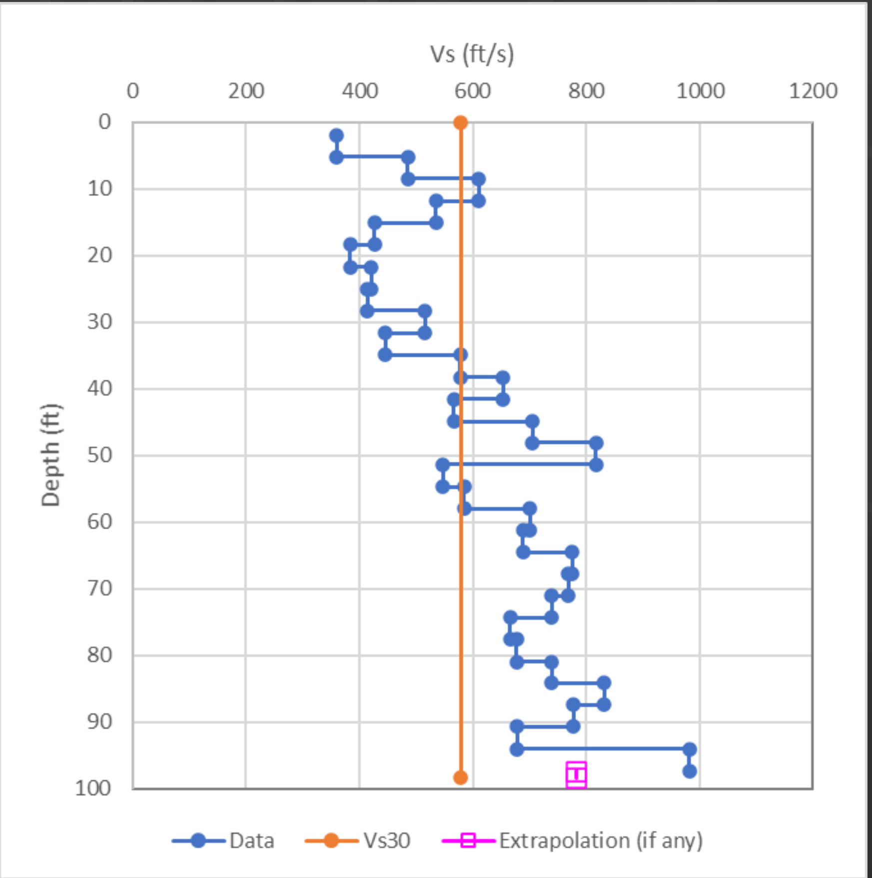


LOCAL SITE (SOIL) EFFECTS

- Key parameter for assessment of site soil effects in US is V_{s30} [V_{s100}]
  - Shear wave velocity in upper 30 meters (100 feet) of soil
  - Calculated as a weighted harmonic mean, not arithmetic mean

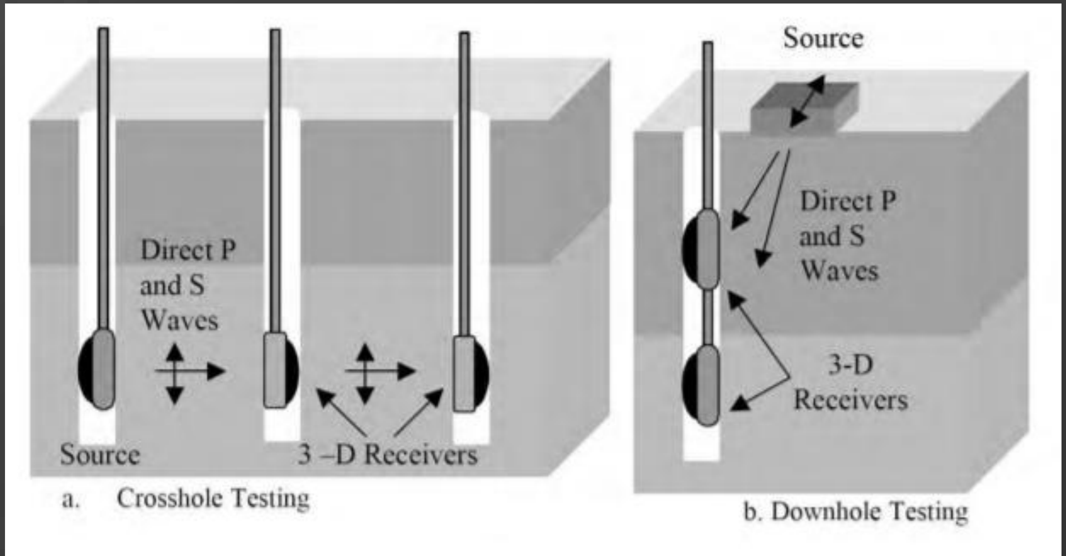
$$\bar{v}_s = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}}$$

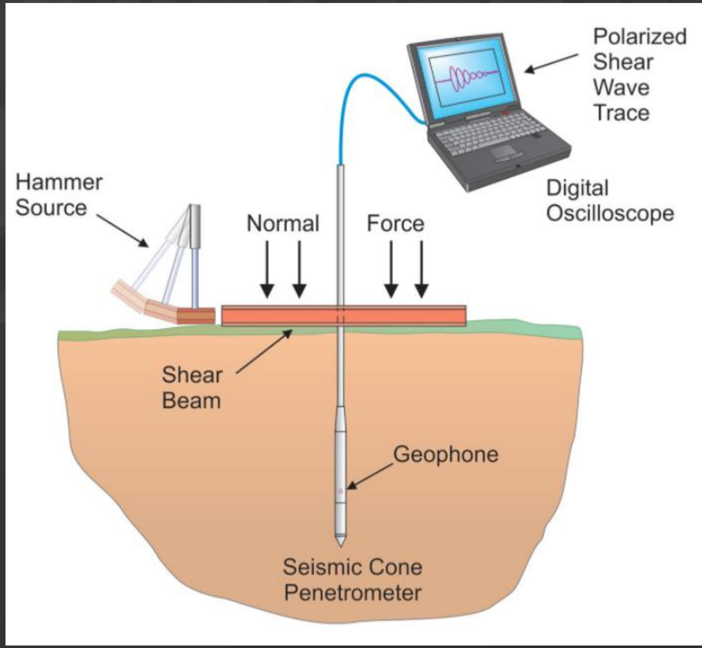
d = layer thickness (not depth)



EVALUATION OF SHEAR WAVE VELOCITY PROFILE

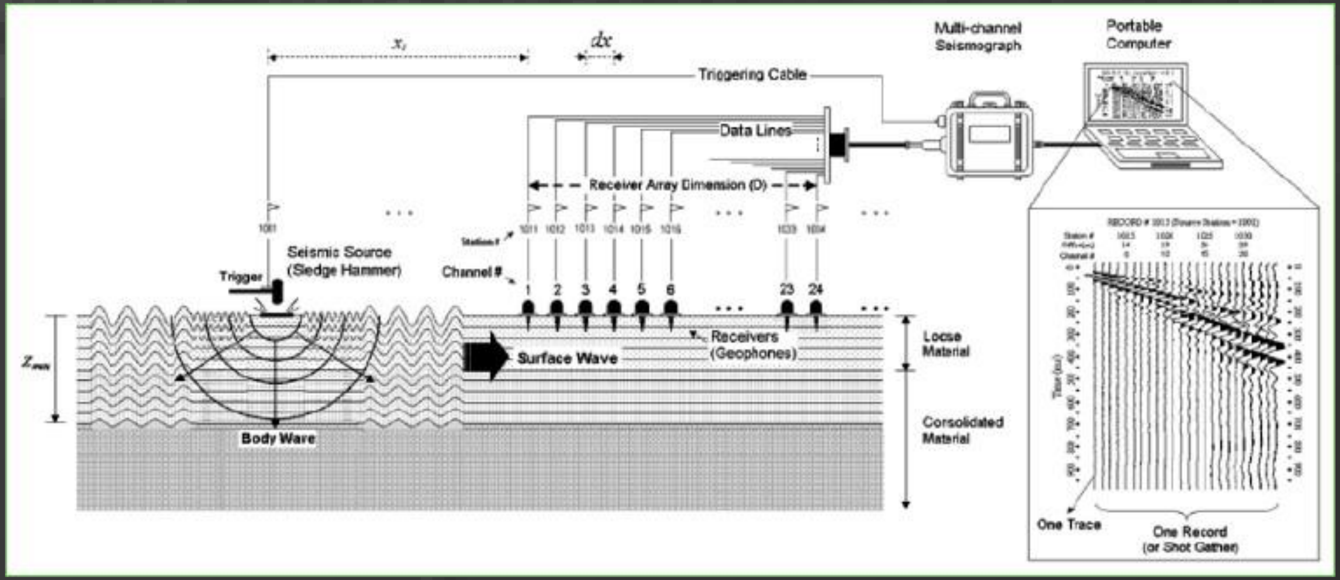
- Downhole or cross-hole
  - time and effort intensive
- CPT seismic cone
  - use to gather V_{s30} measurements and subsurface data otherwise used for typical geotechnical evaluations



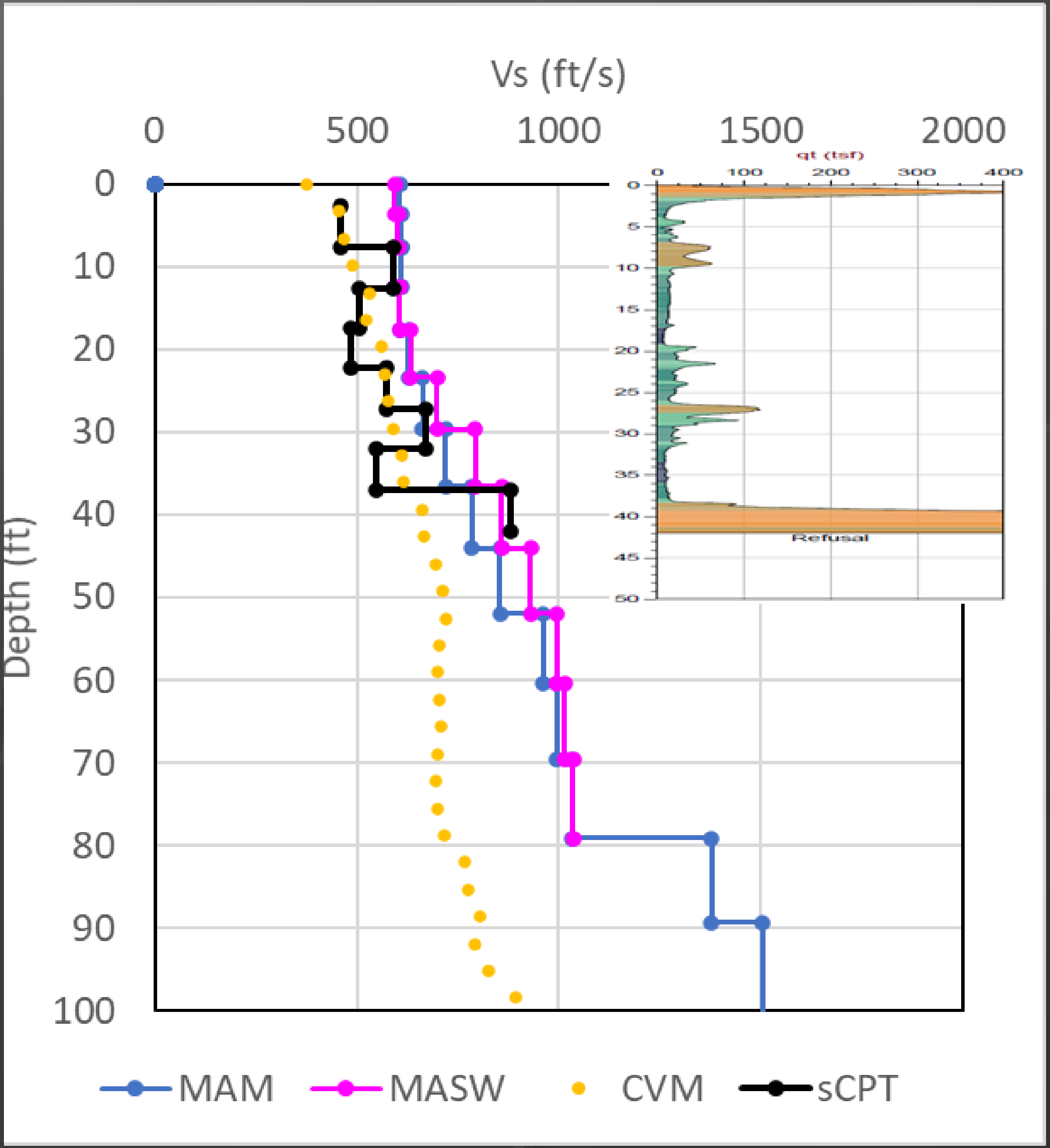


EVALUATION OF SHEAR WAVE VELOCITY PROFILE

- Geophysics
  - Spectral Analysis of Surface Waves (SASW) / Multichannel Analysis of Surface Waves (MASW)
  - Microtremor Array Measurement (MAM) / Refraction Microtremor (ReMi)
  - Depth and Resolution? (maybe ok for evaluating site class but enough for SRA?)

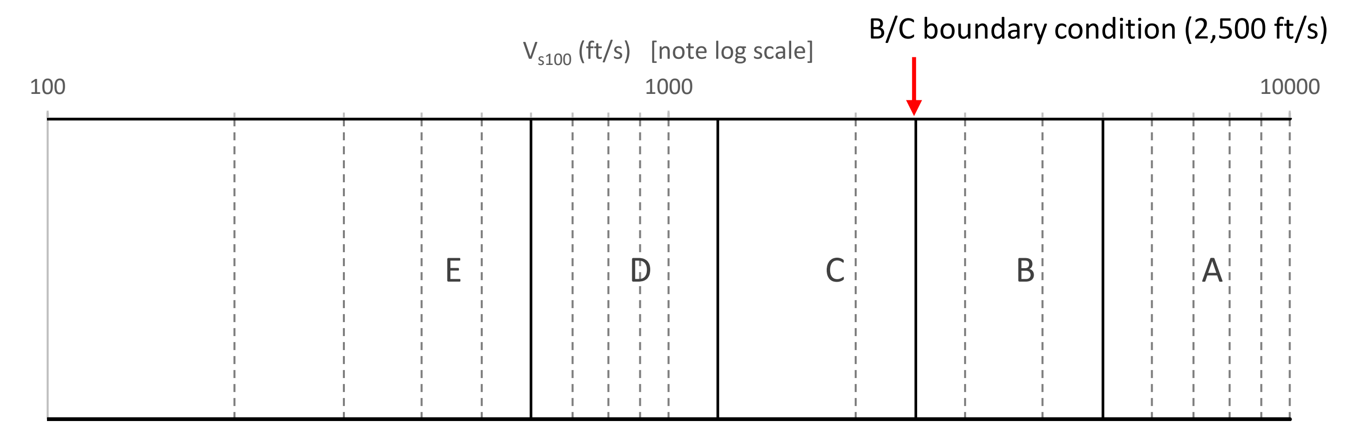


SHEAR WAVE VELOCITY PROFILE CASE HISTORY



LOCAL SITE (SOIL) EFFECTS

- Range of V_{s30} has been discretized into 5 Site Classes (A through E)
  - Sometimes SPT (N), CPT, and undrained shear strength (Su) data can used as proxy for determining Site Class



Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard rock	>5,000 ft/s	NA	NA
B. Rock	2,500 to 5,000 ft/s	NA	NA
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50 blows/ft	>2,000 lb/ft^2
D. Stiff soil	600 to 1,200 ft/s	15 to 50 blows/ft	1,000 to 2,000 lb/ft^2
E. Soft clay soil	<600 ft/s	<15 blows/ft	<1,000 lb/ft^2
	Any profile with more than 10 ft of soil that has the following characteristics: Also E: — Plasticity index $PI > 20$, — Moisture content $w \geq 40\%$, — Undrained shear strength $\bar{s}_u < 500$ lb/ft^2		

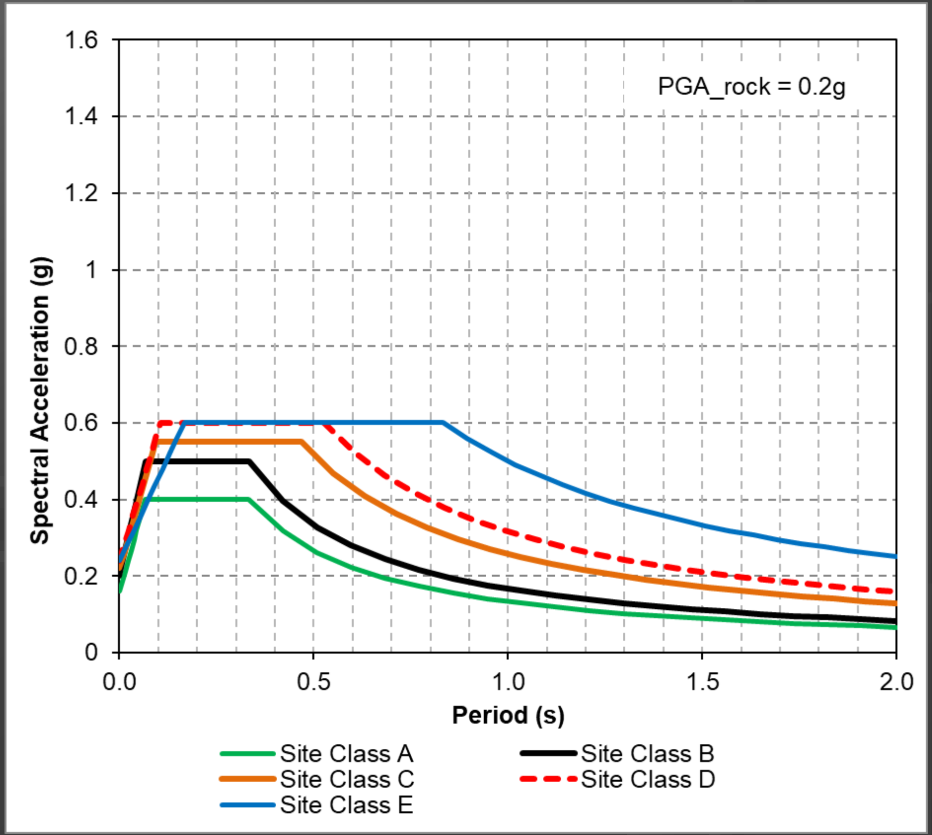
NON-LINEAR SOIL RESPONSE

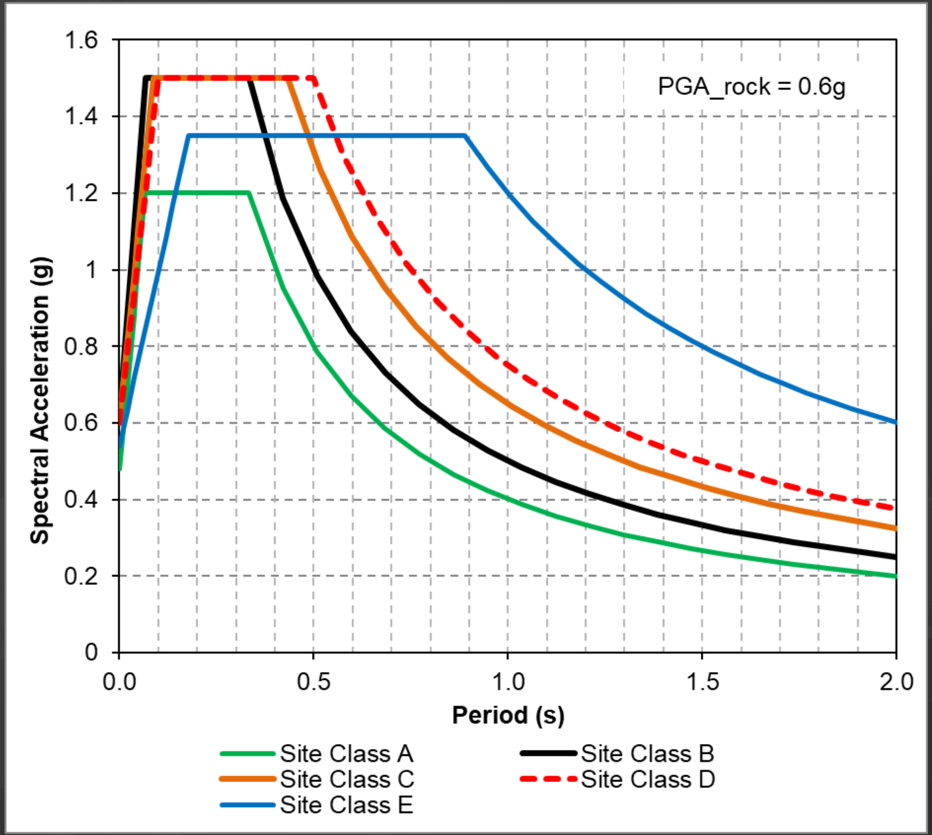
- Amplification (deamplification) is typically quantified relative to "bedrock" response [B/C boundary conditions]
- Simplification in current NEHRP-based codes (Site Classes A to F)
  - In process of being revised; can obtain more precise results with V_{s30}

Fa	Ss					
Site Class	<= 0.25	0.5	0.75	1	1.25	>= 1.5
A	0.8	0.8	0.8	0.8	0.8	0.8
B (with Vs)	0.9	0.9	0.9	0.9	0.9	0.9
B (no Vs)	1.0	1.0	1.0	1.0	1.0	1.0
C	1.3	1.3	1.2	1.2	1.2	1.2
D (with data)	1.6	1.4	1.2	1.1	1.0	1.0
D (default)	1.6	1.4	1.2	**1.2**	**1.2**	**1.2**
E	2.4	1.7	1.3	SSS	SSS	SSS
F	N/A	N/A	N/A	N/A	N/A	N/A

Fv	S1					
Site Class	< =0.1	0.2	0.3	0.4	0.5	>= 0.6
A	0.8	0.8	0.8	0.8	0.8	0.8
B (with Vs)	0.8	0.8	0.8	0.8	0.8	0.8
B (no Vs)	1.0	1.0	1.0	1.0	1.0	1.0
C	1.5	1.5	1.5	1.5	1.5	1.4
D (with data)	2.4	SSS (2.2)	SSS (2.0)	SSS (1.9)	SSS (1.8)	SSS (1.7)
D (default)	2.4	SSS (2.2)	SSS (2.0)	SSS (1.9)	SSS (1.8)	SSS (1.7)
E	4.2	SSS (3.3)	SSS (2.8)	SSS (2.4)	SSS (2.2)	SSS (2.0)
F	N/A	N/A	N/A	N/A	N/A	N/A

CODE-BASED RESPONSE SPECTRA EXAMPLES

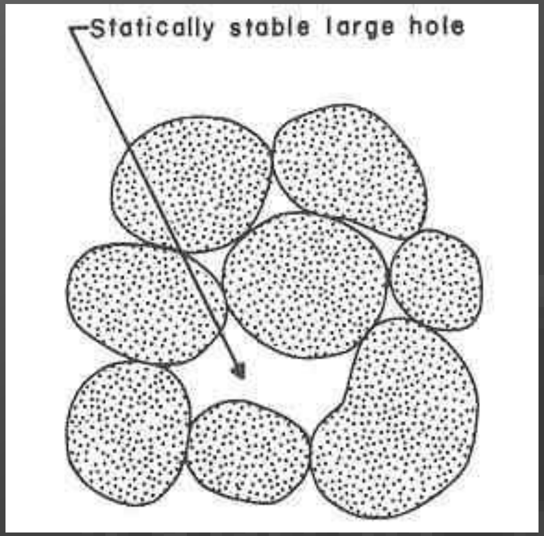


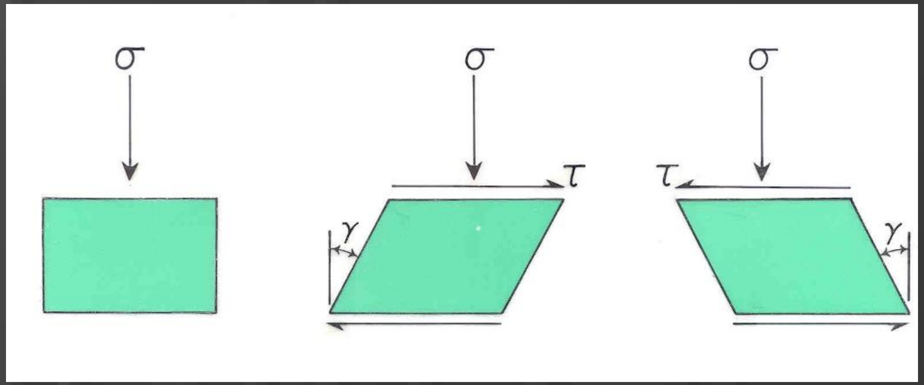


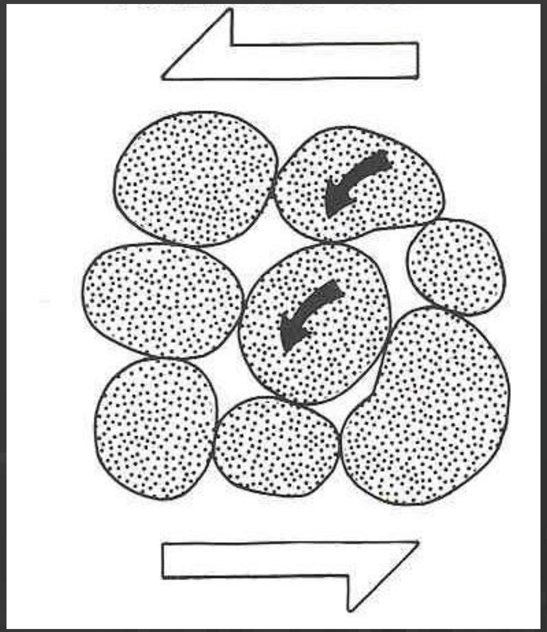
NON-LINEAR SOIL RESPONSE

- Sometimes, site effects cannot be reasonably estimated using simple methods such as Site Class or even V_{s30}
  - Site Class F
    - Liquefiable, Sensitive, or Collapsible soils
    - Peat and/or Highly Organic Clay (H>10ft)
    - Very High Plasticity Clays (H>25ft & PI>75)
    - Very Thick Soft/Medium Stiff Clays (H>120 ft & Su<1000 psf)
  - Shallow soil over Bedrock (impedance contrast)
- What to do?
  - Site-specific study, explicitly modeling soil column (site response analysis, SRA)

SITE CLASS F - LIQUEFIABLE







When soil tries to contract, interstitial water becomes pressurized, causing effective stress (grain-to-grain contact) in soil to decrease, causing soil to lose strength; also, as pressure dissipates, soil settles

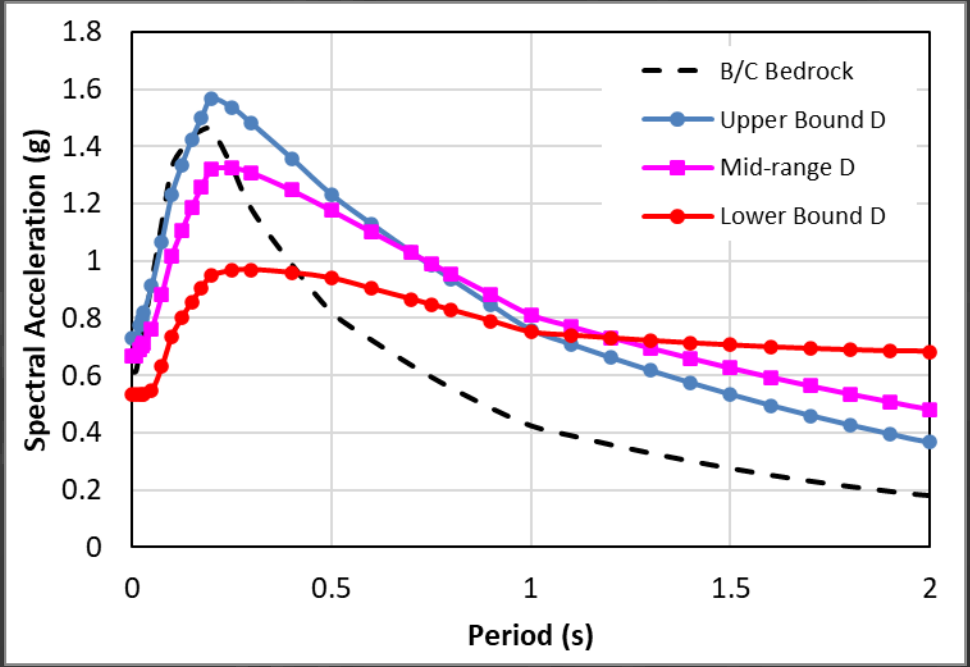
SITE CLASS F - LIQUEFIABLE

- For short (stiff) structures ($T_o \leq 0.5$ s), liquefaction does not significantly affect spectral response
  - High frequency accelerations usually occur before onset of liquefaction
  - Site response analysis is not required by IBC
  - Use Site Class absent any liquefaction
  - However, still must consider liquefaction-induced settlement and lateral spread
  - Ground improvement may change site class

Loss of bearing strength in Adapazari
1999 Koaceli Turkey earthquake

ISSUES WITH SEISMIC SITE CLASSIFICATION

- Site Class D is too broad; Look for to more Site Classes (intermediate Site Classes) in future codes

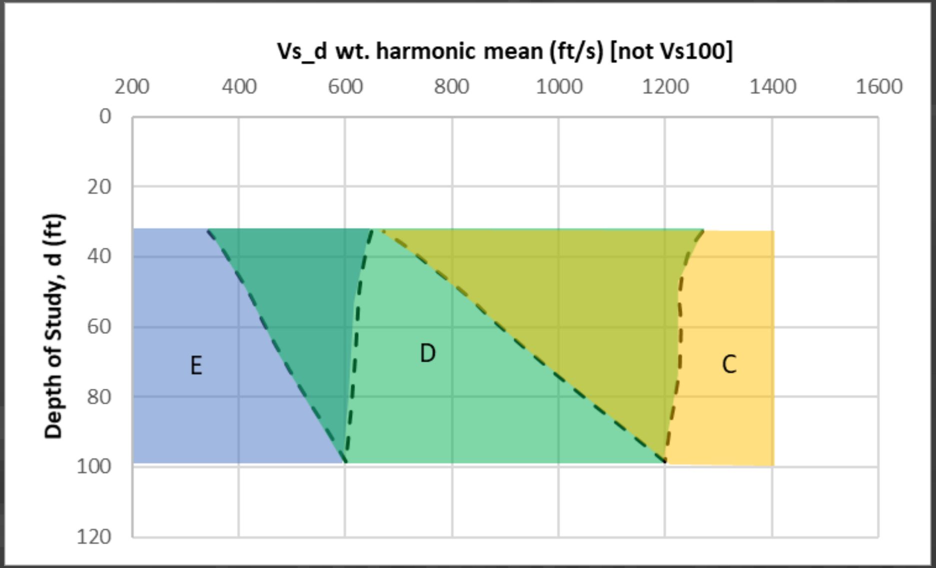


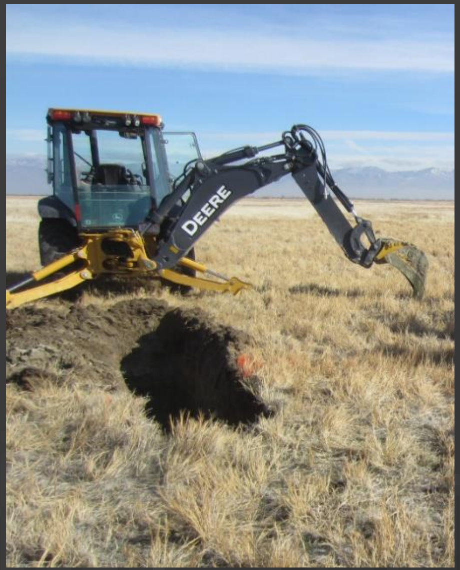
(Example only; variance will differ for different B/C bedrock [baseline] spectrum)

- Requires deeper depth of study than may otherwise be needed for foundation design

ISSUES WITH SEISMIC SITE CLASSIFICATION

- Cannot classify using only shallow (8 to 15’) test pits or boreholes





- Typically recommend at least 50 feet with some reasonable projection and accounting of potential uncertainty
- Future IBC: estimates will need to consider +/- 1.3 x Vs profiles and take worst case

OTHER EFFECTS – DEEP BASIN

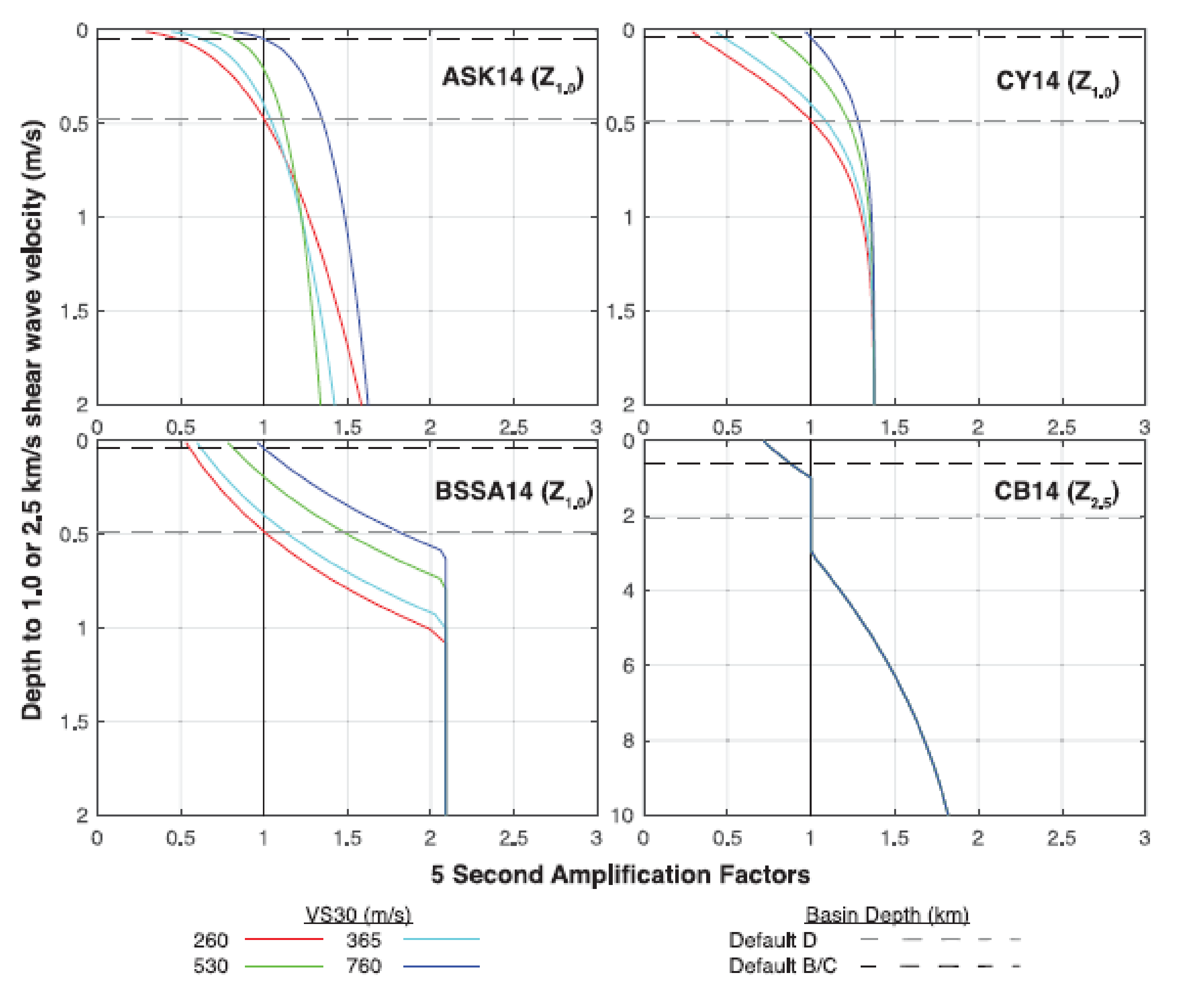


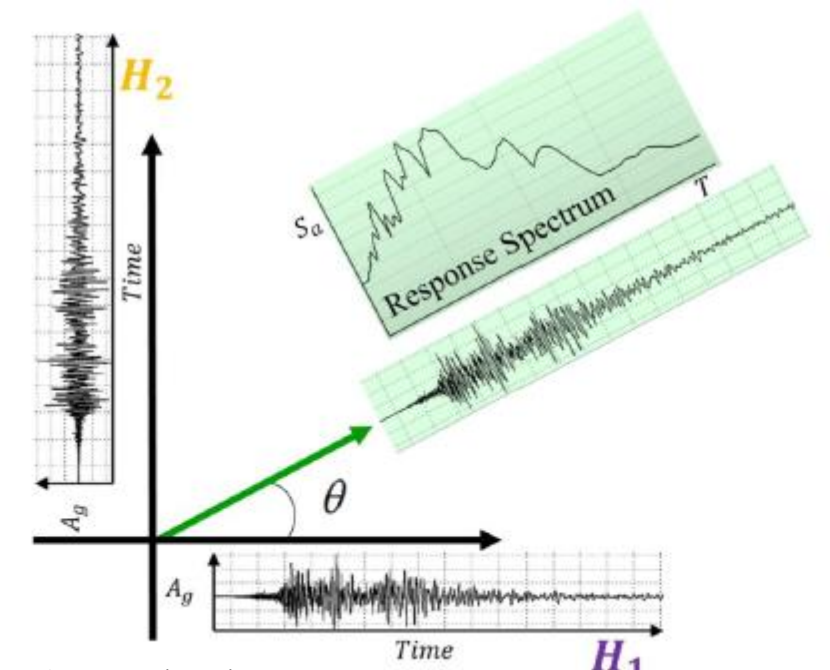
Figure 8. Five-second amplification factors for NGA-West2 ground motion models. ASK14 (Abrahamson et al., 2014), CY14 (Chiou and Youngs, 2014), and BSSA14 (Boore et al., 2014) use $Z_{1.0}$, and CB14 (Campbell and Bozorgnia, 2014) use $Z_{2.5}$ to calculate default basin depths. Note that for the first three, if $Z_{1.0}$ is equal to the default value, the amplification factor is 1. For CB14, the amplification factor is 1, for $Z_{2.5}$ between 1- and 3-km depth.

Petersen et al. (2020)

- Not all site effects are captured by Site Class or V_{S30}
- Deep sedimentary basins amplify long period ground motions
  - Need $Z_{1.0}$ or $Z_{2.5}$
- Only default correlations used in 2014 USGS NSHM

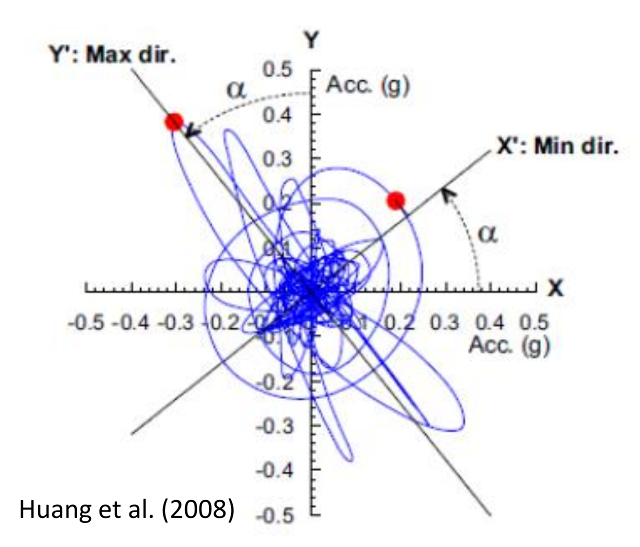
TYPES OF RESPONSE SPECTRA

- Response spectrum is not invariant; depends upon orientation of ground motion time histories
- In past, spectra have usually been "Geo-Mean" = square-root of the product of the spectral values of two, as-recorded components, at a particular period



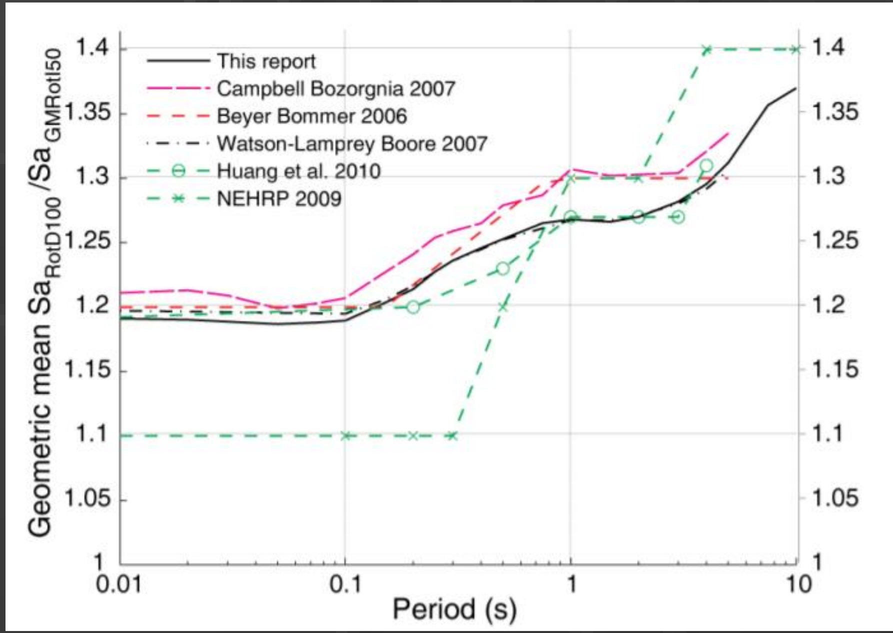
PalmaParra (2019)

- RotI50 spectrum = median values of spectral acceleration calculated for single orientation which maximizes overall response ("period Independent")
- RotD50 spectrum = median values of spectral acceleration calculated over all angles of rotation (peak responses for each period per may occur at different rotations; "period Dependent rotation angle")
  - Usually the value provided by current GMPEs
- RotD100 spectrum = "maximum direction" values of spectral acceleration calculated over all angles of rotation
  - Often what structural engineers want to design to



Huang et al. (2008)

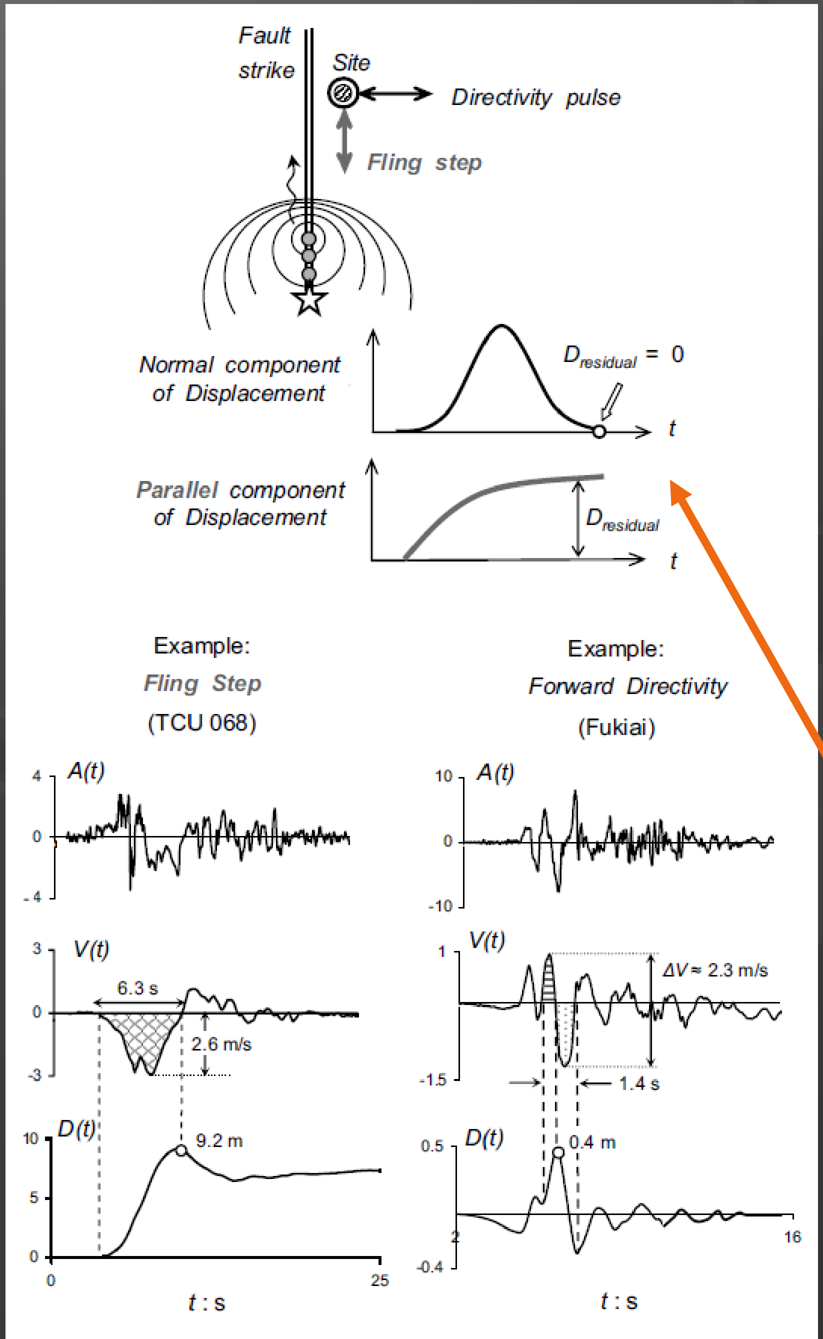
- This topic is referred to as Directionality
- Often need to convert from RotD50 to RotD100
  - Per ASCE 7-16: scale using 1.1 for T ≤ 0.2s, 1.3 for T = 1.0s, and 1.5 for T ≥ 5.0s, and interpolate in between [derived from Huang et al., 2008]
  - Recommend using Shahi and Baker (2014) instead
    - Use 1.2 instead of 1.1 at short periods



  - This conversion is often missed in GMHAs

OTHER NEAR FAULT EFFECTS - DIRECTIVITY

STRIKE SLIP FAULT



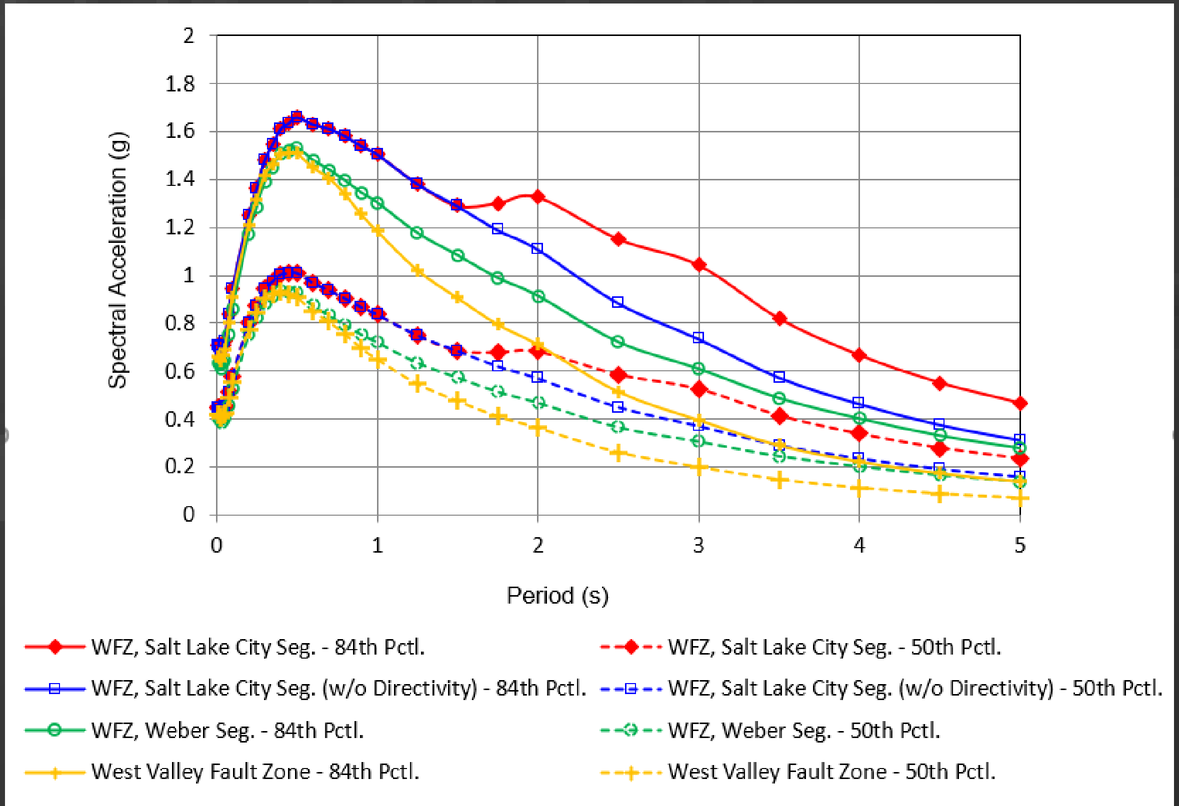
- Focusing of wave energy along a fault in the direction of rupture (doppler effect; "fling" is another related effect)

For dip-slip fault (normal or thrust), both directivity and fling occur normal (perpendicular) to strike (surface trace) of fault

[with both vertical and horizontal components]

DIRECTIVITY

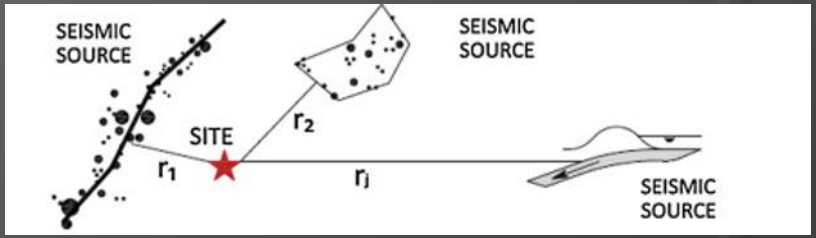
- Directivity effects occur near fault (say within 5 to 10 km)
- Pronounced at larger periods
- Example from DSHA (based on Bayless and Somerville, 2013)



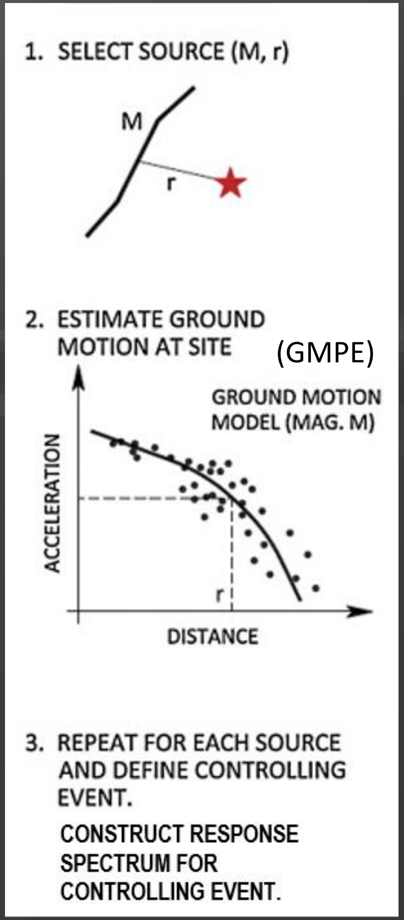
METHODS OF SEISMIC GROUND SHAKING HAZARD ANALYSIS

- Probabilistic Seismic Hazard Analysis (PSHA)
- Deterministic Seismic Hazard Analysis (DSHA)

DETERMINISTIC SEISMIC HAZARD ANALYSIS (DSHA)

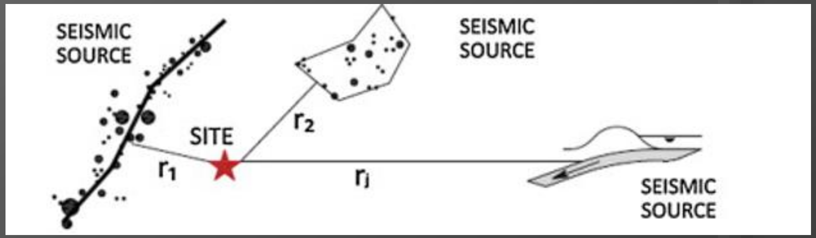


After Fernandez, 2010



- Ground shaking hazard is assessed by identifying a specific earthquake “event scenario” – one for which the combination of magnitude and distance (together with other pertinent source and site parameters) provide large levels of ground shaking
- Does not explicitly consider when the event may occur
- Event must be “reasonable” (Maximum Credible Earthquake)
  - Is NOT “worst case” scenario
- Because of variability, results are presented in terms of percentile

PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)



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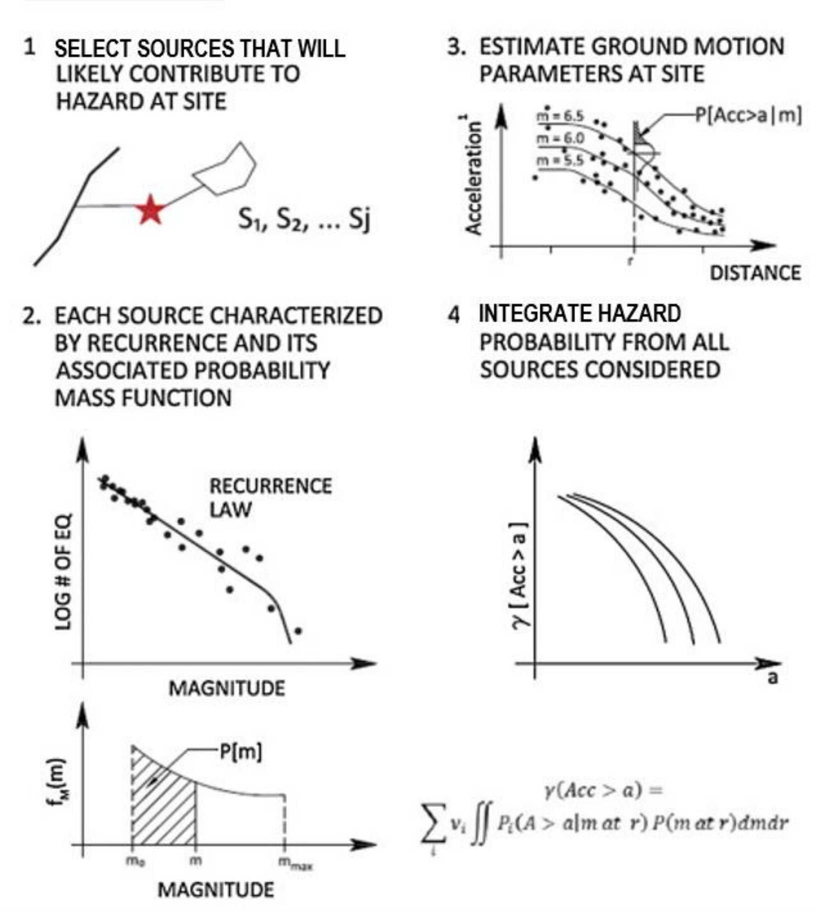
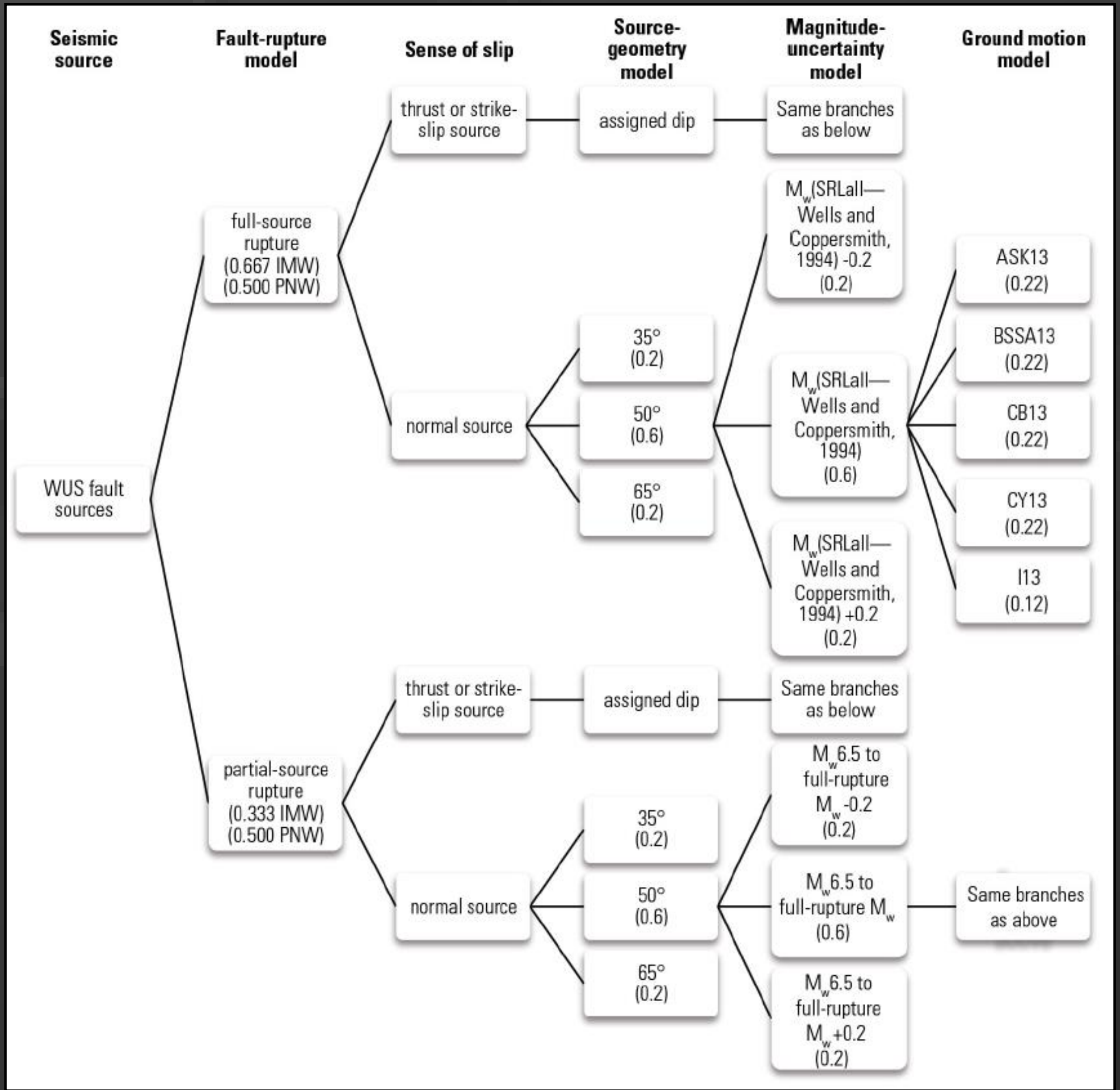


- Ground shaking hazard is assessed in terms of statistical likelihood of occurrence (e.g., 2PE50 = 2% probability of exceedance in 50 years = annual probability of occurrence of 0.0004 = return period of 2475 years)
- Reflects the combined effects of multiple potential seismic sources, including a background or gridded event, each with its own recurrence relationship
- Does not correspond to a single, specific earthquake!

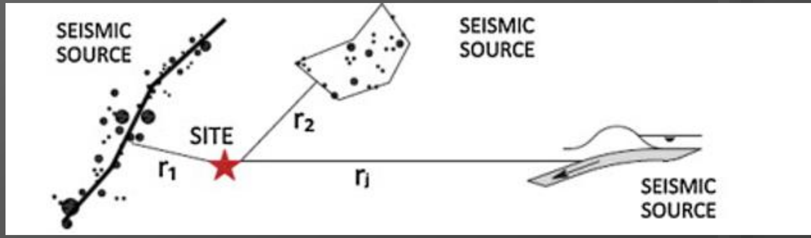
PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)

- Treatment of Uncertainty can by shown using logic trees

Partial Example:



PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)



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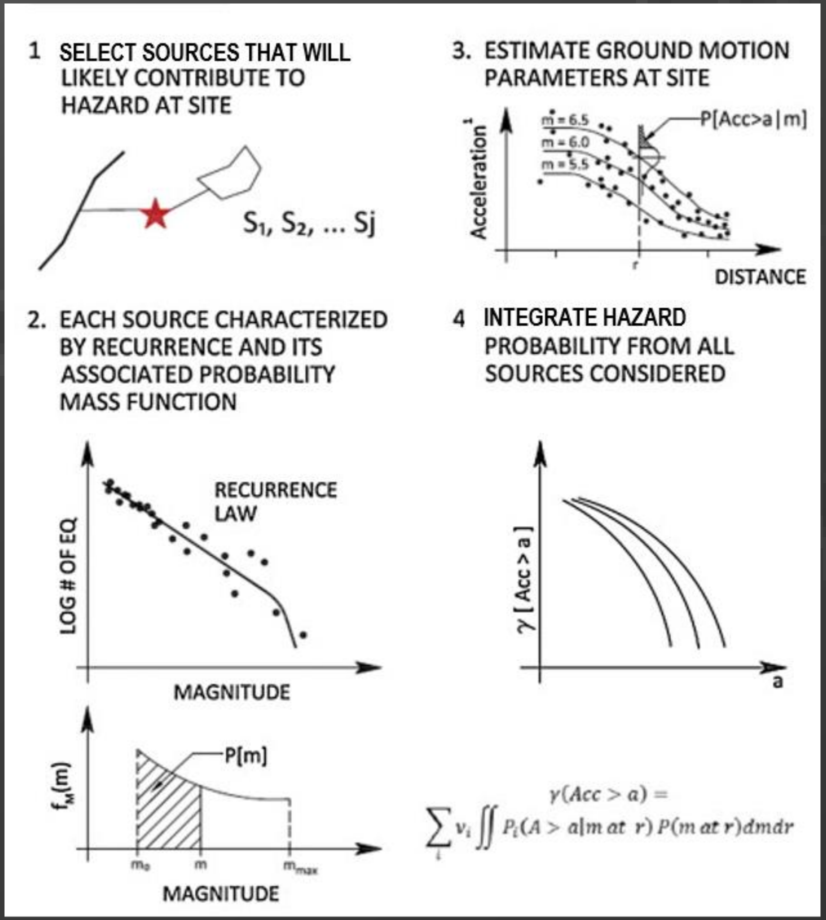


- Accounts for uncertainties in the size (magnitude, M), location (site distance, R), and rate of occurrence of each seismic source, as well as the variation of the ground motions themselves given a specific earthquake M and R
- Result is a hazard curve from which a Uniform Hazard Response Spectrum can be constructed (ordinate for each period has same likelihood of occurrence)

RISK-TARGETED GROUND MOTIONS

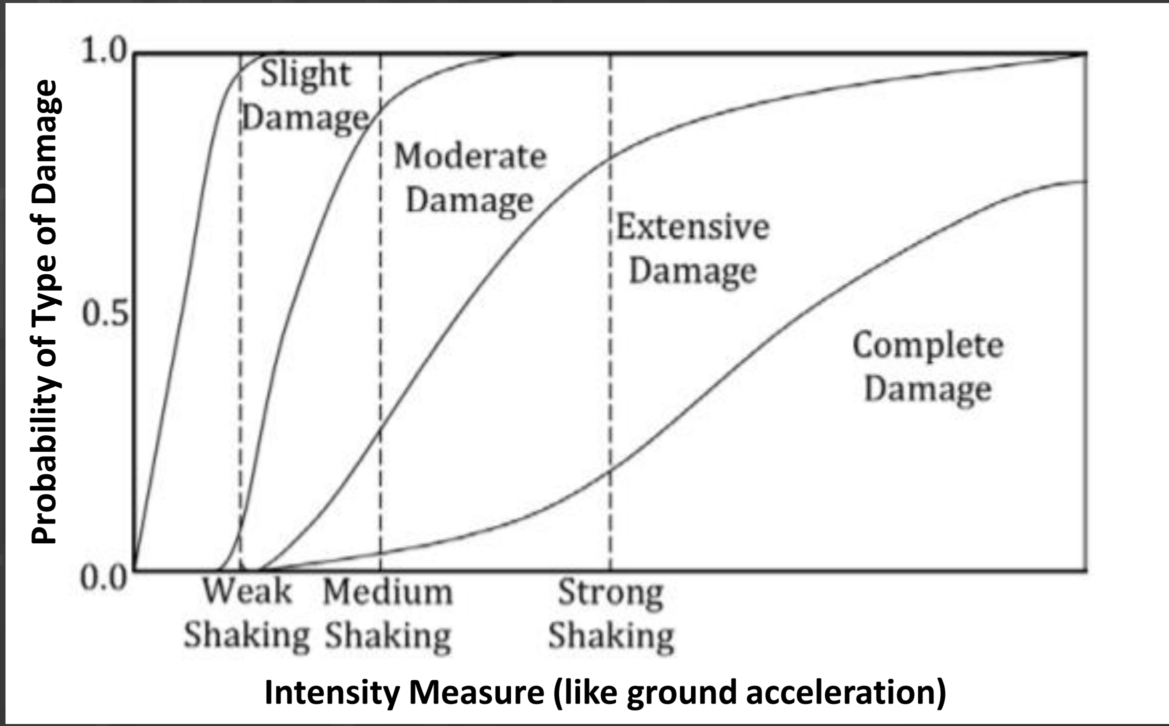
- In earlier versions of IBC and ASCE 7, basis of design was a combination of:
  - Probabilistic ground motions having a 2% probability of exceedance in 50 years (2PE50)
  - Deterministic ground motions from major faults, 50% percentile x 1.5 (to approximate one stdev above median)
- Lesser of the two, but with consideration of some empirical minima, = MCE = Maximum Considered (~~Credible~~) Earthquake
- Design ordinary structures by taking 2/3 of the MCE (increase using seismic use or importance factors for more critical structures)

RISK-TARGETED GROUND MOTIONS

- In 2018 IBC and ASCE 7-16, basis of STRUCTURAL design is:
  - Probabilistic ground motions corresponding to a 1% probability of structural collapse in 50 years at design level motions ("risk targeted"; uses fragility concepts; [actually 10% probability of collapse at MCE_R])
  - Deterministic ground motions from major faults, 84th percentile
  - Ground motions adjusted to maximum direction
  - Same combinations to obtain MCE_R
- Shifts from Uniform Hazard to Uniform Risk
- Basis of GEOTECHICAL evaluations is based on older MCE approach (not risk-targeted; fragility curve not applicable), but without 2/3 factor

FRAGILITY

- Fragility curve shows probability that a structure will exceed some type of damage state as a function of some measure of ground motion intensity (IM)

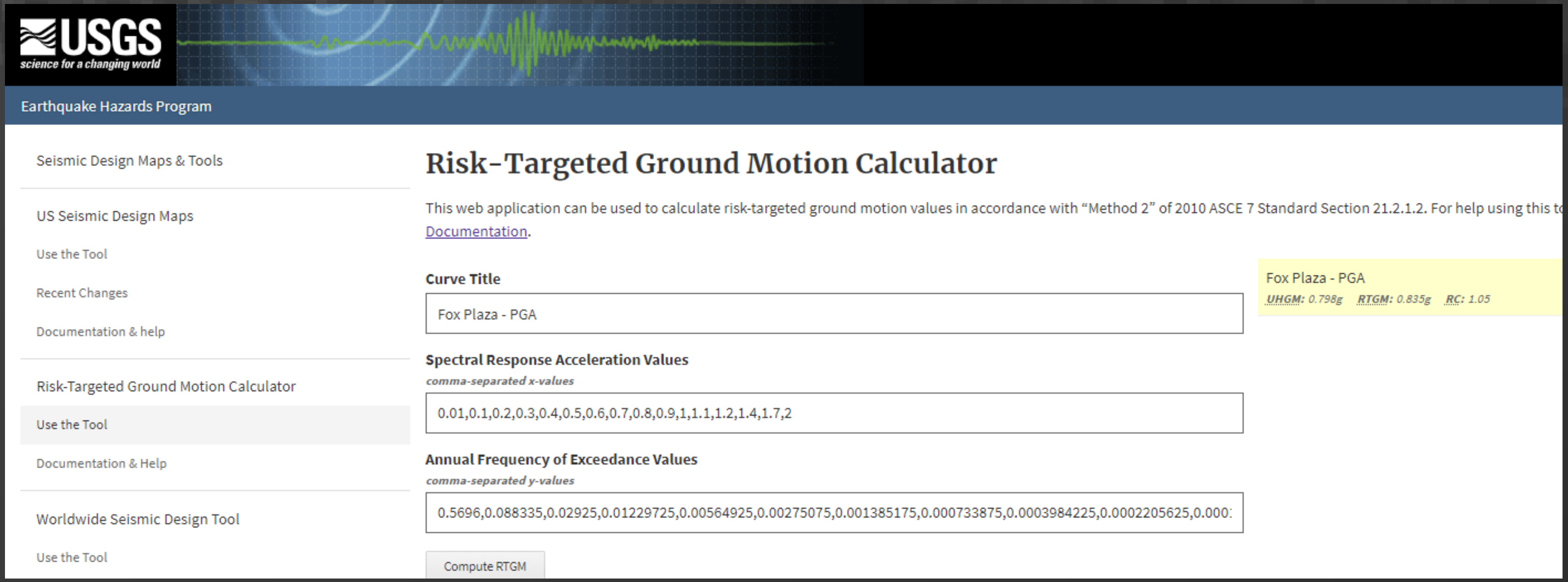


FRAGILITY CALCULATIONS

- Solve the Risk Integral

$$P(Collapse) = \int_0^\infty \frac{dP(Collapse|Sa = a)}{da} P(Sa > a)\, da$$

- Iterative process, using hazard curve to define IM
- Section 21.2.1.2 (“Method 2”) of ASCE 7-16

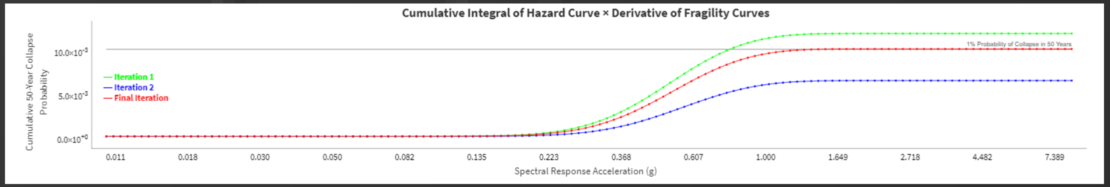


- Solving the risk integral

$$P(Collapse) = \int_0^\infty \frac{dP(Collapse|Sa = a)}{da} P(Sa > a)\, da$$

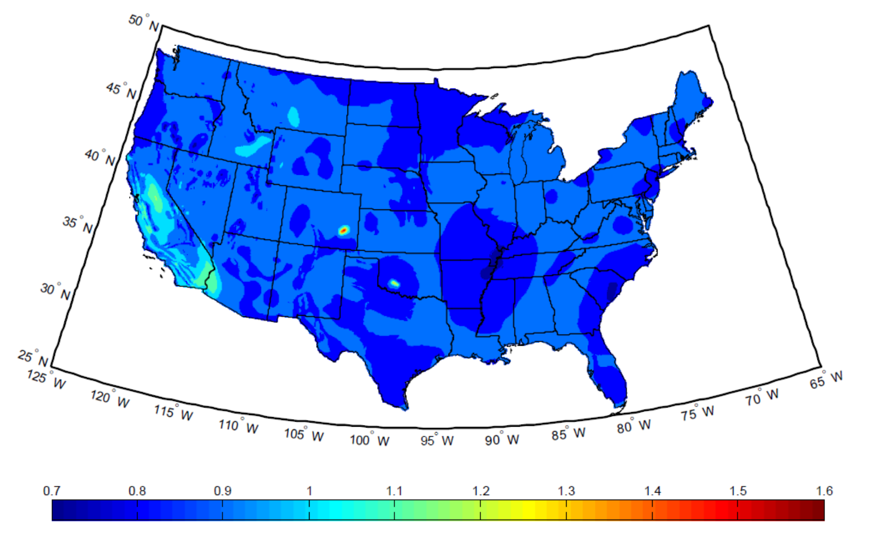
Numerical Steps

1. Select acceleration for hazard curve (start with 2PE50)
2. Construct fragility curve (standard fragility curve with 10% probability of structural collapse and standard deviation (beta) = 0.6)
   a. Curve changes based on value of spectral acceleration (where mean of cumulative distribution is centered)
3. Take derivative of fragility curve (gives density function)
4. Calculate product of hazard curve and derivative of fragility curve to obtain annual collapse frequency density function
5. Integrate curve from previous step to find 50-year collapse probability
6. Repeat steps by changing target acceleration Sa until probability of collapse is 1%



FRAGILITY SIMPLIFIED

- To avoid the hairy math, risk coefficients (C_{RS} and C_{R1}) can be used to convert 2PE50 ground motions (max. direction) to motions corresponding to 1% probability of structural collapse in 50 years
  - 2PE50 x C_{Rx} = Risk-Targeted (ASCE 7-16 Section 21.2.1.1 "Method 1")
  - Risk coefficients vary across county because temporal distribution of ground motions (i.e., hazard curves) vary from place to place
  - Risk coefficients do not apply in DSHA



WHY ARE SITE-SPECIFIC SEISMIC ANALYSES REQUIRED IN BUILDING CODES?

- Subsurface conditions are too complex to be standardized / site soil effects cannot be reliably quantified for prescriptive use (Example: Site Class F)
  - Site Response Analysis (SRA)
- Standardized shape may underpredict actual response (situations involving relatively large high accelerations with softer soils for longer period structures)
  - Usually Ground Motion Hazard Analysis (GMHA) but can also be SRA
- Can always perform site-specific analyses in lieu of simplified code approach
  - May be able to reduce conservatism and seismic loads

- With ASCE 7-16 and IBC 2018, attempts are made to correct several previous deficiencies with the general procedure response spectrum method
  - Standardized shape and/or broadness of Site Class D (large range of V_{s30}) can lead to under-quantified response (esp. at lower V_{s30})

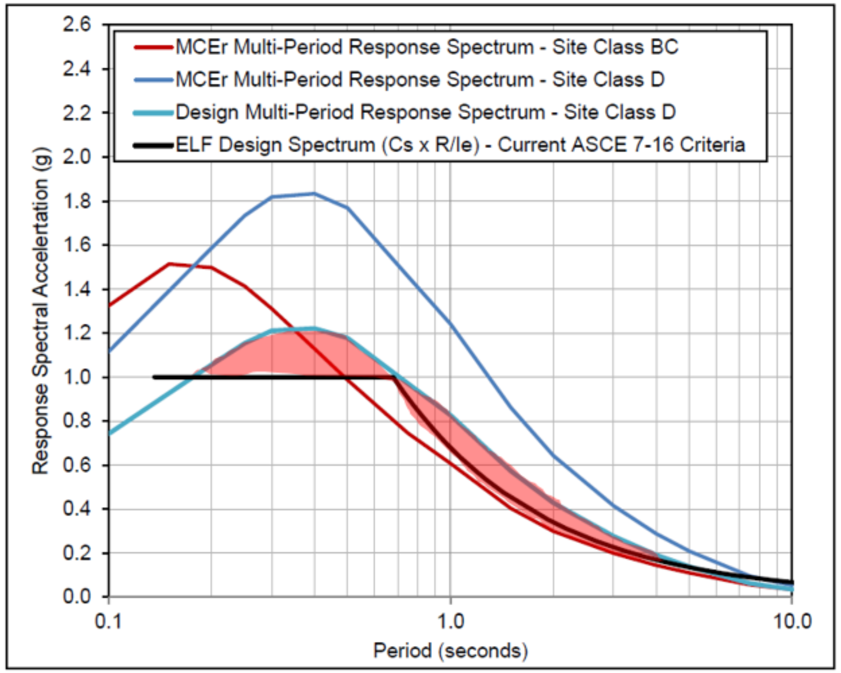


FIGURE C11.4-2 Comparison of ELF and Multi-Period Design Spectra – Site Class D Ground Motions ($v_{s,30}$ = 870 ft/s)

– Site coefficients (F_a and F_v) for Site Class E can under-represent response
- Site Class E sites also have higher variability in response shape

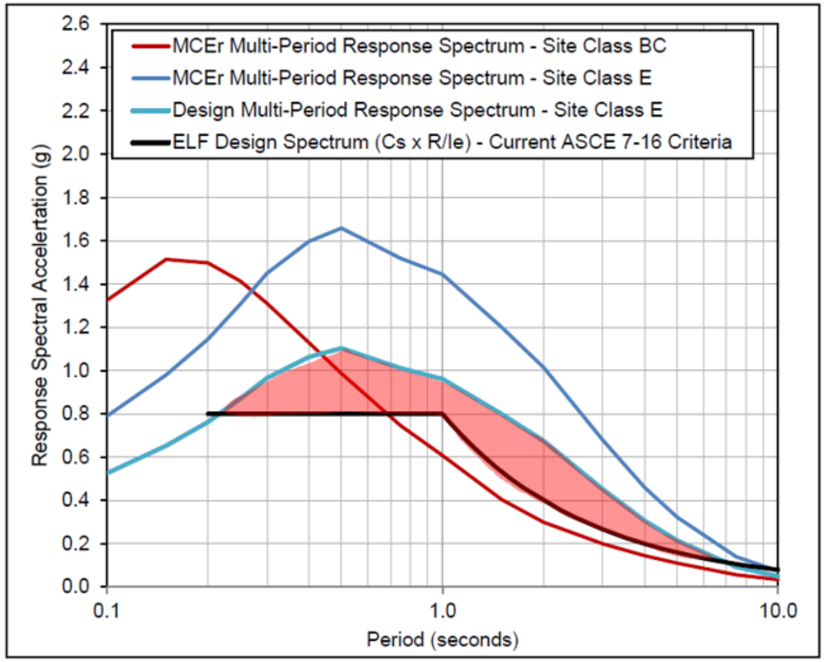


FIGURE C11.4-3 Comparison of ELF and Multi-Period Design Spectra – Site Class E Ground Motions ($v_{s,30}$ = 510 ft/s)

After 2015 NEHRP
(also see Kircher & Associates, 2015)

- As a short-term fix until spectral shapes can be more correctly defined with more points (see future editions of codes), and to reduce number of situations in which site-specific studies would be required, 2018 IBC and ASCE 7-16 created "Exceptions" (ASCE 7-16, Section 11.4.8)

Table 11.4-1 Short-Period Site Coefficient, F_a

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

Note: Use straight-line interpolation for intermediate values of S_s.

Table 11.4-2 Long-Period 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	0.8	0.8	0.8	0.8	0.8	0.8
C	1.5	1.5	1.5	1.5	1.5	1.4
D	2.4	2.2[a]	2.0[a]	1.9[a]	1.8[a]	1.7[a]
E	4.2	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8
F	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8	See Section 11.4.8

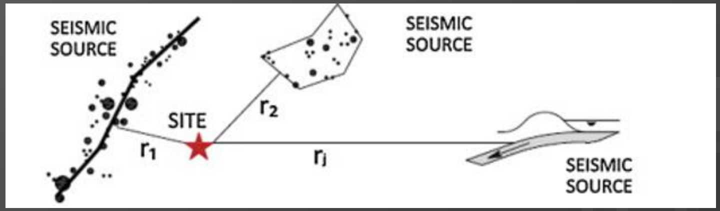
Note: Use straight-line interpolation for intermediate values of S_1.
[a]Also, see requirements for site-specific ground motions in Section 11.4.8.

TYPES OF SITE-SPECIFIC SEISMIC ANALYSES

- GROUND MOTION HAZARD ANALYSIS (GMHA)
  - Involves both PSHA and DSHA
- SITE RESPONSE ANALYSIS (SRA)
  - Earthquake wave propagation is explicitly modeled in a soil column or continuum
  - Less frequently performed

GROUND MOTION HAZARD ANALYSIS (GMHA)

- Consists of both probabilistic and deterministic seismic hazard analyses (PSHA and DSHA) using GMPEs



  – Probabilistic "Triple Integral" (triple summation)

$$\lambda_{y*} = \sum_{i=1}^{N_S} \sum_{j=1}^{N_M} \sum_{k=1}^{N_R} v_i \cdot P[Y > y* \,|\, m_j, r_k] \cdot P[M = m_j] \cdot P[R = r_k]$$

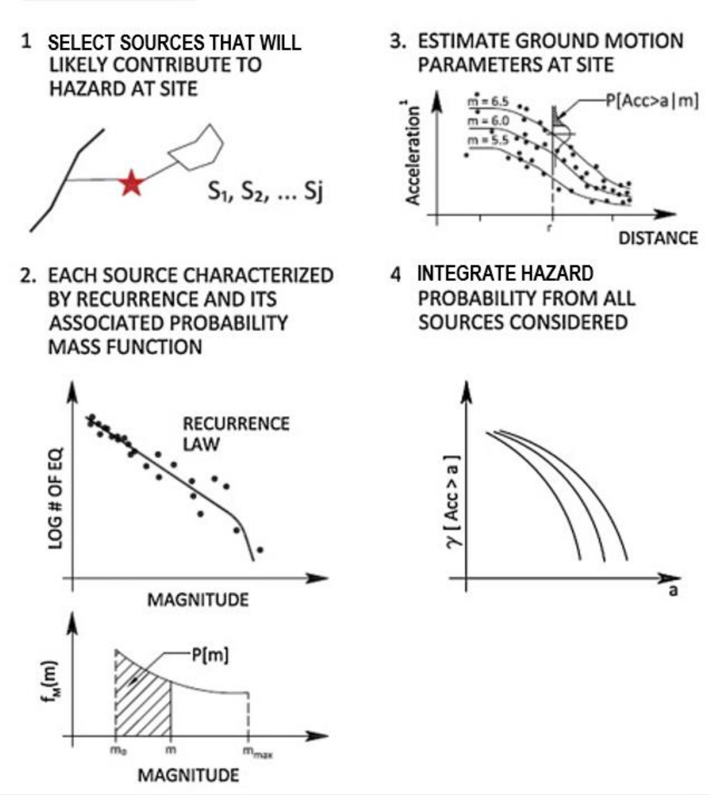
λ_{y*} = average rate of exceedance for aggregate hazard (#/year)

$P[Y > y^* | m_j, r_k]$ = probability that ground motion parameter, Y, will exceed a particular value, y*, given that specified M and R occur

$P[R = r_k]$ = probability that event occurs at specificed distance R

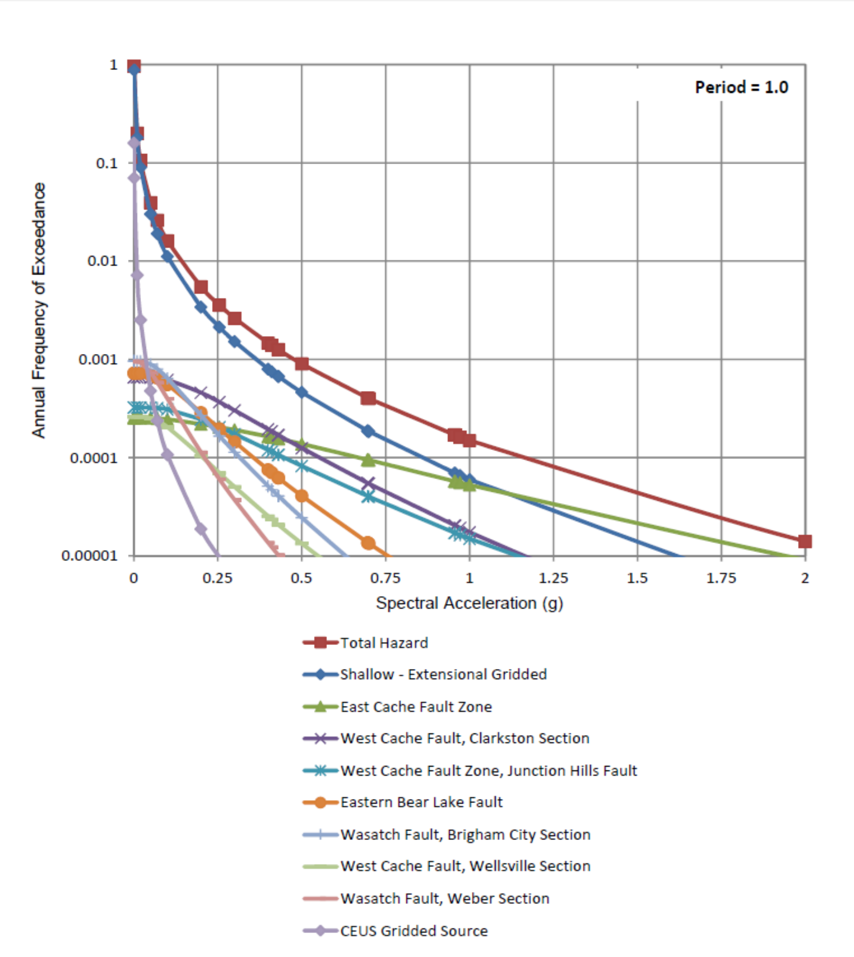
$P[M = m_j]$ = probability that event occurs at specified magnitude M

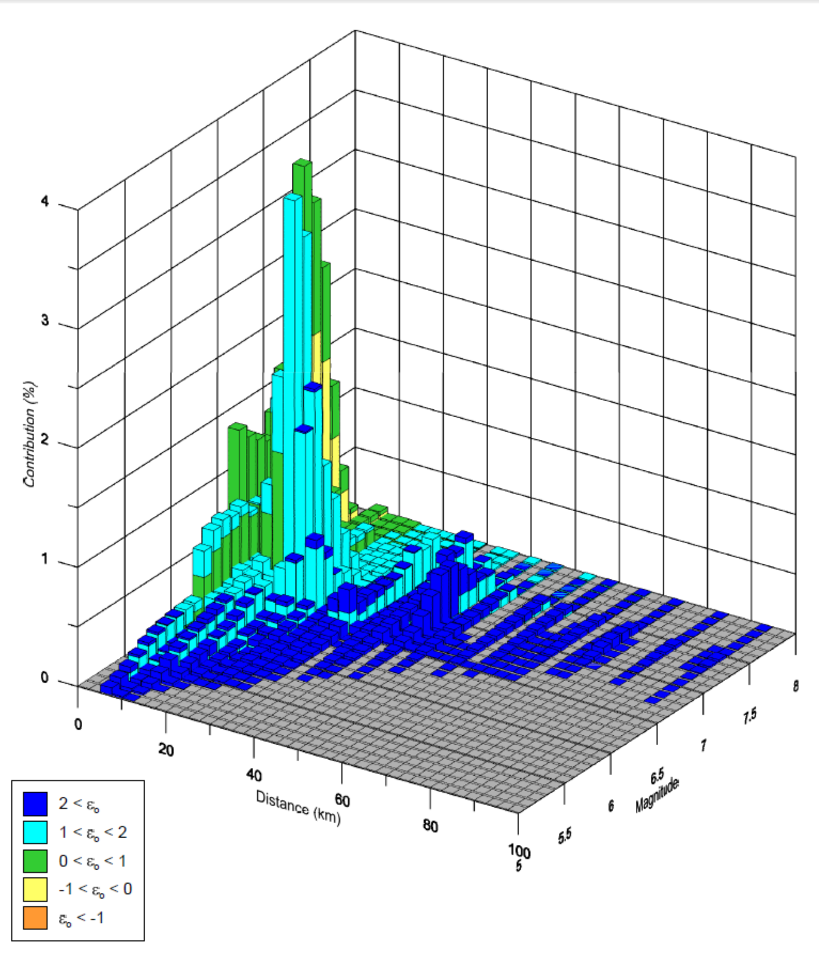
v_i = average rate of threshold magnitude exceedance (#/yr) for each Source i



GROUND MOTION HAZARD ANALYSIS (GMHA)

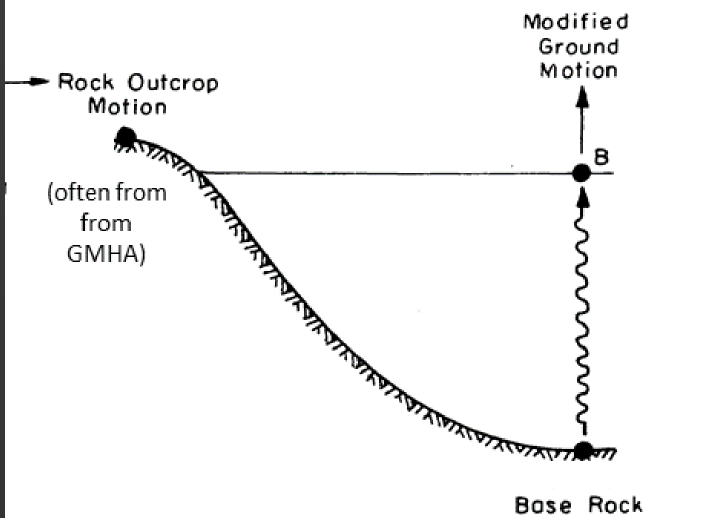
- Provides hazard curves and response spectra
- Does not provide time histories (unlike SRA)





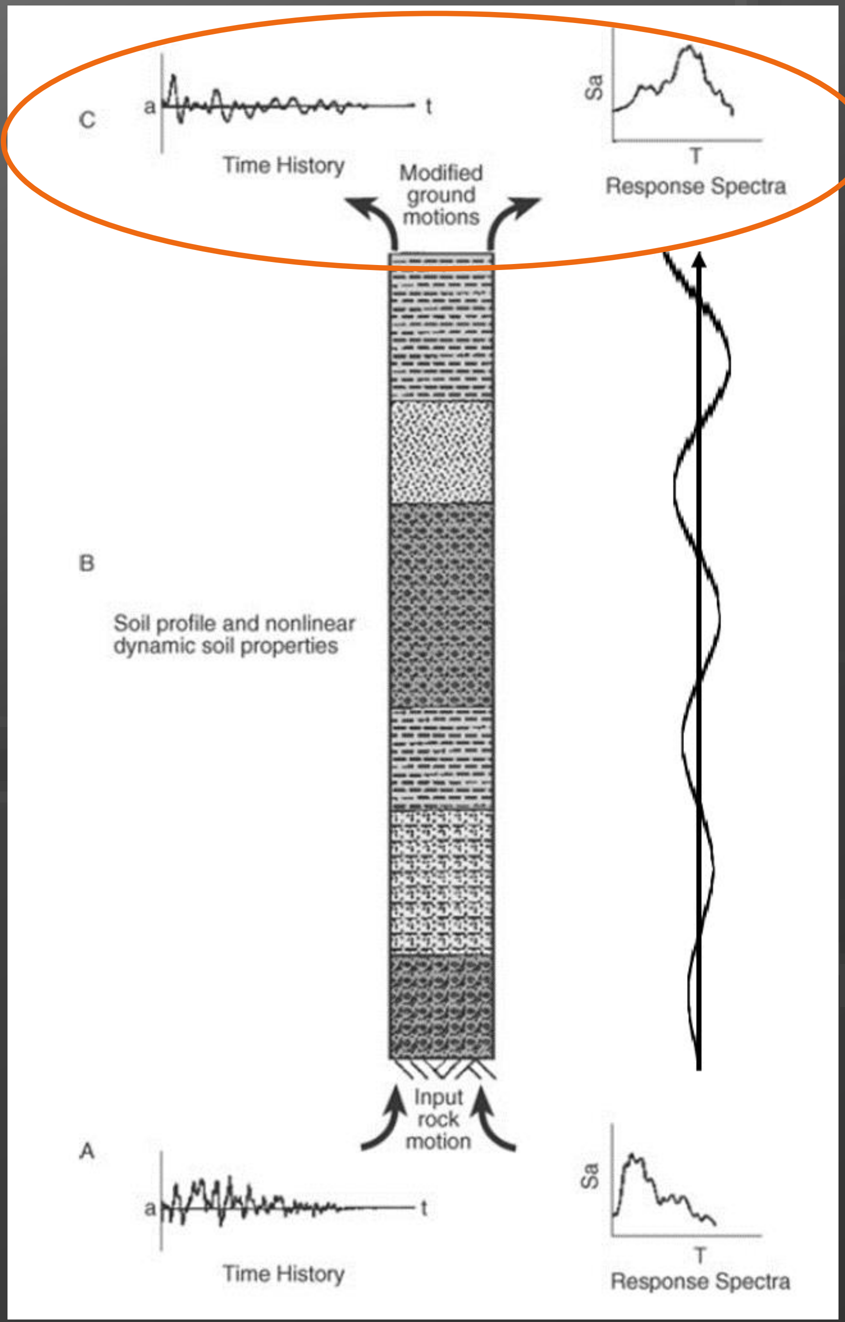
SITE RESPONSE ANALYSIS (SRA)

- Ground motions are transformed from a base layer (usually bedrock) through a modelled soil profile to provide estimates of ground motions (and corresponding response spectrum) at the ground surface
  - Evaluates F_a and F_v directly; not from a table



After Schnabel et al., 1972

After Hengesh and Lettis, 2004



SITE RESPONSE ANALYSIS (SRA)

- A one-dimensional SRA with vertically propagating shear waves is sometimes informally referred to as a “SHAKE” analysis
- More analytically and site data intensive than GMHA
  - More expensive

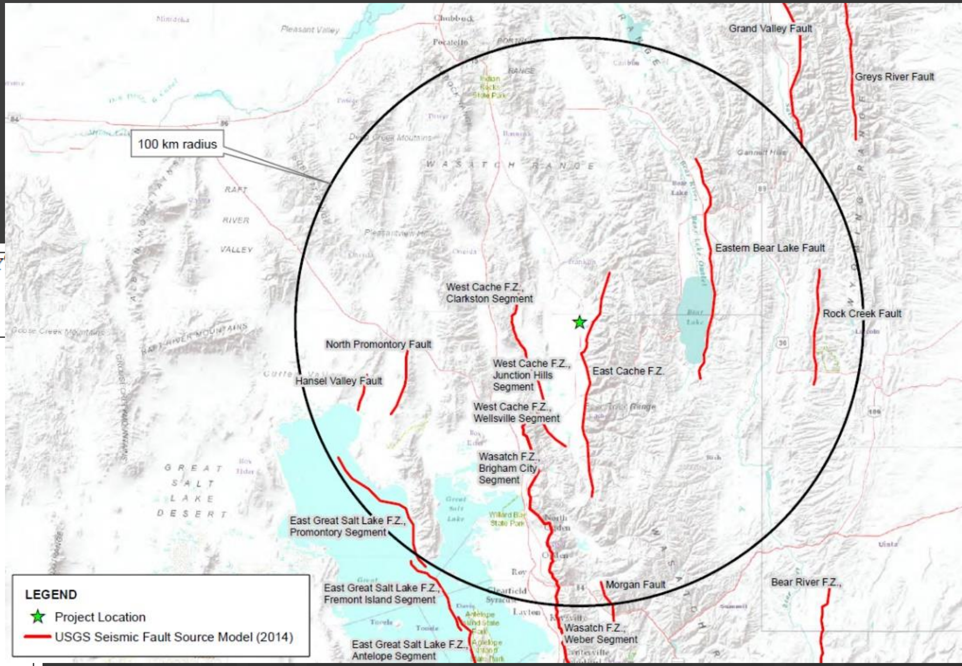
NOT A SITE-SPECIFIC ANALYSIS!

- Simply using coordinates to obtain parameters from USGS-data based Web Application (“It’s site specific because I used the site coordinates”)
- Use of USGS’ Unified Hazard Tool by itself
  - but could inform the answer
- Use of PEER’s NGA-West2 GMPE Spreadsheet by itself
  - but could be a part of the answer

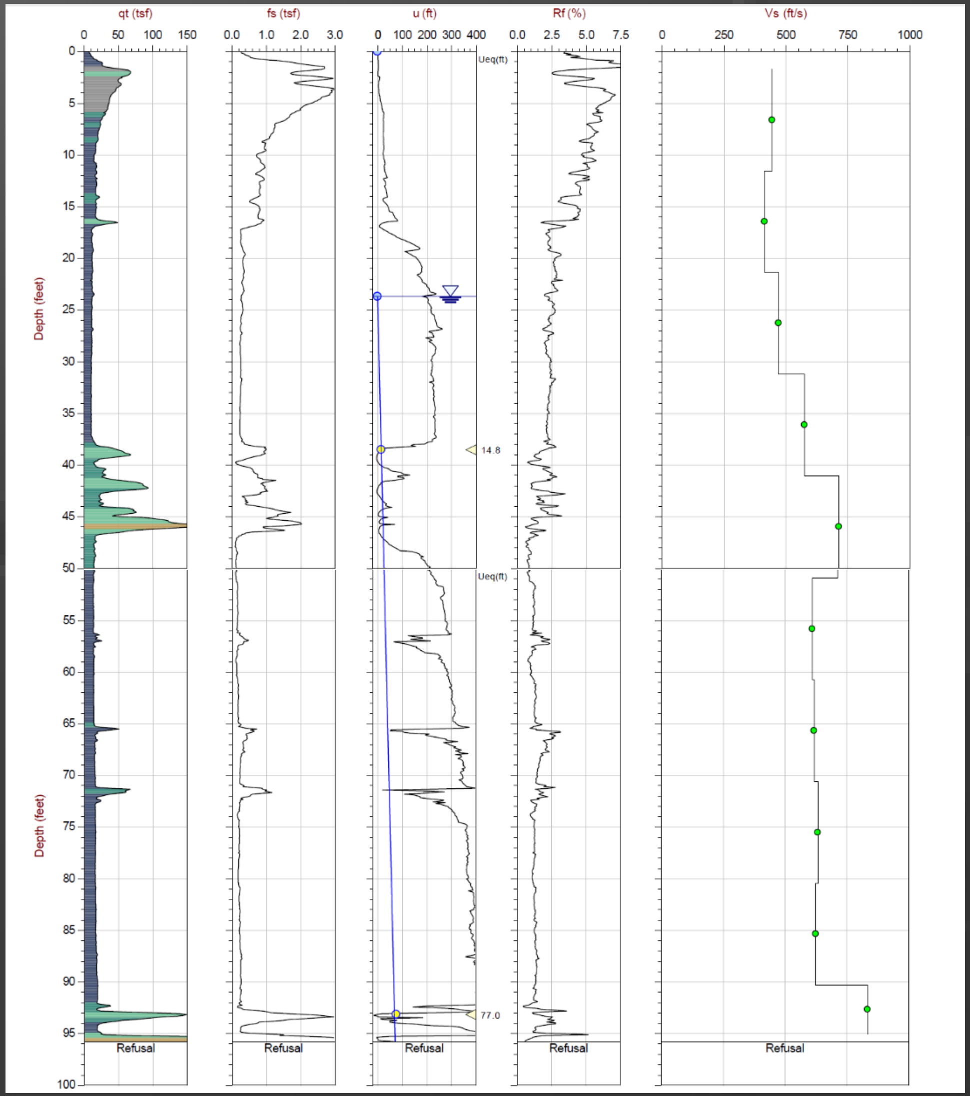
EXAMPLE CONTENT OF GMHA REPORT

SITE, SETTING, AND SEISMIC MODEL

FAULT NO.[1]	FAULT NAME	RUPTURE MODEL	MAXIMUM RUPTURE LENGTH[2] (km)	MAXIMUM MAGNITUDE[3] (M)	DIP[4] (degrees)	APPROXIMATE AGE OF YOUNGEST OFFSET	PROBABILITY OF ACTIVITY[5]	RATE OF ACTIVITY (mm/yr)
11-08 2364c-Southern Segment, 2364b-Central Segment, 2364a-Northern Segment	East Bear Lake fault	Rupture Scenario A – after USGS (0.5): Segmented (0.7)	Southern Segment – 35	6.8 (0.2) 7.1 (0.6) 7.4 (0.2)	30 W (0.4) 50 W (0.4) 60 W (0.2)	Late Holocene	1.0	0.3 (0.2) 0.8 (0.6) 2.1 (0.2)
			Central Segment - 24	6.6 (0.2) 6.9 (0.6) 7.2 (0.2)	(same for all)	Holocene (?)	(same for all)	0.01 (0.2) 0.15 (0.6) 1.0 (0.2)
			Northern Segment - 19	6.5 (0.2) 6.8 (0.6) 7.1 (0.2)		Late Quaternary (?)		0.01 (0.2) 0.15 (0.6) 1.0 (0.2)
		Unsegmented (0.3)	Floating 29 km (1.5 times avg. segment length) on 78 km	6.7 (0.2) 7.0 (0.6) 7.3 (0.2)		Holocene		0.3 (0.2) 0.8 (0.6) 2.1 (0.2)
		Rupture Scenario B – after Breckenridge *et al*. (2003) (0.5): Segmented (0.7)	Southern – 35	6.8 (0.2) 7.1 (0.6) 7.4 (0.2)				0.3 (0.2) 0.8 (0.6) 2.1 (0.2)
			Central – 24	6.6 (0.2) 6.9 (0.6) 7.2 (0.2)				0.01 (0.2) 0.15 (0.6) 1.0 (0.2)
			Northern – 58	7.0 (0.2) 7.3 (0.6) 7.6 (0.2)				0.01 (0.2) 0.15 (0.6) 1.0 (0.2)
		Unsegmented (0.3)	Floating 39 km (1.5 times avg. segment length) on 117 km	6.8 (0.2) 7.1 (0.6) 7.4 (0.2)				0.3 (0.2) 0.8 (0.6) 2.1 (0.2)



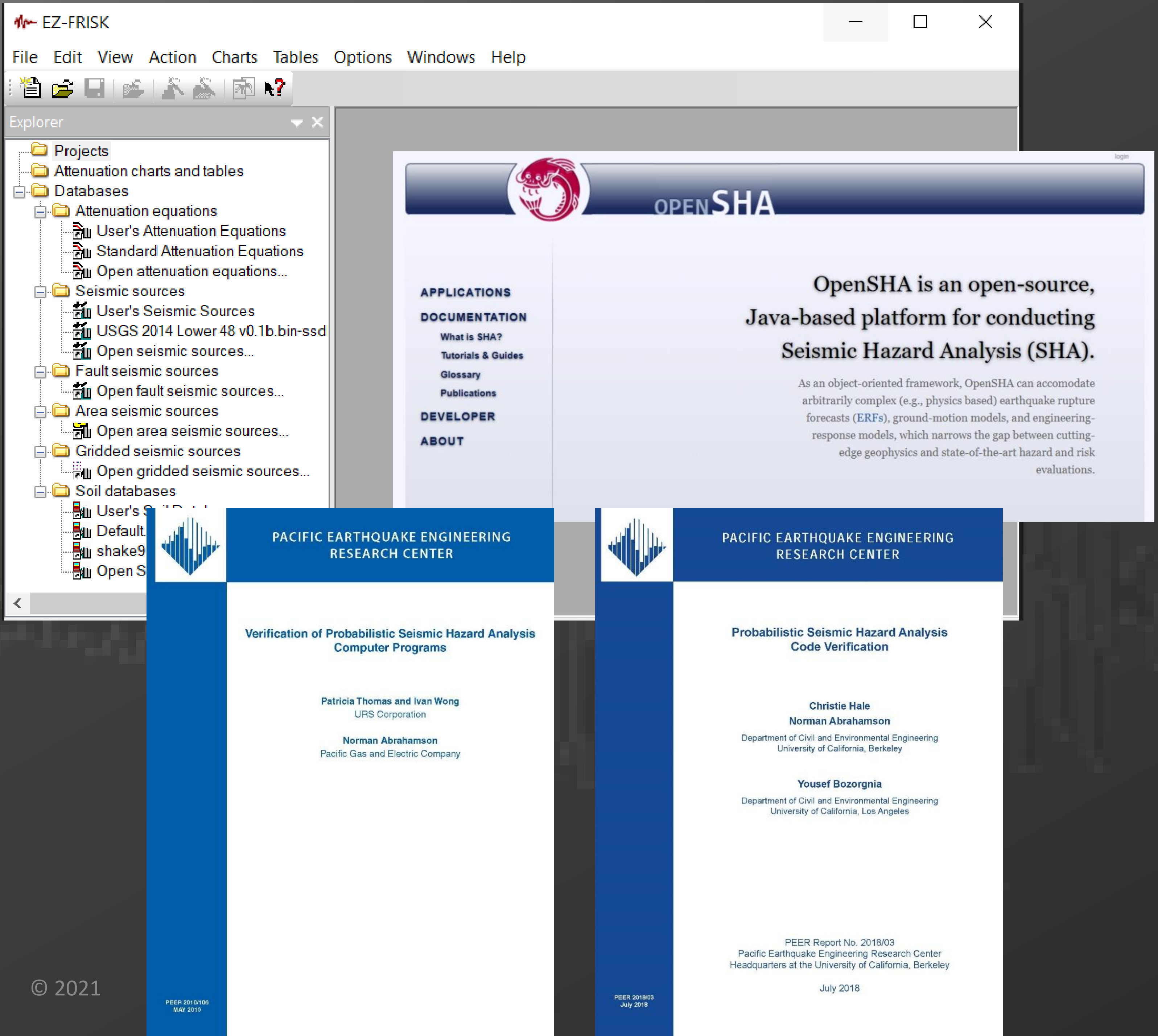
ASCE 7-16 CODE-BASED ("GENERAL PROCEDURE") SEISMIC DESIGN PARAMETERS

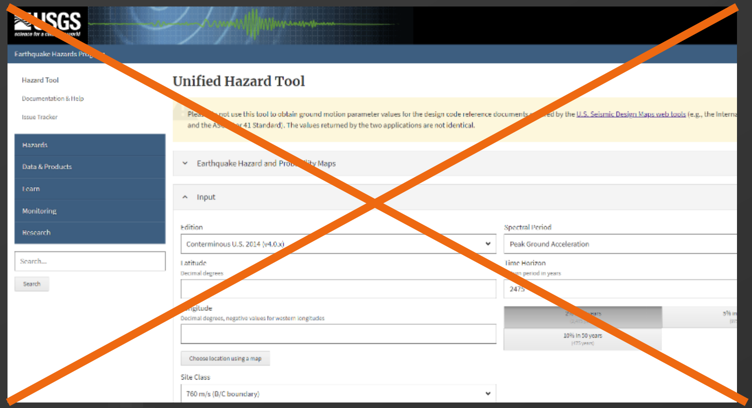


Parameter	Value
Site Classification	E
$V_{s,30}$ (ft/s)	568
Mapped value MCE_R S_s (g)	0.951
Mapped value MCE_R S_1 (g)	0.313
Mapped value MCE_G PGA(g)	0.409
Mapped value C_{RS}	0.902
Mapped value C_{R1}	0.914

Only for site-specific

PSHA


EZ-FRISK
File Edit View Action Charts Tables Options Windows Help
Explorer
Projects
Attenuation charts and tables
Databases
Attenuation equations
User's Attenuation Equations
Standard Attenuation Equations
Open attenuation equations...
Seismic sources
User's Seismic Sources
USGS 2014 Lower 48 v0.1b.bin-ssd
Open seismic sources...
Fault seismic sources
Open fault seismic sources...
Area seismic sources
Open area seismic sources...
Gridded seismic sources
Open gridded seismic sources...
Soil databases
login
OPENSHA
APPLICATIONS
DOCUMENTATION
What is SHA?
Tutorials & Guides
Glossary
Publications
DEVELOPER
ABOUT
OpenSHA is an open-source, Java-based platform for conducting Seismic Hazard Analysis (SHA).
As an object-oriented framework, OpenSHA can accomodate arbitrarily complex (e.g., physics based) earthquake rupture forecasts (ERFs), ground-motion models, and engineering-response models, which narrows the gap between cutting-edge geophysics and state-of-the-art hazard and risk evaluations.
PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER
Verification of Probabilistic Seismic Hazard Analysis Computer Programs
Patricia Thomas and Ivan Wong
URS Corporation
Norman Abrahamson
Pacific Gas and Electric Company
PEER 2010/106
MAY 2010
PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER
Probabilistic Seismic Hazard Analysis Code Verification
Christie Hale
Norman Abrahamson
Department of Civil and Environmental Engineering
University of California, Berkeley
Yousef Bozorgnia
Department of Civil and Environmental Engineering
University of California, Los Angeles
PEER Report No. 2018/03
Pacific Earthquake Engineering Research Center
Headquarters at the University of California, Berkeley
July 2018
PEER 2018/03
July 2018


USGS
Unified Hazard Tool

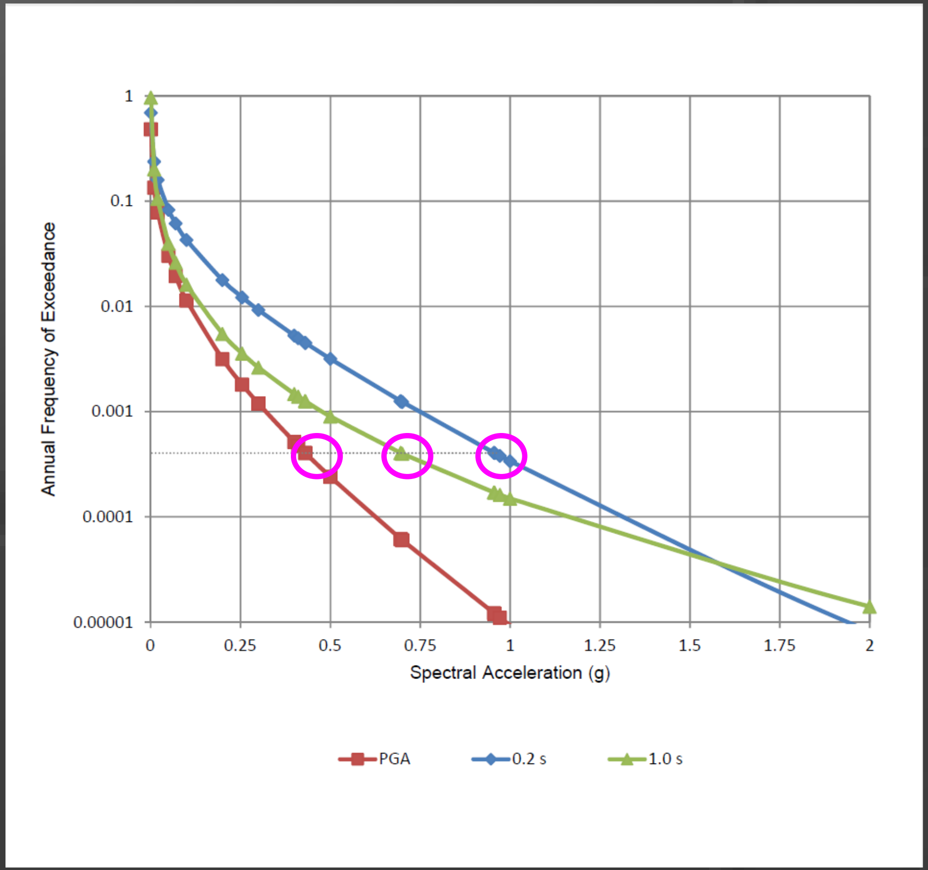
PSHA – REPORT CONTENT

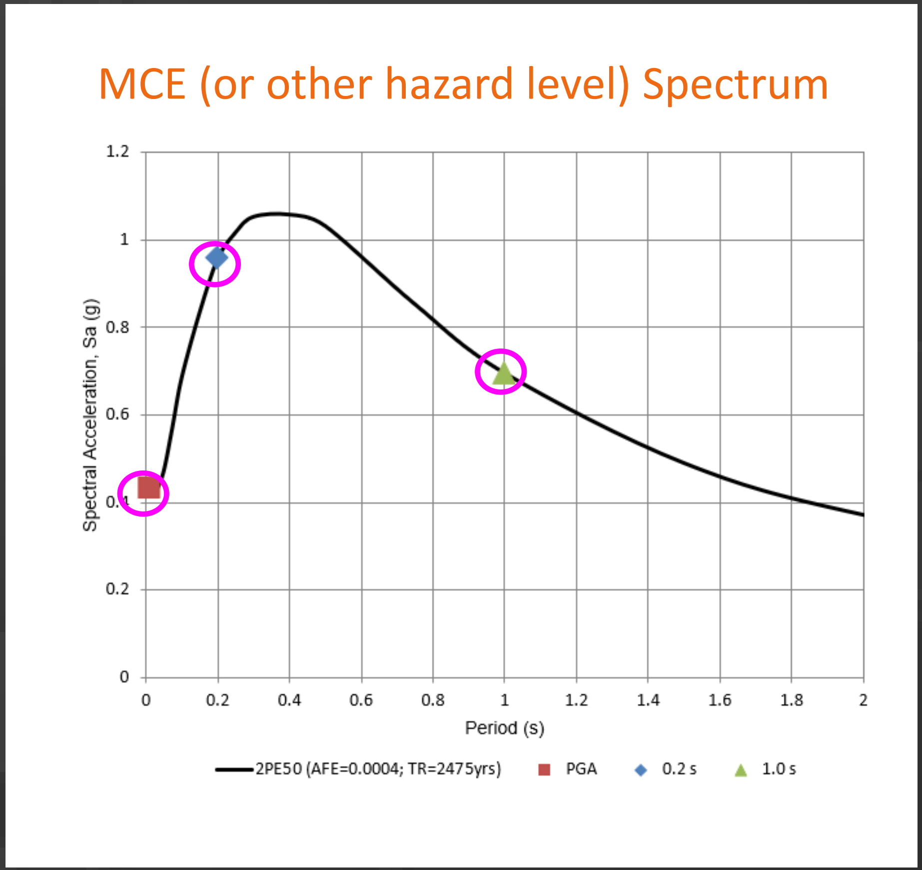
- How was V_{s30} obtained?
  - Maximum measurement depth (extrapolation?)
  - Correctly calculated (weighted harmonic mean)
  - Any impedance contrasts
- Ground Motion Predictions Equations (GMPE)
  - Which ones used (and why)
  - Use more than one
  - Weighting
  - Other necessary parameters
    - Site/basin parameters (such as $Z_{1.0}$) – use site specific

PSHA – REPORT CONTENT

- Seismic source model used
  - Which faults/sources included, omitted?
    - Don’t delete gridded seismicity or double up; include both WUS and CEUS
  - How are uncertainties accounted for (logic tree type of information)?
    - Magnitude
    - Recurrence
    - Fault geometry and linkages
- Adjustments
  - Orientation (Rot_{D50} vs maximum)
  - Ground motions vs probability of collapse [risk-based]; use risk coefficients or RTGM calculator
  - Near-source effects (directivity)

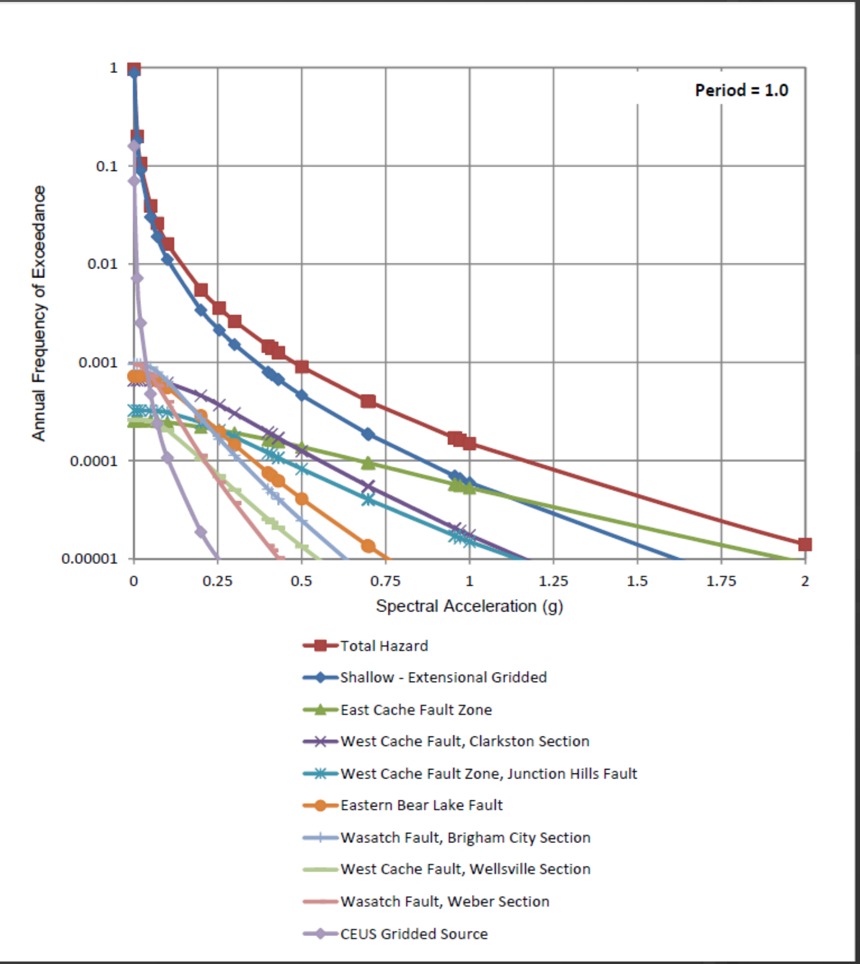
PSHA – HAZARD CURVES AND RESPONSE SPECTRUM

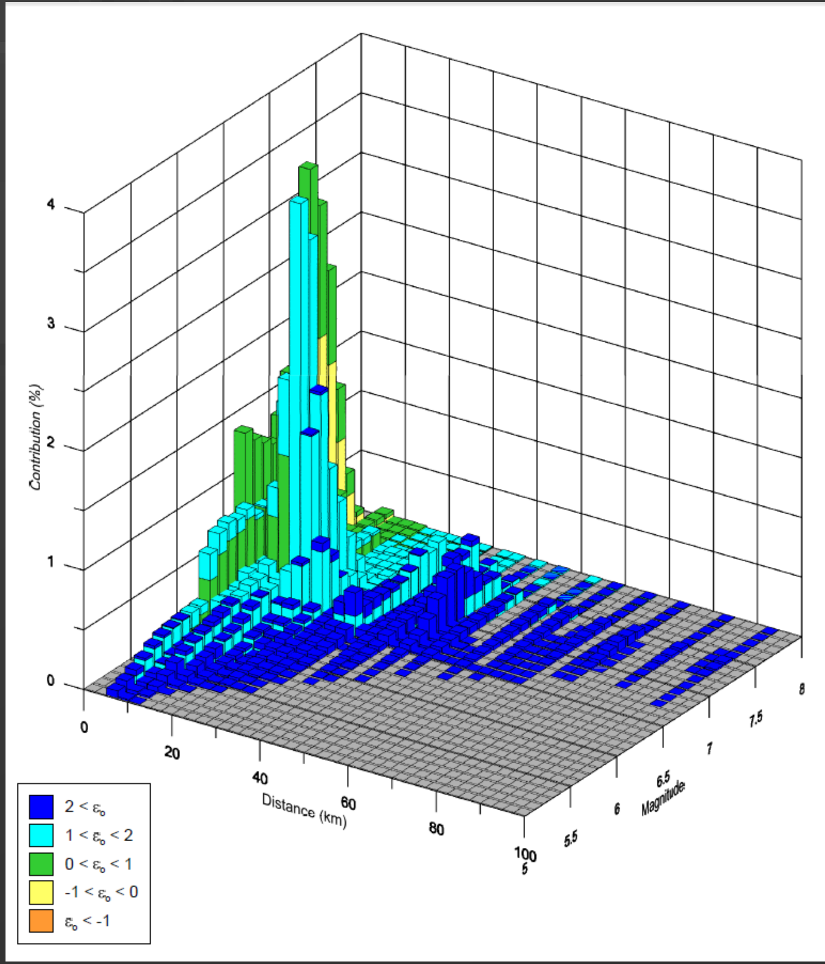




PSHA – SOURCE CONTRIBUTION AND DEAGG

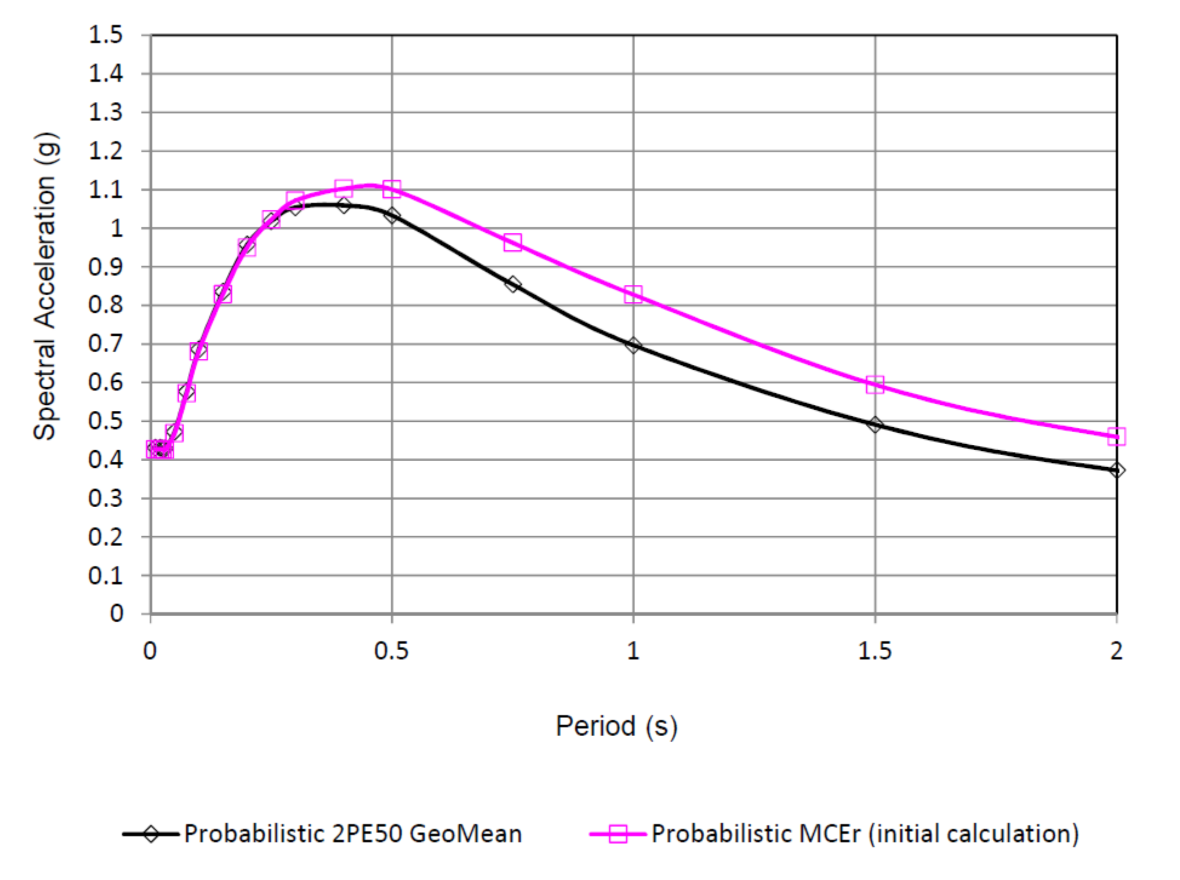
- Helps with assessing correctness of results
- Provides information regarding "most representative" earthquake



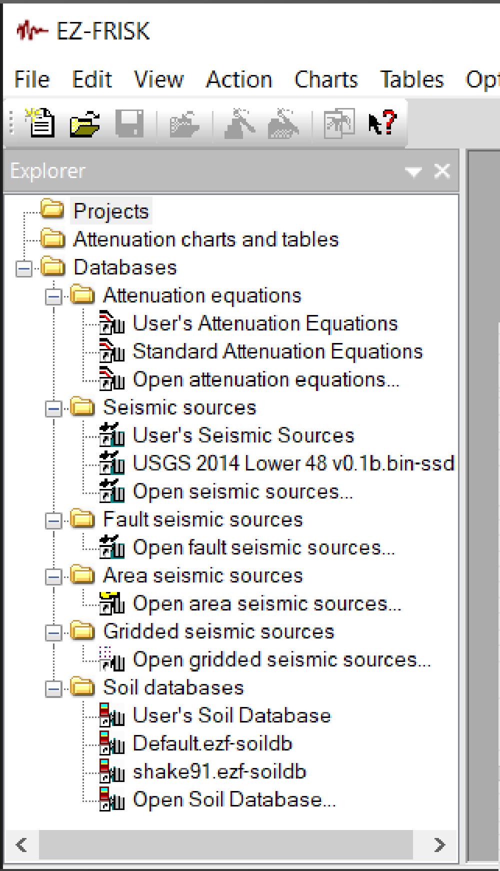


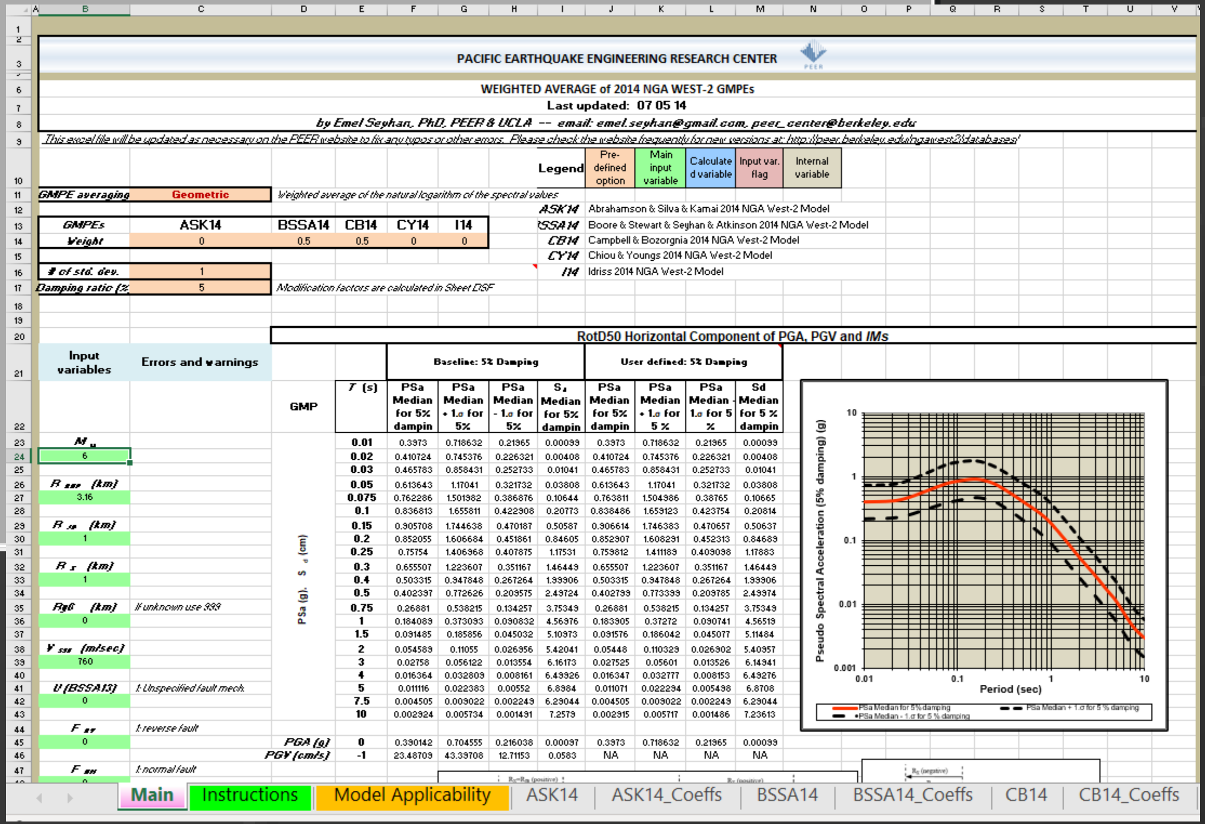
PSHA – CONVERT FROM MCE TO MCE_R

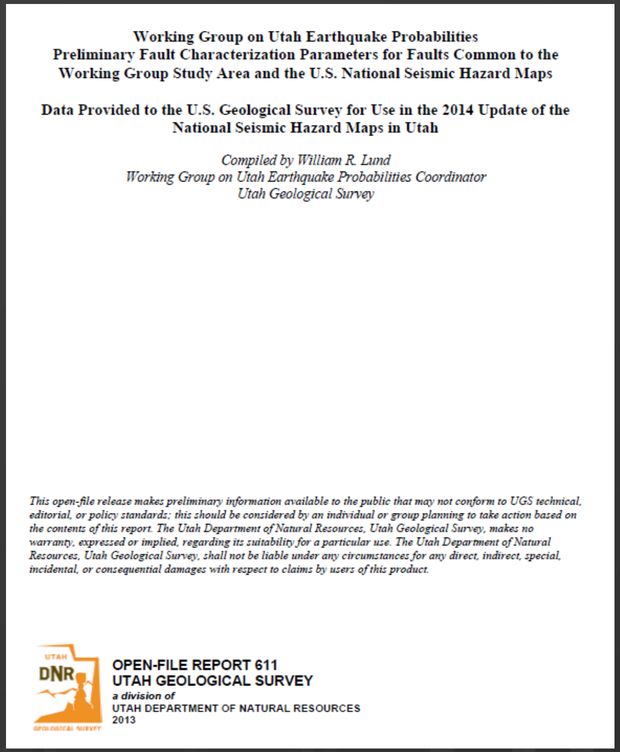
- Depending on PSHA code, likely need to convert from RotD50 2PE50 hazard to max. orientation and 1%PC50yr risk
  - These steps are often missed



DSHA


EZ-FRISK
File Edit View Action Charts Tables Options Windows Help
Explorer
Projects
Attenuation charts and tables
Databases
Attenuation equations
User's Attenuation Equations
Standard Attenuation Equations
Open attenuation equations...
Seismic sources
User's Seismic Sources
USGS 2014 Lower 48 v0.1b.bin-ssd
Open seismic sources...
Fault seismic sources
Open fault seismic sources...
Area seismic sources
Open area seismic sources...
Gridded seismic sources
Open gridded seismic sources...
Soil databases
User's Soil Database
Default.ezf-soildb
shake91.ezf-soildb
Open Soil Database...

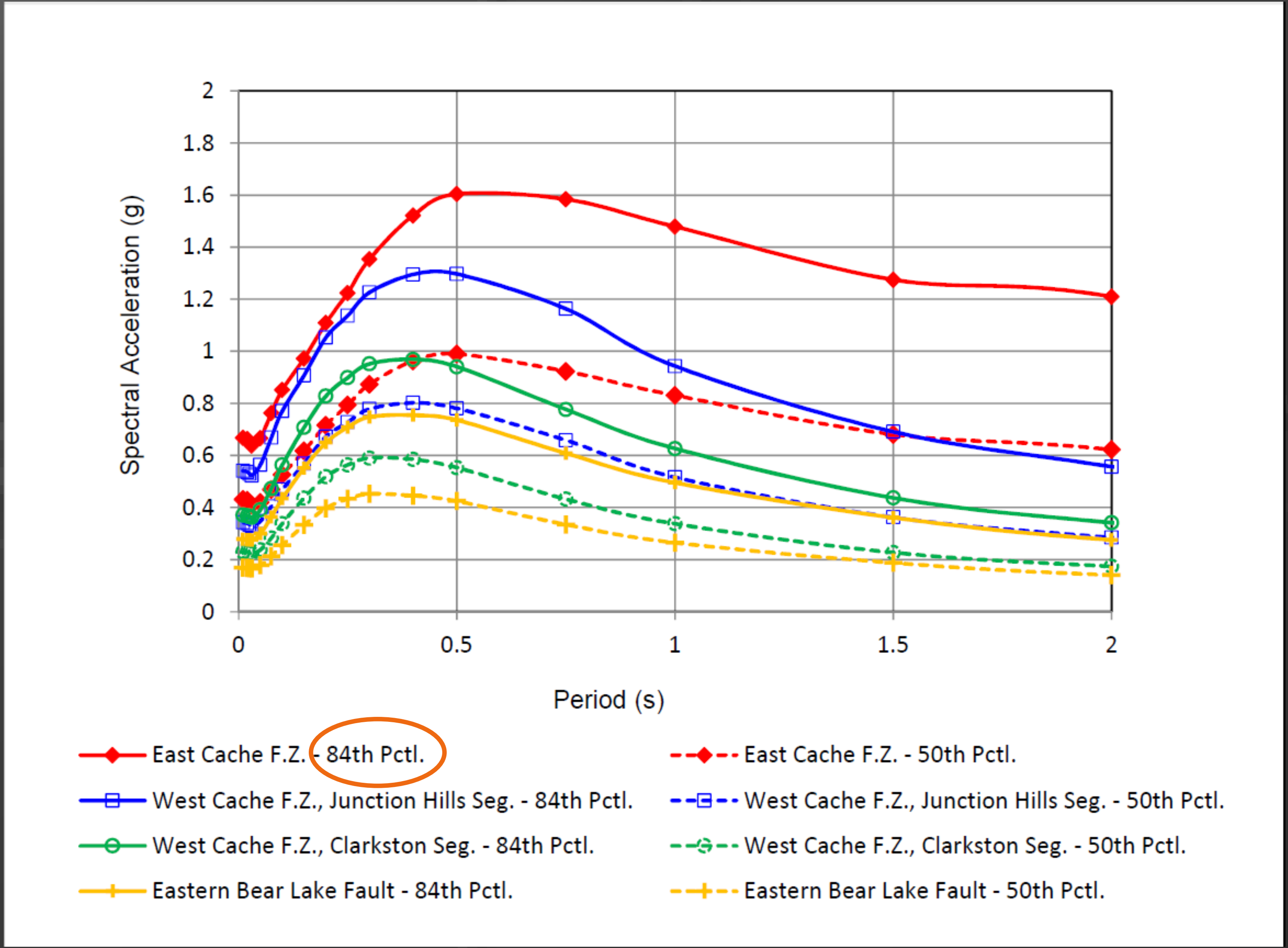

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER
WEIGHTED AVERAGE of 2014 NGA WEST-2 GMPEs
Last updated: 07 05 14
by Emel Seyhan, PhD, PEER & UCLA -- email: emel.seyhan@gmail.com, peer_center@berkeley.edu
Legend
Pre-defined option
Main input variable
Calculated variable
Input var. flag
Internal variable
GMPE averaging
Geometric
ASK14 Abrahamson & Silva & Kamai 2014 NGA West-2 Model
BSSA14 Boore & Stewart & Seyhan & Atkinson 2014 NGA West-2 Model
CB14 Campbell & Bozorgnia 2014 NGA West-2 Model
CY14 Chiou & Youngs 2014 NGA West-2 Model
I14 Idriss 2014 NGA West-2 Model
RotD50 Horizontal Component of PGA, PGV and IMs
Input variables
Errors and warnings
Baseline: 5% Damping
User defined: 5% Damping
Pseudo Spectral Acceleration (5% damping) (g)
Period (sec)
Main
Instructions
Model Applicability
ASK14
ASK14_Coeffs
BSSA14
BSSA14_Coeffs
CB14
CB14_Coeffs


Working Group on Utah Earthquake Probabilities
Preliminary Fault Characterization Parameters for Faults Common to the
Working Group Study Area and the U.S. National Seismic Hazard Maps
Data Provided to the U.S. Geological Survey for Use in the 2014 Update of the
National Seismic Hazard Maps in Utah
Compiled by William R. Lund
Working Group on Utah Earthquake Probabilities Coordinator
Utah Geological Survey
OPEN-FILE REPORT 611
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2013

DSHA – REPORT CONTENT

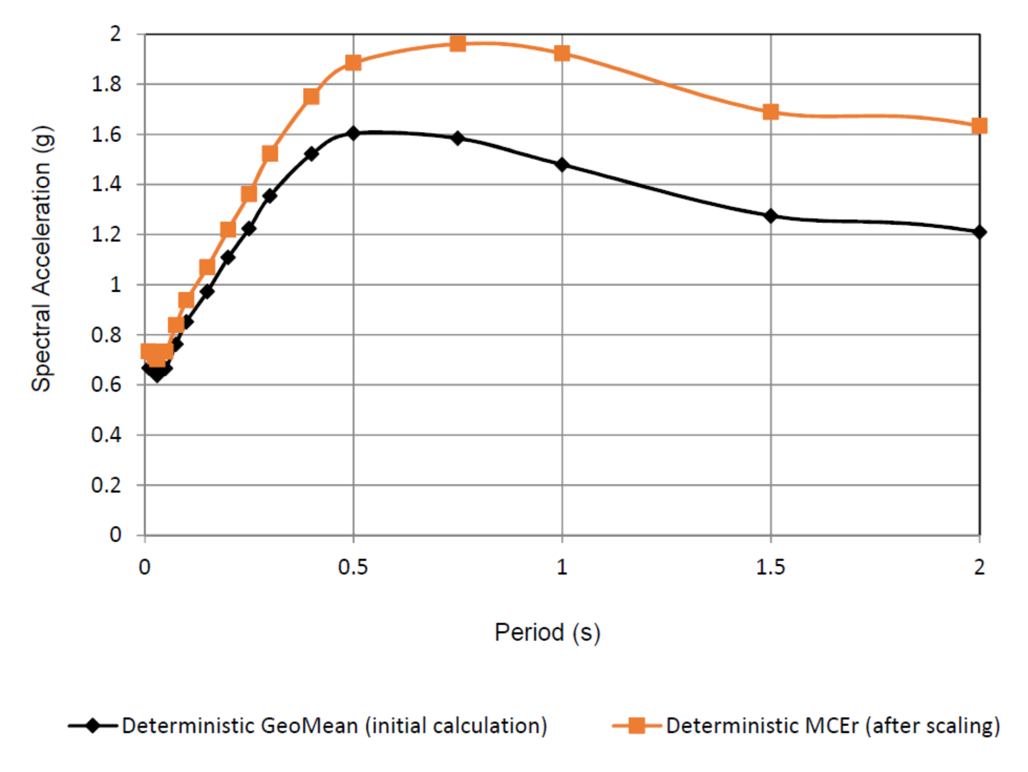
- Site characterization (same as for PSHA)
- What seismic sources were considered/evaluated
  - Characteristics
- Adjustments
  - Orientation (Rot_{D50} vs maximum)
  - Near-source effects (directivity)
  - Percentile (50^{th} vs 84^{th})
    - Only 84^{th} required; 50^{th} (median) can be informative
  - Minimum spectrum (ASCE 7-16 Supplement #1)

DSHA –RESPONSE SPECTRUM



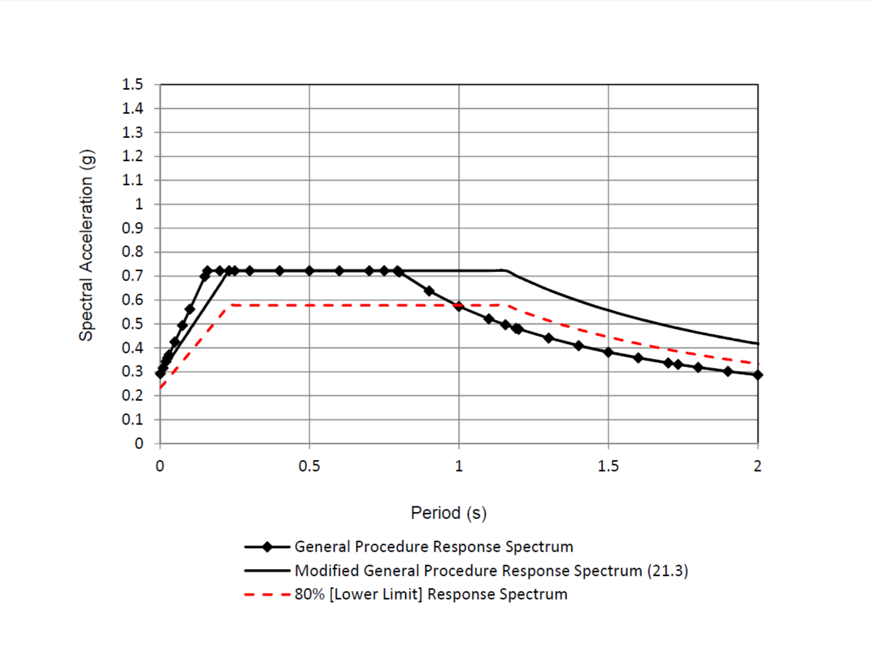
DSHA – CONVERT FROM MCE TO MCE_R

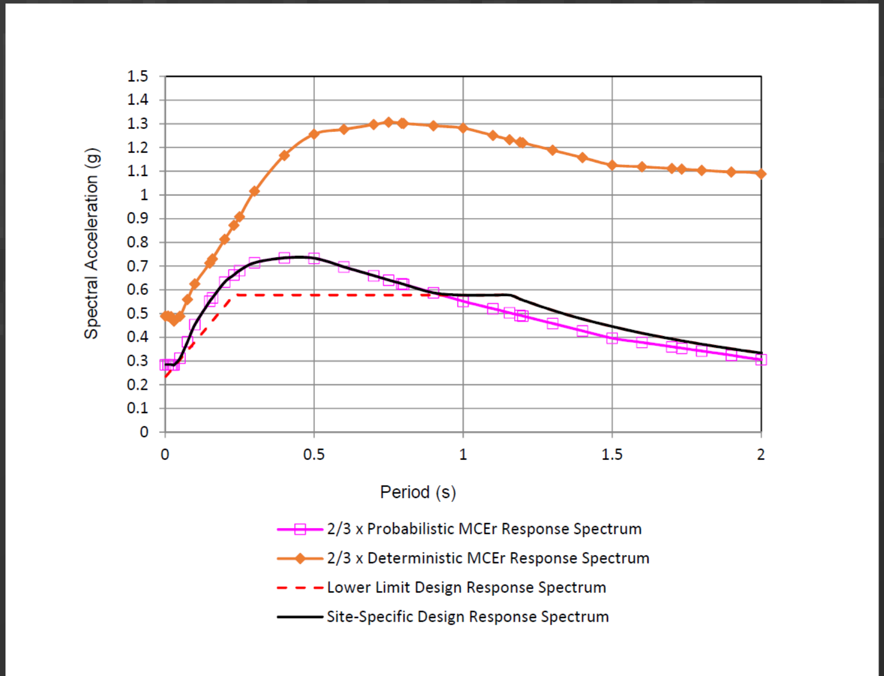
- Depending on GMPEs in DSHA, likely need to convert from RotD50 (or something else) to max. orientation
- Adjust as needed for Minimum Deterministic Limit
  - These steps are often missed



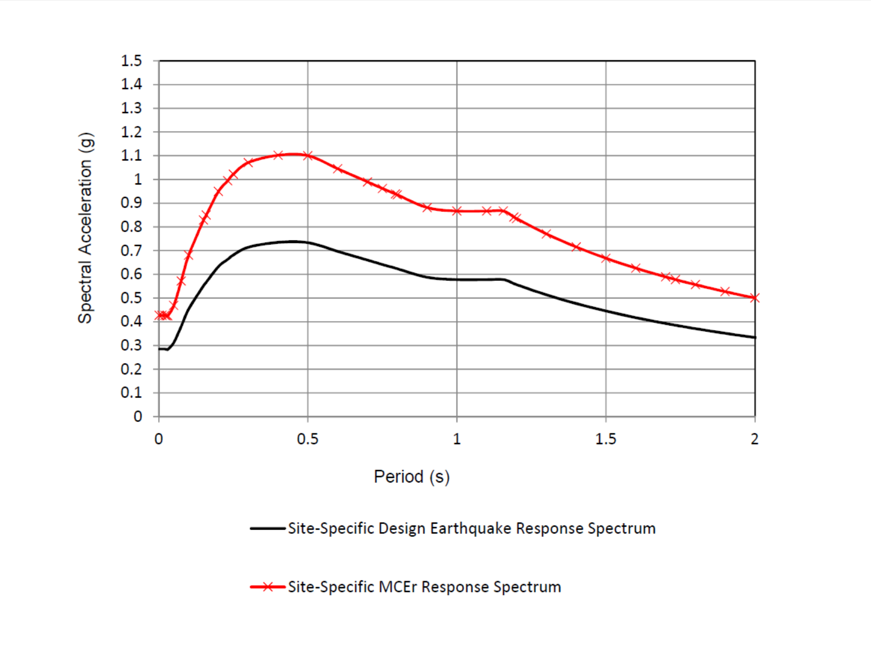
GMHA – NEXT AND FINAL STEPS

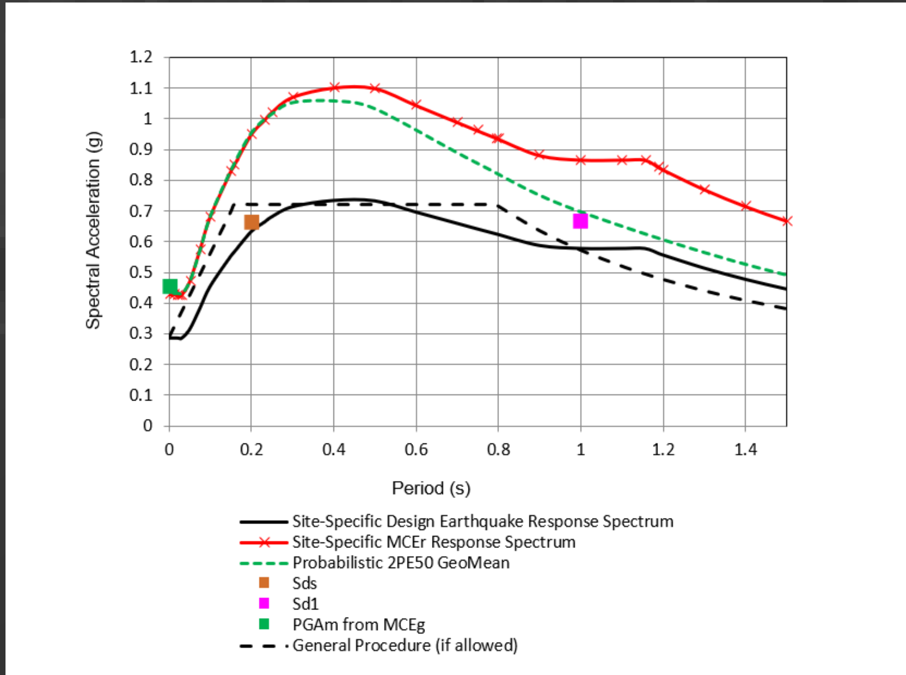
- There are likely limits as to how much reduction in demand may be taken in a site-specific analysis (varies per Code; 80% lower limit)
- For 2018 IBC and ASCE 7-16, take lower of 2/3 × PSHA and 2/3 × DSHA, but not lower than minimum spectrum





- Present Design [Earthquake, DE] Response Spectrum
- Present MCE_R Response Spectrum (scale DE Spectrum by 3/2)
- Calculate parameters S_{ds} , S_{d1} , and PGA_m
  – See ASCE 7-16 Section 21.4 for procedure; involves averaging of certain structural periods such the acceleration may not plot directly on spectrum



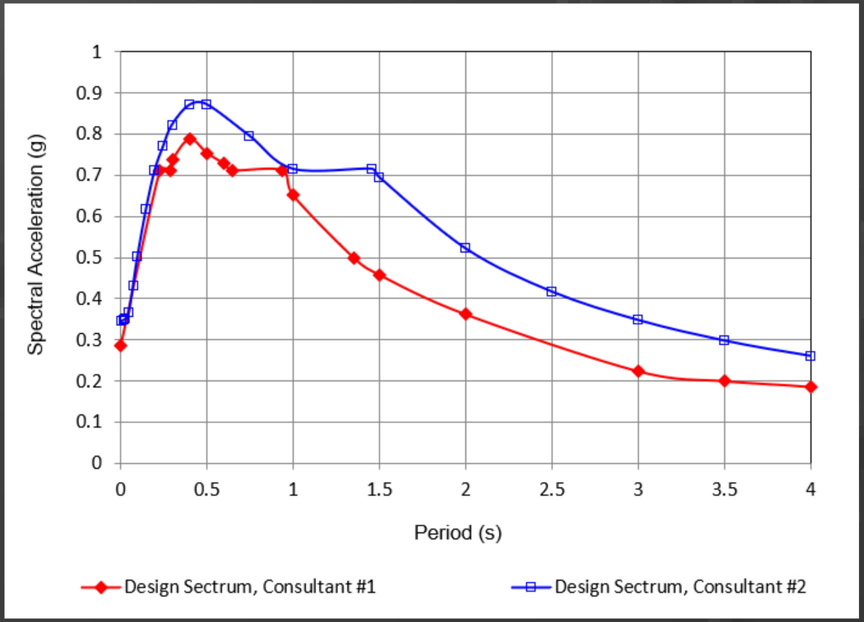


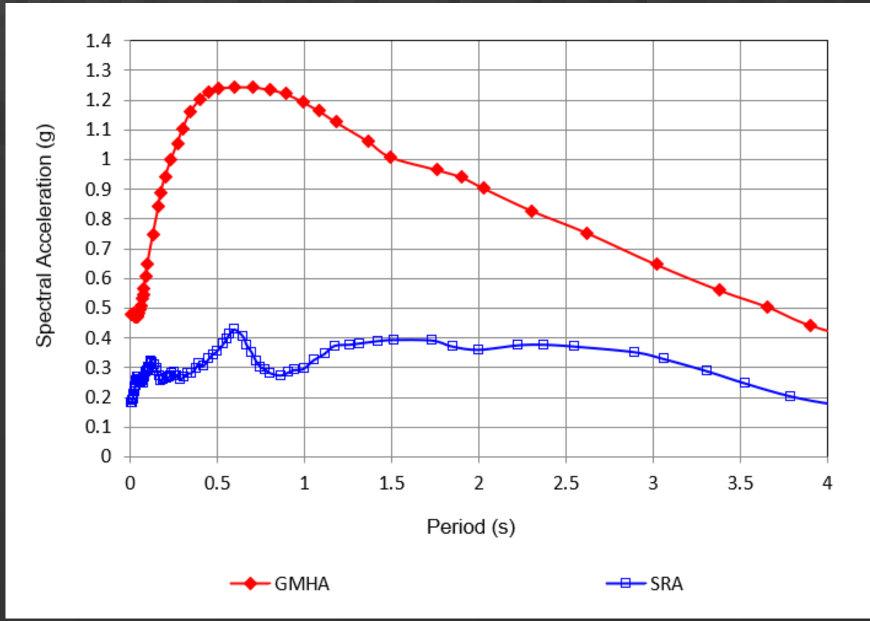
SOME ISSUES REGARDING SRA (DISCUSSIONS FOR ANOTHER TIME)

- Selection of seed time histories
- Spectral matching
  - Strongly encouraged (if done right)
- Equivalent-linear vs Non-linear analysis
  - If Liquefied, must be non-linear
- Conditions at bottom of model
- Outcropping vs in-body motions
- Layer thicknesses

STUDIES GONE WRONG

- Site-specific studies require extensive experience and skill
  - Not everybody who tries does them right (even if they say/think they can, sadly)

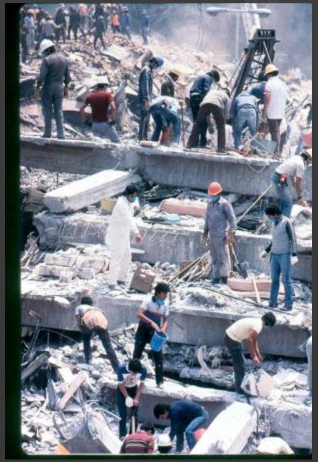




RELATED THOUGHTS

- Structural Engineering is like plastic surgery and sushi – never get it at a bargain price
  - Same holds for Geotechnical and Seismic Engineering
- If this is why you are doing a site-specific study: ☑

then maybe it doesn't matter



(or maybe it does)

GETTING A GOOD GMHA OR SRA

- Request qualifications
  - Ask proposer to send example of previous work
- Do a peer- or third-party review
  - Formal or informal
  - If formal, involve reviewer from beginning of the process

GETTING A GOOD GMHA OR SRA

- Follow recommendations for good practice

CHANGES IN SEISMIC DESIGN CRITERIA AND DESIGN GROUND MOTIONS IN IBC 2018 AND ASCE 7-16, AND RECOMMENDATIONS FOR SEISMIC DESIGN PRACTICE IN UTAH

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Endorsed by: Utah Geo-Institute Chapter of the American Society of Civil Engineers (ASCE),
Utah Section of ASCE, Structural Engineers Association of Utah (SEAU),
Utah Chapter of the Earthquake Engineering Research Institute (EERI), and
Utah Chapter of the Structural Engineering Institute (SEI).

January 31, 2020

ABSTRACT

The 2018 International Building Code (IBC 2018), and by extension referenced provisions of ASCE 7-16, was adopted July 2019 by the State of Utah. ASCE 7-16 introduces significant changes to prescribed seismic forces for the design of structures when compared to IBC 2015 and ASCE 7-10. These changes include updated mapped B/C boundary seismic values S_s and S_1 as well as revised site coefficients (with the coefficients typically being larger). Most notable are new requirements to perform site-specific ground motion hazard analyses (GMHA, which is comprised of both deterministic seismic hazard analysis [DSHA] and probabilistic seismic hazard analysis [PSHA]) for areas of moderate to high seismicity and softer soil sites (Site Classes D and E). This site-specific study requirement is the result of deficiencies which are now more widely recognized in the shape and magnitude of the code-based ("standard") design response spectrum. In some cases, exceptions exist where an otherwise required GMHA may be omitted; however, these exceptions together with the other changes in ASCE 7-16 can increase design base shears by as much as 70%. In early 2019, a group of individuals from several professional societies formed an ad-hoc committee to develop a workshop whose purpose was to help inform fellow engineering and geological professionals in Utah about these changes. In preparing for the workshop, various design practice issues not explicitly addressed in IBC 2018 or ASCE 7-16 were discussed. The outcome of these discussions were consensus recommendations which are believed by committee members to represent good seismic design practices. This document presents several of

SELF-ASSESSMENT OF QUALIFICATIONS FOR PERFORMING GMHA

- Do you understand what each of these variables are?

ATC Hazards by Location

Search Information

Coordinates:	40.611987, -111.911952
Elevation:	4349 ft
Timestamp:	2021-02-04T16:48:56.773Z
Hazard Type:	Seismic
Reference Document:	ASCE7-16
Risk Category:	II
Site Class:	D

Basic Parameters

Name	Value	Description
S_S	1.342	MCE_R ground motion (period=0.2s)
S_1	0.47	MCE_R ground motion (period=1.0s)
S_{MS}	1.342	Site-modified spectral acceleration value
S_{M1}	* null	Site-modified spectral acceleration value
S_{DS}	0.895	Numeric seismic design value at 0.2s SA
S_{D1}	* null	Numeric seismic design value at 1.0s SA

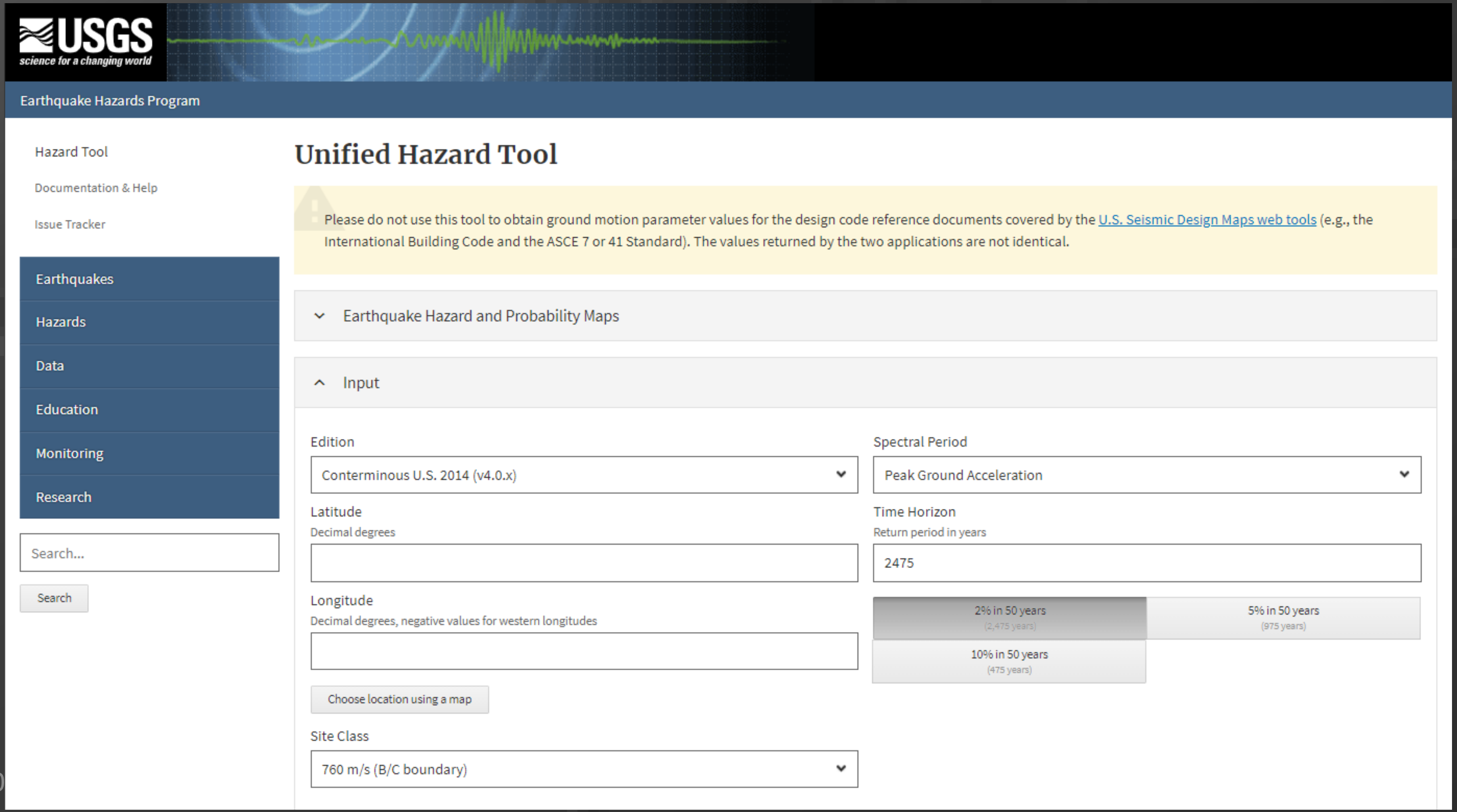
* See Section 11.4.8

Additional Information

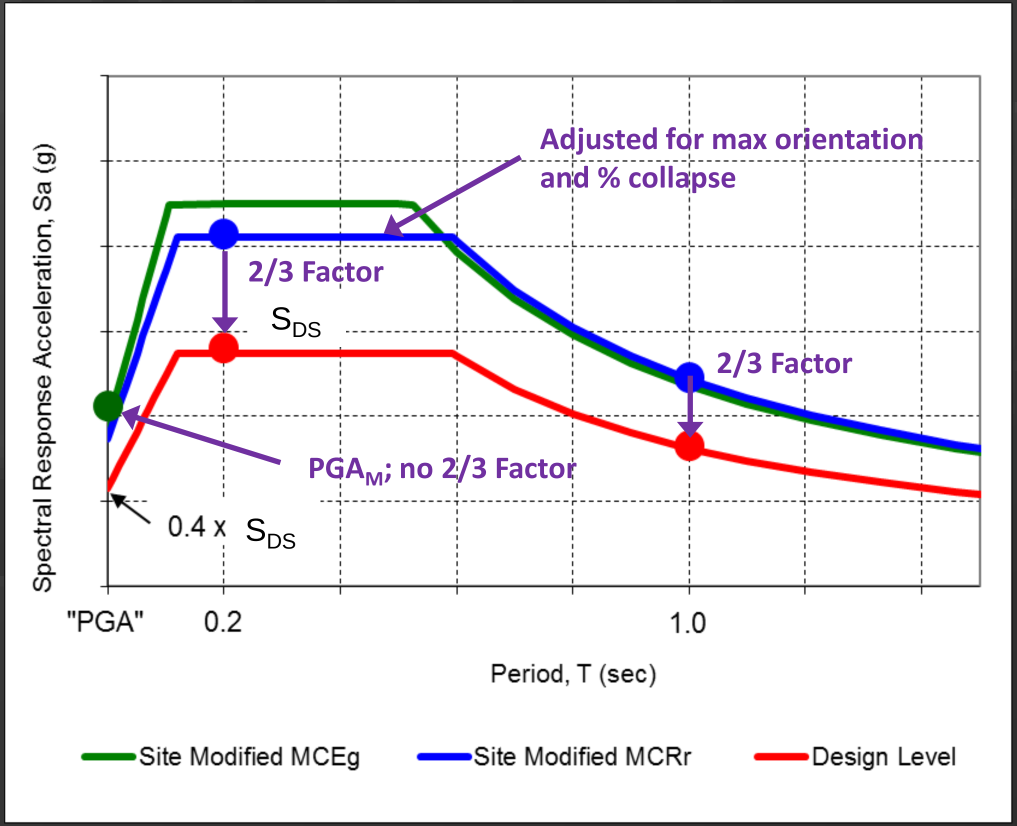
Name	Value	Description
SDC	* null	Seismic design category
F_a	1	Site amplification factor at 0.2s
F_v	* null	Site amplification factor at 1.0s
CR_S	0.864	Coefficient of risk (0.2s)
CR_1	0.874	Coefficient of risk (1.0s)
PGA	0.596	MCE_G peak ground acceleration
F_{PGA}	1.1	Site amplification factor at PGA
PGA_M	0.655	Site modified peak ground acceleration
T_L	8	Long-period transition period (s)
SsRT	1.342	Probabilistic risk-targeted ground motion (0.2s)
SsUH	1.552	Factored uniform-hazard spectral acceleration (2% probability of exceedance in 50 years)
SsD	2.835	Factored deterministic acceleration value (0.2s)
S1RT	0.47	Probabilistic risk-targeted ground motion (1.0s)
S1UH	0.538	Factored uniform-hazard spectral acceleration (2% probability of exceedance in 50 years)
S1D	1.043	Factored deterministic acceleration value (1.0s)
PGAd	1.127	Factored deterministic acceleration value (PGA)

* See Section 11.4.8

- Can you use USGS' Unified Hazard Tool to obtain the values of SsUH, S1UH (note that UHT does not give these values directly), and then SsRT and S1RT as shown?
- What does "factored" mean? (which factor)



- Could you calculate each of these variables on your own if you needed to? (that is the service you will be providing)
- Essay Question: Can you explain the conceptual similarities and differences between $0.4 \times S_{SM}$, $0.4 \times S_{DS}$, and PGA_M? (as a starting point, do you understand that they are from different spectra?)

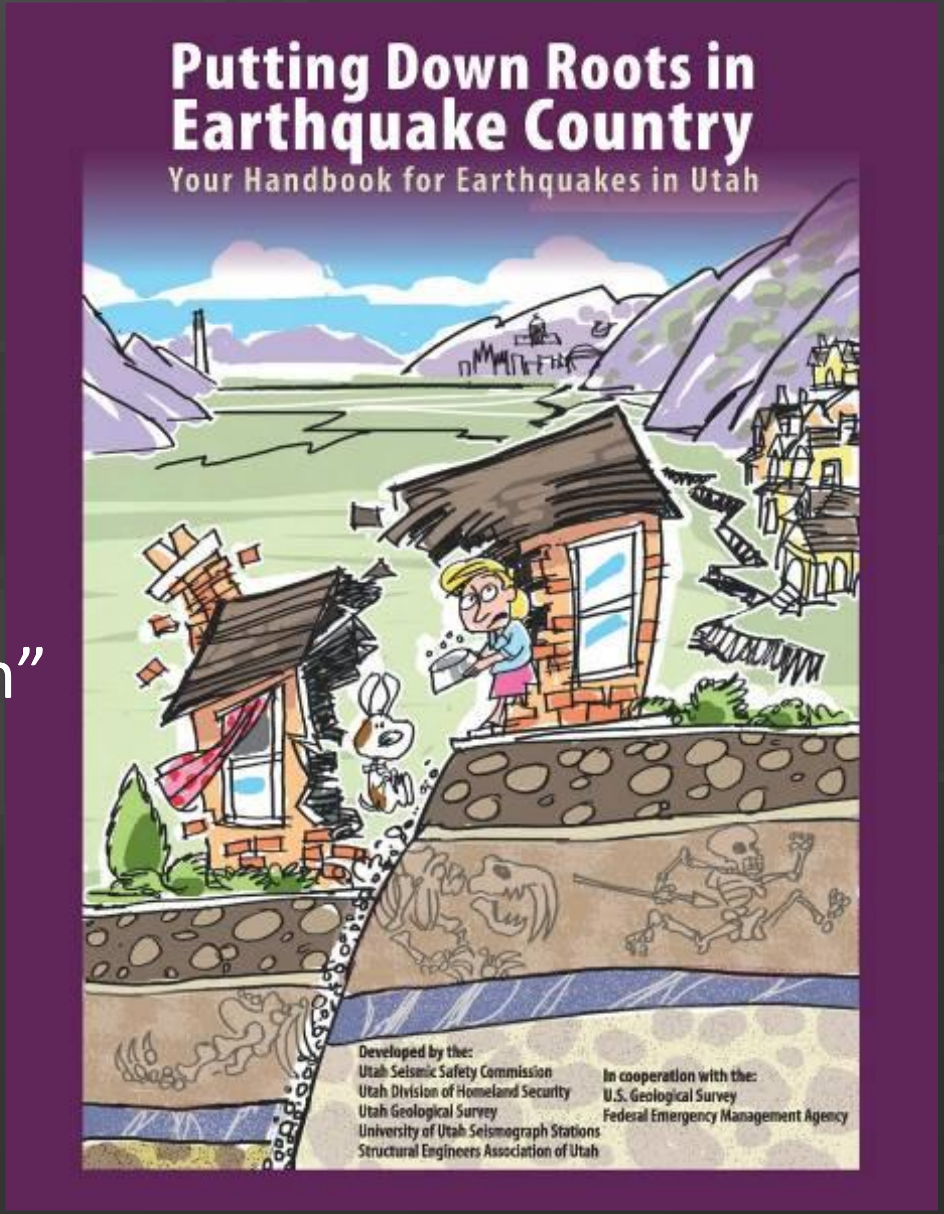


A PERSONAL PLEA

- <u>GET PERSONALLY PREPARED</u>

"Putting Down Roots
in Earthquake Country,
Your Handbook
for Earthquakes in Utah"

Prepared by
the Utah Seismic
Safety Commission



https://ussc.utah.gov/pages/view.php?ref=1&search=%21unused&order_by=relevance&sort=DESC&offset=0&archive=0&k=&curpos=0&restypes=