Understanding ADRS Curves

- SCDOT has used 2 different ways to develop ADRS curves
  - 3-Point Method (used in GDM 1.0 and 1.1)
  - Andrus 3-Point Method (used in 2019 GDM)

Old 3-Point Method

- ADRS curves based on Site Class
  - Site Classes developed based on California type soils
  - For AASHTO Site Class is based on
    - $\overline{V}_s$
    - $\overline{N}$
    - $\overline{S}_u$
  - For SCDOT Site Class is based on $\overline{V}_s$ only
  - Based on top 100 feet of soil column

- Amplification Factors F_{PGA}, F_a and F_v based on
  - Site Class
  - Accelerations determined at the B-C Boundary
    - PGA
    - S_s ($S_{0.2}$)
    - S_1
  - Amplification factors
    - For Site Class B are 1.0
    - For Site Classes C, D and E are greater than 1 (i.e., amplification)

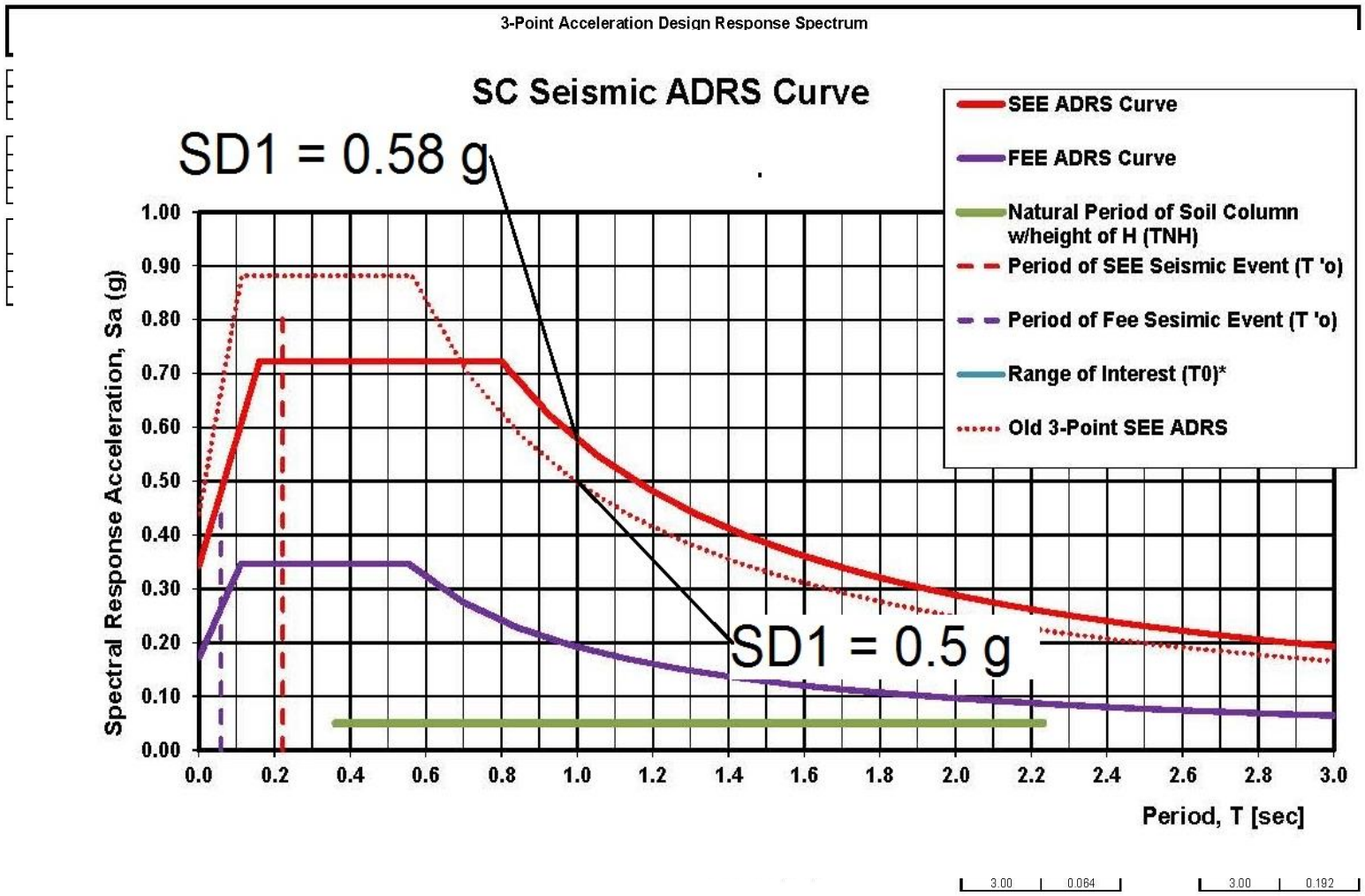
Things to Note

Andrus 3-Point Method

- Andrus Method was developed specifically for SC
  - No Site Class
  - The amplification factors (F_{PGA}, F_a, F_v) are based on V_s measured on-site
  - $PSA_{B\text{-}C,t}$ = Pseudo-acceleration at the B-C Boundary outcrop at a specific spectral period, from SCENARIO_PC (2006)
  - ADRS developed at the ground surface.

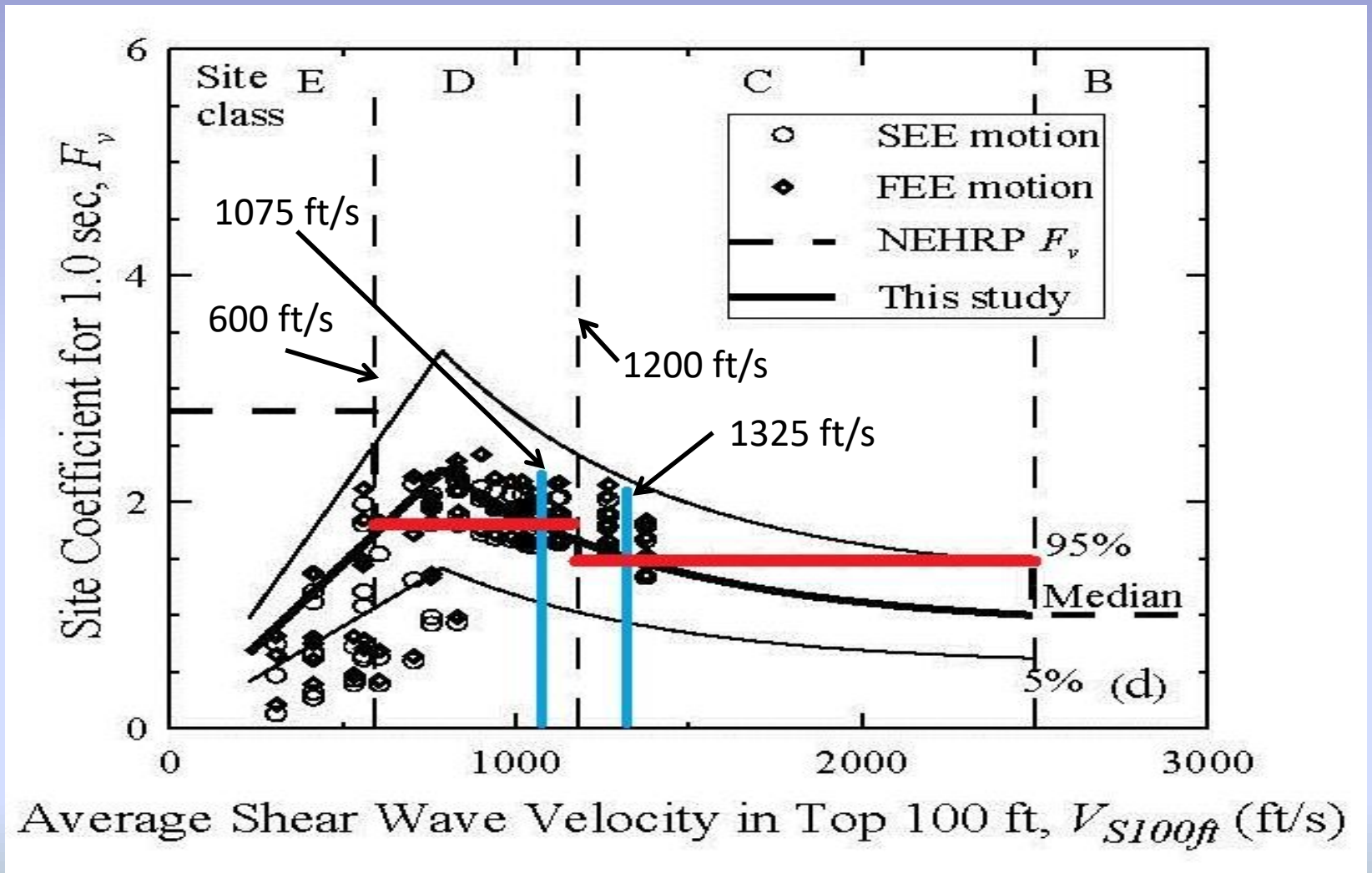
Spectral Period Ranges and Designations

Spectral Period Range, t (sec)	Spectral Period Designation, t (sec)	Corresponding Pseudo-Acceleration, $PSA_{B\text{-}C,t}$ (g)	F_t Factor Designation
≤ 0.01	0.0	$PGA_{B\text{-}C}$	F_{PGA}
0.01 – 0.40	0.2	S_s	$F_{0.2}$ (F_a)
0.41 – 0.80	0.6	$S_{0.6}$	$F_{0.6}$
0.81 – 1.20	1.0	$S_{1.0}$	$F_{1.0}$ (F_v)
1.21 – 2.00	1.6	$S_{1.6}$	$F_{1.6}$
2.01 – 4.00	3.0	$S_{3.0}$	$F_{3.0}$



*The SEOR is encouraged to check the fundamental period of the structure versus the period of the seismic event and the period of the site. According to LRFD Seismic Analysis and Design of Transportation Geotechnical Features and Structural Foundations, FHWA-NHI-11-032, GEC No. 3 "So, the damage potential of an earthquake ground motion increases when the predominant period of the earthquake motion is close to the resonant period of the site and when the resonant period of the site is close to the fundamental period of the structure. The damage potential of an earthquake ground motion is greatest when all three of the predominat or fundamental periods coincide."

F_v for 1.0 sec spectral period with S_1 equal to 0.3 g for Lake Marion



3-Point Acceleration Design Response Spectrum

SCDOT v3.0 - 05/30/2018

Project ID:	37465	Latitude:	33.4706
Route:	S-50	County: 38 - Orangeburg	Longitude: 80.7464
Project:	Replace Four Holes Road over I-26		

Designer:	N. Harman - Support
Date:	5/17/2018

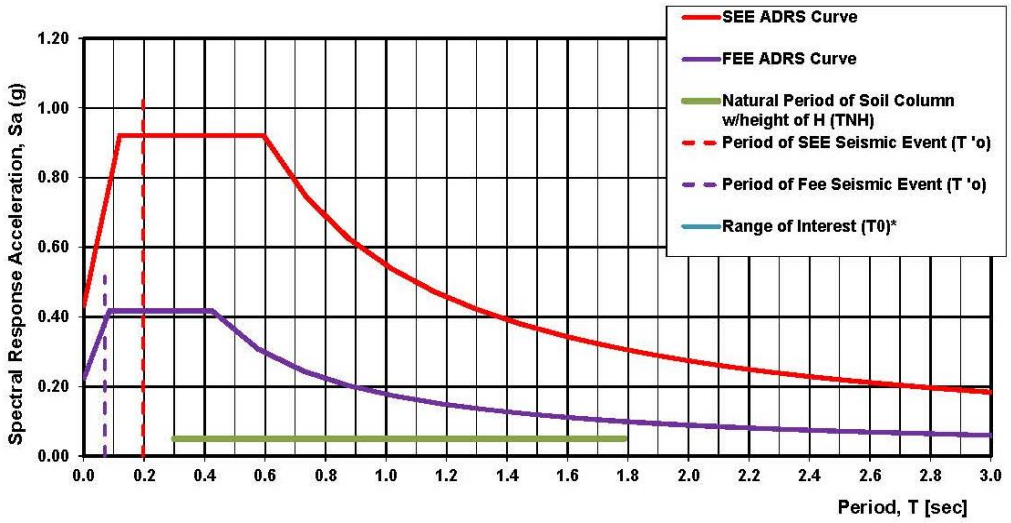
Design EQ	PGA	S_{DS}	S_{D1}	M_W	R	PGV	$D_{a5\text{-}95}$	T'_o
	g	g	g	-	km	ft/sec	sec	sec
FEE	0.22	0.42	0.18	7.30	74.57	6.72	31.82	0.07
SEE	0.43	0.92	0.55	7.30	67.93	20.80	29.26	0.20

Damping:	5%
Geologic Condition:	Geologically Realistic (Q = 100)
	SCCP
ADRS Loction within Soil Column:	At Ground Surface

South Carolina Coastal Plain

Fundamental Period of Structure, T_0^*	Range of Interest*		$V^*_{s,H}$	H	T_{NH}	
	sec				sec	
sec	0.5^*T_0	2.0^*T_0	ft/sec	ft	$(4^*H)/V^*_{s,H}$	$(6^*H)/V^*_{s,H}$
0.00	0.00	0.00	1688.78	503.00	0.30	1.79
0.00	0.00	0.00	H = B-C Boundary			

SC Seismic ADRS Curve



	FEE Data			SEE Data	
	T	S_a		T	S_a
	0.00	0.223		0.00	0.433
	0.01	0.255		0.02	0.514
	0.03	0.287		0.04	0.595
	0.04	0.320		0.06	0.677
	0.06	0.352		0.08	0.758
	0.07	0.384		0.10	0.839
To	0.08	0.417	To	0.12	0.921
	0.11	0.417		0.16	0.921
	0.14	0.417		0.20	0.921
	0.17	0.417		0.24	0.921
	0.20	0.417		0.28	0.921
	0.23	0.417		0.32	0.921
	0.25	0.417		0.36	0.921
	0.28	0.417		0.40	0.921
	0.31	0.417		0.44	0.921
	0.34	0.417		0.48	0.921
	0.37	0.417		0.52	0.921
	0.40	0.417		0.55	0.921
Ts	0.42	0.417	Ts	0.59	0.921
	0.58	0.307		0.74	0.744
	0.73	0.243		0.88	0.624
	0.88	0.201		1.02	0.537
	1.03	0.172		1.16	0.472
	1.18	0.150		1.30	0.420
	1.33	0.133		1.44	0.379
	1.48	0.119		1.59	0.345
	1.64	0.108		1.73	0.317
	1.79	0.099		1.87	0.293
	1.94	0.091		2.01	0.272
	2.09	0.085		2.15	0.254
	2.24	0.079		2.29	0.239
	2.39	0.074		2.43	0.225
	2.55	0.069		2.58	0.213
	2.70	0.066		2.72	0.201
	2.85	0.062		2.86	0.191
	3.00	0.059		3.00	0.182

*The SEOR is encouraged to check the fundamental period of the structure versus the period of the seismic event and the period of the site. According to LRFD Seismic Analysis and Design of Transportation Geotechnical Features and Structural Foundations, FHWA-NHI-11-032, GEC No. 3 "So, the damage potential of an earthquake ground motion increases when the predominant period of the earthquake motion is close to the resonant period of the site and when the resonant period of the site is close to the fundamental period of the structure. The damage potential of an earthquake ground motion is greatest when all three of the predominat or fundamental periods coincide."

Terms to Know

- Period
- Frequency
- Natural Period
- Resonant Period
- Predominant Period
- Fundamental Period

Period/Frequency

- Period is the duration of time of one cycle in a repeating event and is measured in seconds
- Frequency is the reciprocal of period and is measured in Hertz (Hz) or cycles per second
- Period and frequency can and are used interchangeably

Natural/Resonant Period

- Natural – having a specified character by nature
- Resonant – capable of inducing resonance
  - Resonance – a large amplitude vibration caused by relatively small periodic stimulus
- Natural period and resonant period can and are used interchangeably

Predominant/Fundamental

- Predominant has 2 definitions
  - Having superior influence (prevailing)
  - Being most frequent or common
- Fundamental has multiple definitions
  - Of, relating to, or produced by the lowest component of a complex vibration
- Predominant and fundamental can and are used interchangeably

Site Period

- Determine the period of a site (T_{NH}) using:
  - $\boldsymbol{T_{N_{B-C}} = \frac{4 * H_{B-C}}{V^*_{s,H_{B-C}}}}$
- Where:
  - $V^*_{s,H}$ = Equivalent uniform soil profile stiffness of thickness (H), ft/sec
  - H = Thickness of soil deposit above B-C Boundary or Hard Rock basement outcrop depending on the level where ground motion input has been developed, feet

Site Period (cont.)

- Site softening is accounted for using:
  - $T_{N_{B-C}} = \frac{6 * H_{B-C}}{V^*_{s,H_{B-C}}}$
- 2 methods are used to determine T_{NH}
  - Simplified procedure
    - Uses the total layer thickness divided by the average V_s over the total layer thickness
  - Successive 2-Layer Approach
    - Combines 2 successive layers to create a “new layer” that is combined with next layer down
- $\therefore$ a range of T_{NH} is developed and used

Earthquake Period

- Determine the earthquake period (T'_o) using:

$$- \boldsymbol{T'_o} = \frac{\sum\left[t * ln\left(\frac{PSA_{B-C,t}}{PGA_{B-C}}\right)\right]}{\sum ln\left(\frac{PSA_{B-C,t}}{PGA_{B-C}}\right)}$$

- Where:
  - t = Specific spectral period, second
  - $PSA_{B\text{-}C,t}$ = Pseudo-acceleration at the B-C Boundary outcrop at a specific spectral period, from SCENARIO_PC (2006)
  - $PGA_{B\text{-}C}$ = Pseudo Peak Ground Acceleration at the B-C Boundary outcrop at a spectral period of 0.0 seconds, from SCENARIO_PC (2006)

Structure Period

- The fundamental period of the structure T (T_0 in GDM and T, T_F or T_m in AASHTO) is related to the ratio of the overall mass and stiffness of the structural system as shown:
  - $T = 2\pi * \sqrt{\frac{M}{K}} = 2\pi * \sqrt{\frac{W}{gK}}$
  - $M = \frac{W}{g}$
- This a simplified approach

Structure Period (cont.)

- Where:
  - M = Inertial mass of the structure
  - W = Weight of structure
  - g = Acceleration due to gravity
  - K = Overall stiffness (the structure and the foundation) of the system

Period Matching

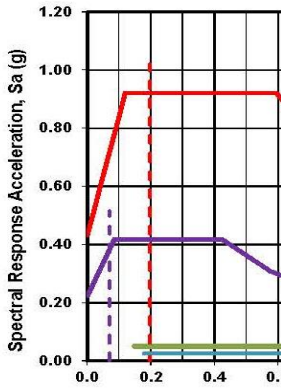
- According to GEC 3 (FHWA-NHI-11-032):
  - "The damage potential of strong ground motions with respect to a specific engineered facility is affected by the fundamental period of the base earthquake motion, the resonant period of any soil layer at the site, and the resonant period of the engineered facility. …The damage potential of an earthquake ground motion will be greatest when all three of the predominant or fundamental periods coincide."

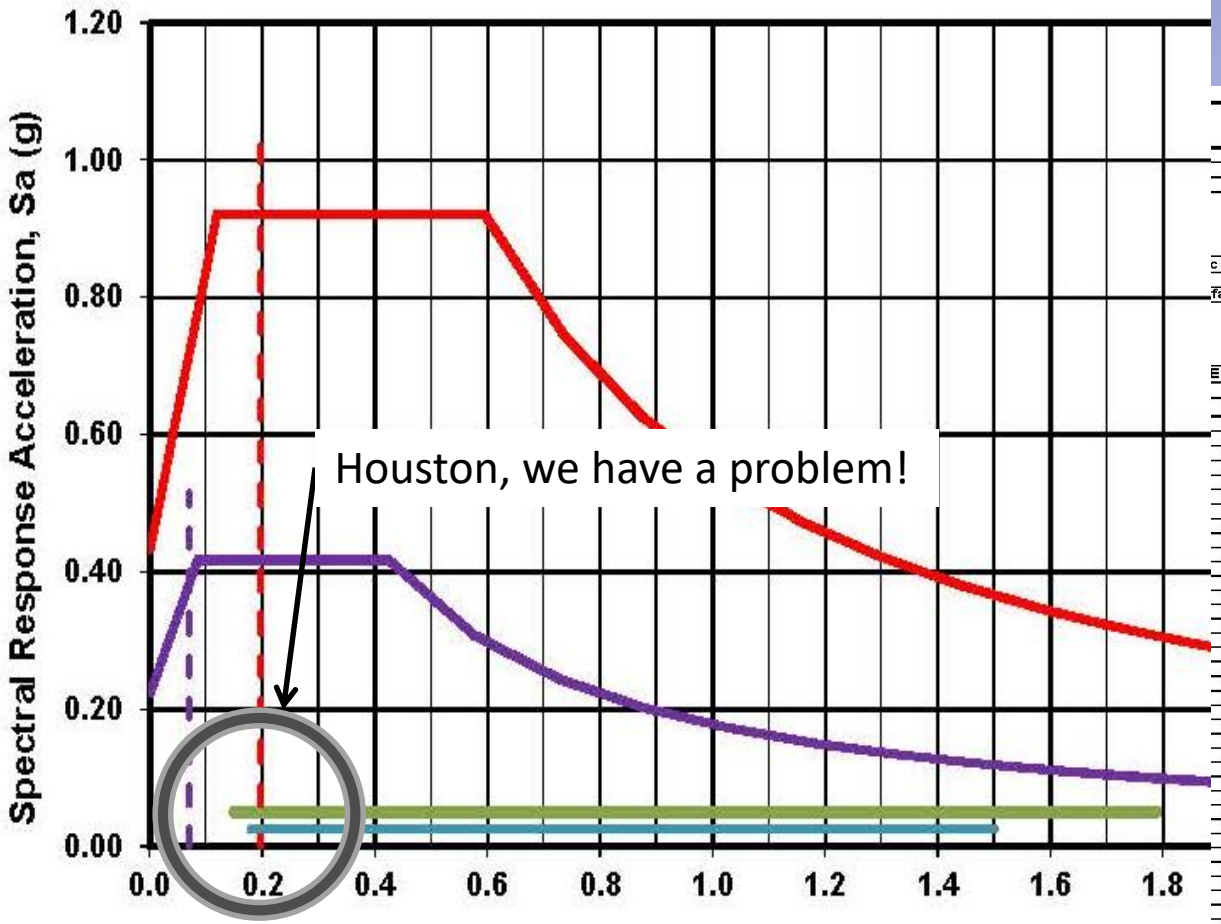
Full Period Matching

Project ID:	37465	
Route:	S-50	County
Project:		

Design EQ	PGA	S_{DS}
	g	g
FEE	0.22	0.42
SEE	0.43	0.92

Fundamental Period of Structure, T_0*	Range c
sec	$0.5*T_0$
0.36	0.18
0.75	0.38





c (Q = 100)
face

E Data

S_a
0.433
0.514
0.595
0.677
0.758
0.839
0.921
0.921
0.921
0.921
0.921
0.921
0.921
0.921
0.921
0.921
0.921
0.921
0.921
0.921
0.744
0.624
0.537
0.472
0.420
0.379
0.345
0.317
0.293
0.272
0.254
0.239
0.225
0.213
0.201
0.191
0.182

*The SEOR is encourage

Transportation Geotechnical Features and Structural Foundations, FHWA-NHI-11-032, GEC No. 3 "So, the damage potential of an earthquake ground motion increases when the predominant period of the earthquake motion is close to the resonant period of the site and when the resonant period of the site is close to the fundamental period of the structure. The damage potential of an earthquake ground motion is greatest when all three of the predominat or fundamental periods coincide."

What do we do!?

- Things to remember
  - The period of the earthquake cannot be changed
  - The period of the site cannot be changed
  - The acceleration of gravity cannot be changed, unless the bridge is relocated to the moon or Mars
- $\therefore$ the period of the structure must be changed!
- How is the period of the structure changed?
  - Change the weight, W
  - Change the stiffness, K

What do we do!? (cont.)

- Changing either W or K will require
  - Either redesign components of the bridge to improve stiffness or
  - Redesign components of the bridge to either reduce or increase the weight of the components
- Dynamic structural analysis to ascertain the effect of period matching

What do we do!? (cont.)

- There is another potential option
  - Use the bridge as designed
  - Accept the risk of potential collapse provided acceptance by:
    - RPE
    - DM
    - PM
    - SEOR

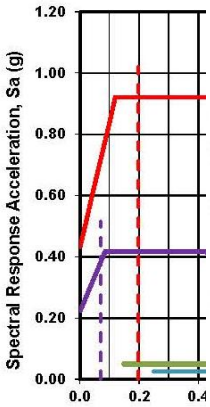
Project ID:	37465
Route:	S-50
Project:	

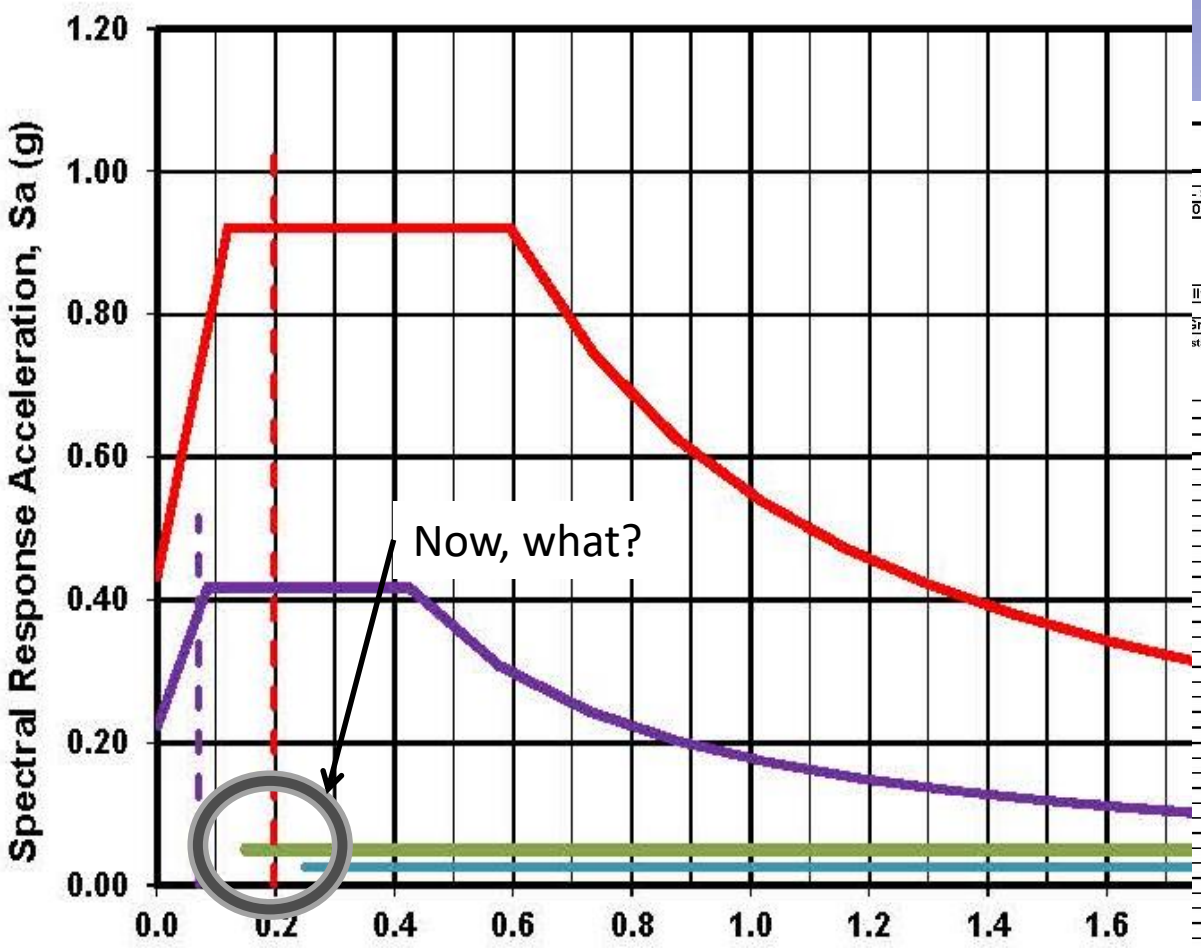
Design EQ	PGA
	g
FEE	0.22
SEE	0.43

Fundamental Period of Structure, T_0^*	
sec	0
0.50	
1.00	

- Support
018

lly Realistic (Q = 100)
SCCP
Ground Surface
stal Plain





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0.28	0.921
0.32	0.921
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Site & EQ Period Matching

- Consequences of Site (T_{NH}) and Earthquake (T'_o) period matching
  - Significant potential for amplification of earthquake motion
  - Increase in damage potential
- Per GDM (2019), Chapter 12 if
  - T_{NH} and T'_o intersect and Site-Specific Seismic Analysis should be considered

Questions?