Designing for Earthquakes in Anchorage: Site Response, Shear Wave Velocity, and Upcoming Changes in the Building Code

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Acknowledgements

- Coauthors
  - Utpal Dutta of University of Alaska Anchorage
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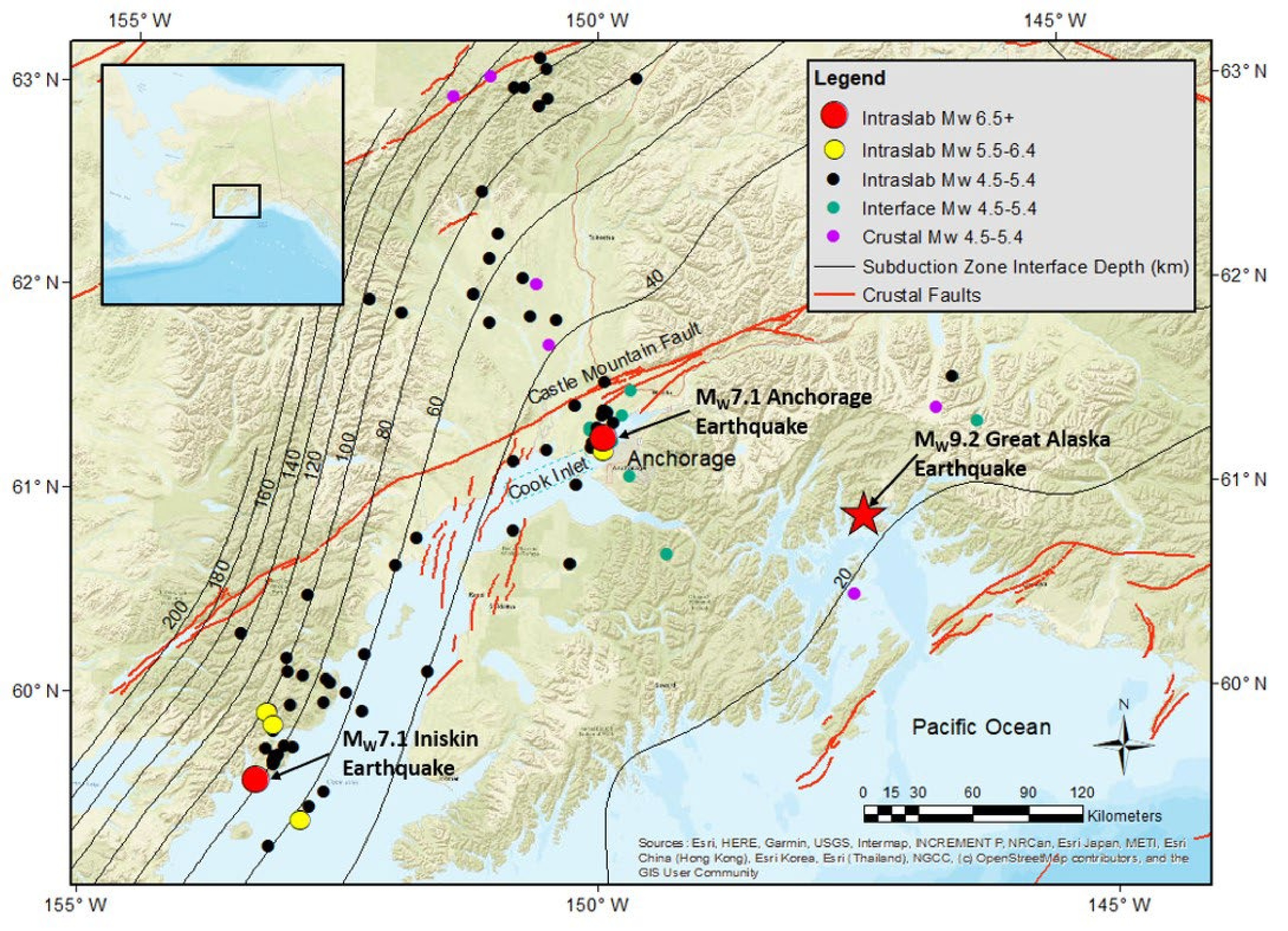
  - Joey Yang of University of Alaska Anchorage

Overview

- Anchorage Earthquake Shaking
- Response Spectra
- Site Response and Shear Wave Velocity
- Upcoming Changes to the Building Code
- Concluding Remarks

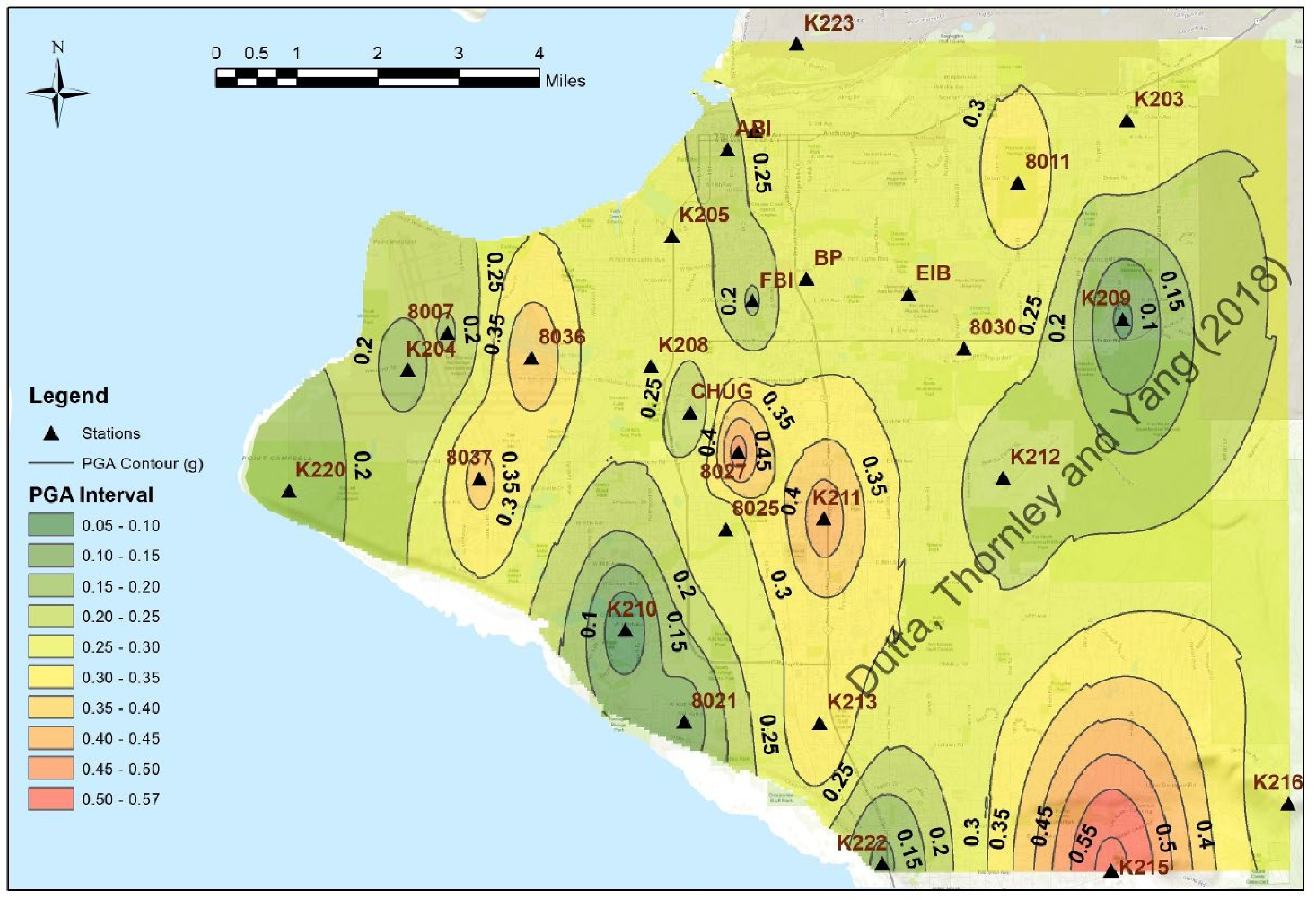
- And then a little something extra with my Geotechnical Advisory Commission hat on

Earthquakes in Southcentral Alaska



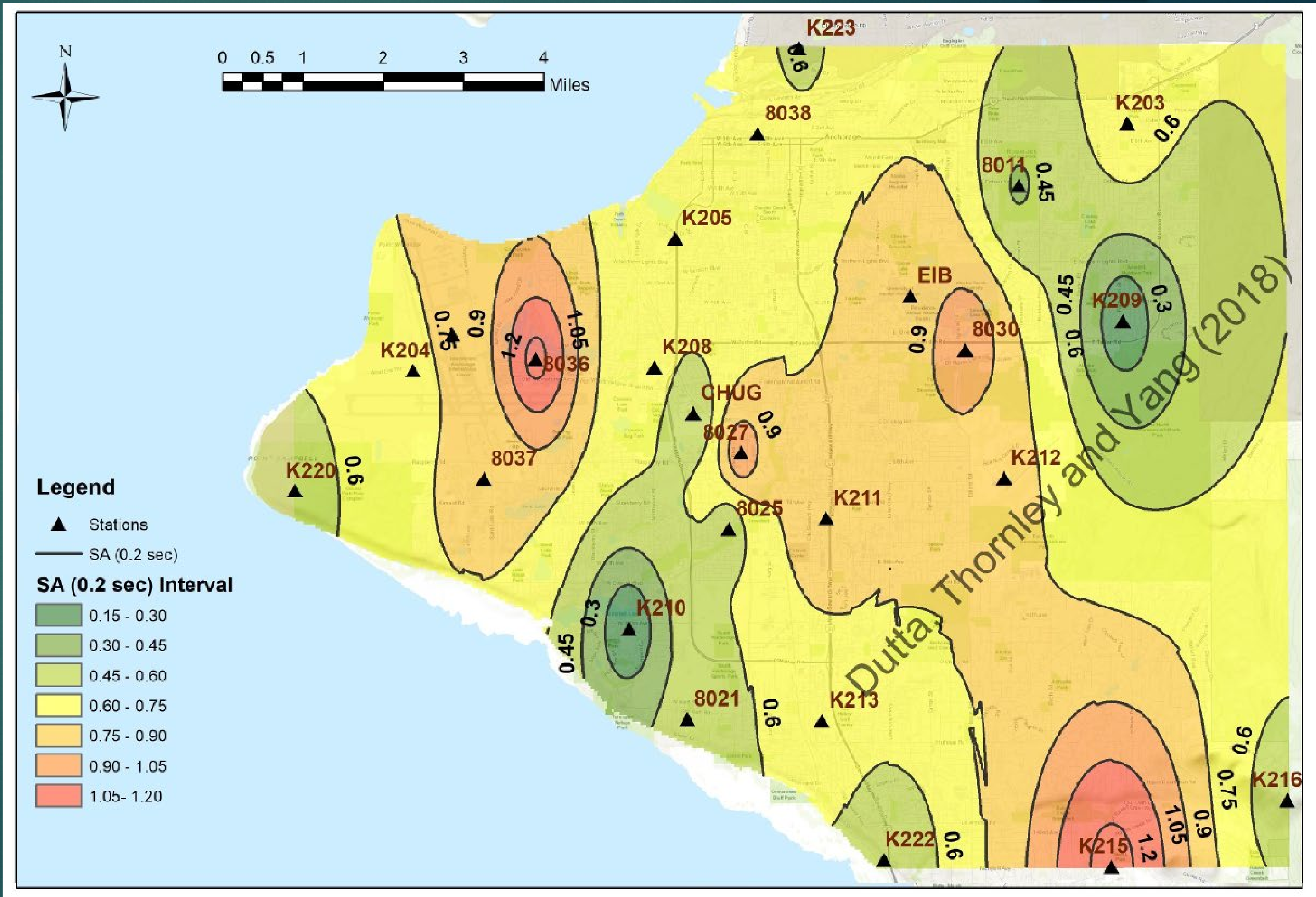
November 30, 2018 Anchorage Earthquake

- Peak ground accelerations (PGA)
- M_W7.1 Intraslab Earthquake
- 47+ km deep
- Largest event since 1964 for Anchorage
- Duration: 20 to 25 seconds
- Geotechnical, Structural, and Nonstructural Failures



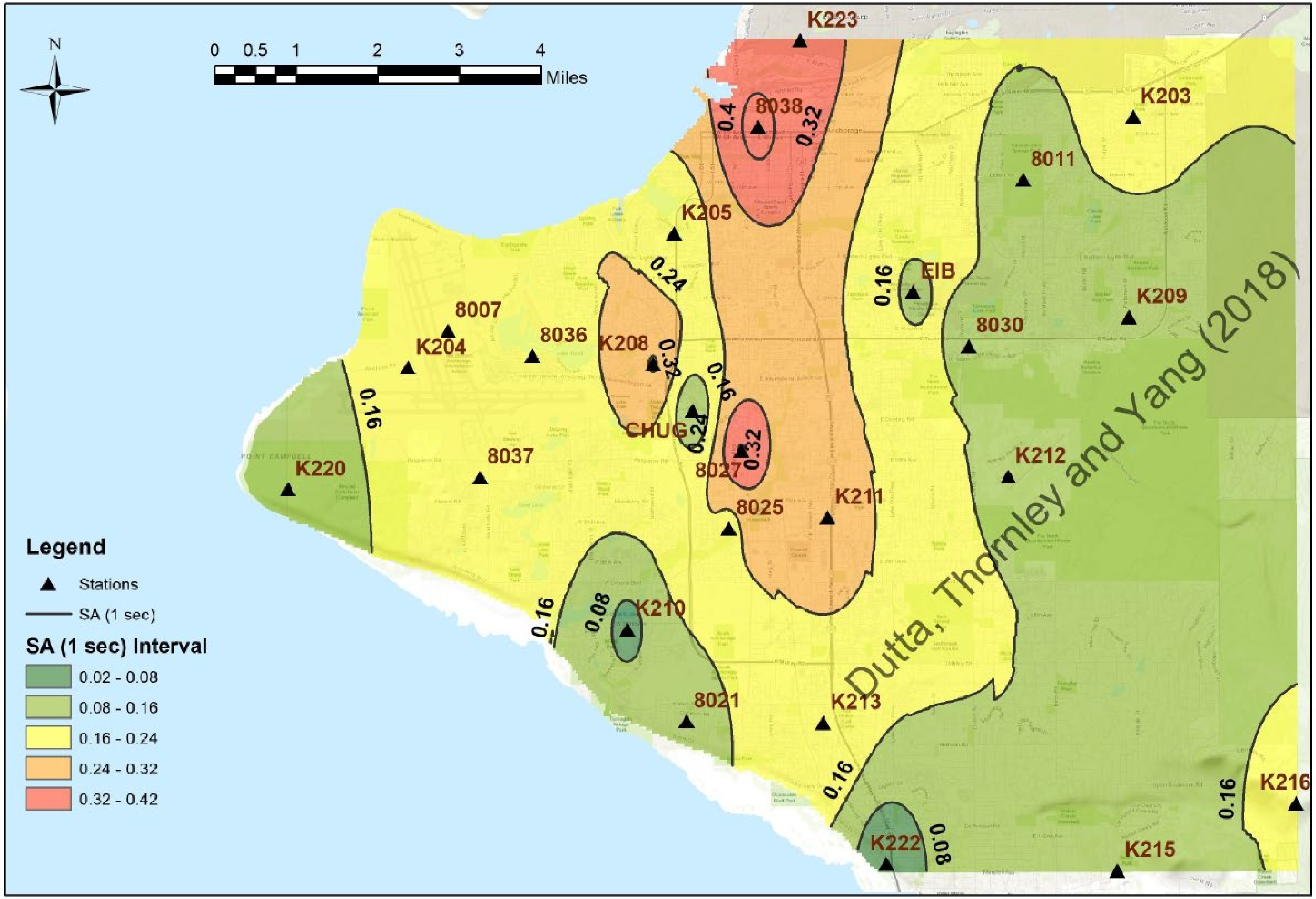
November 30, 2018 Anchorage Earthquake

- Spectral Accelerations at 0.2 seconds



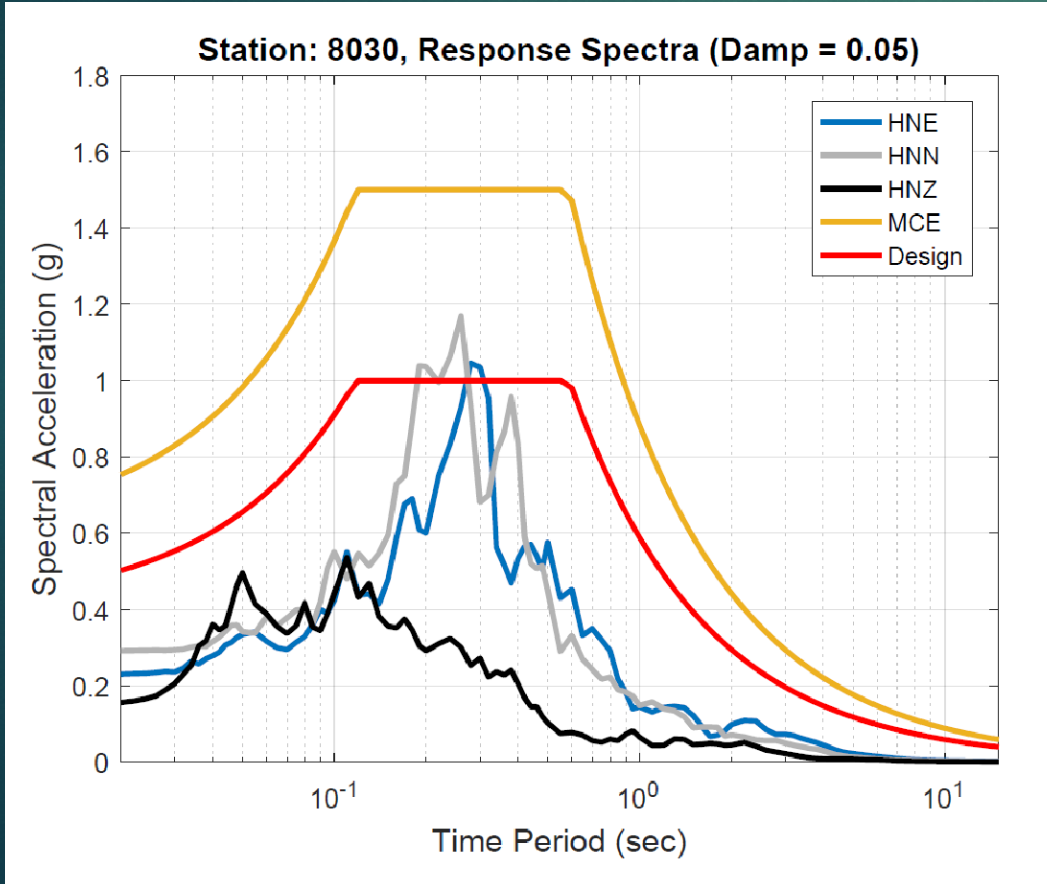
November 30, 2018 Anchorage Earthquake

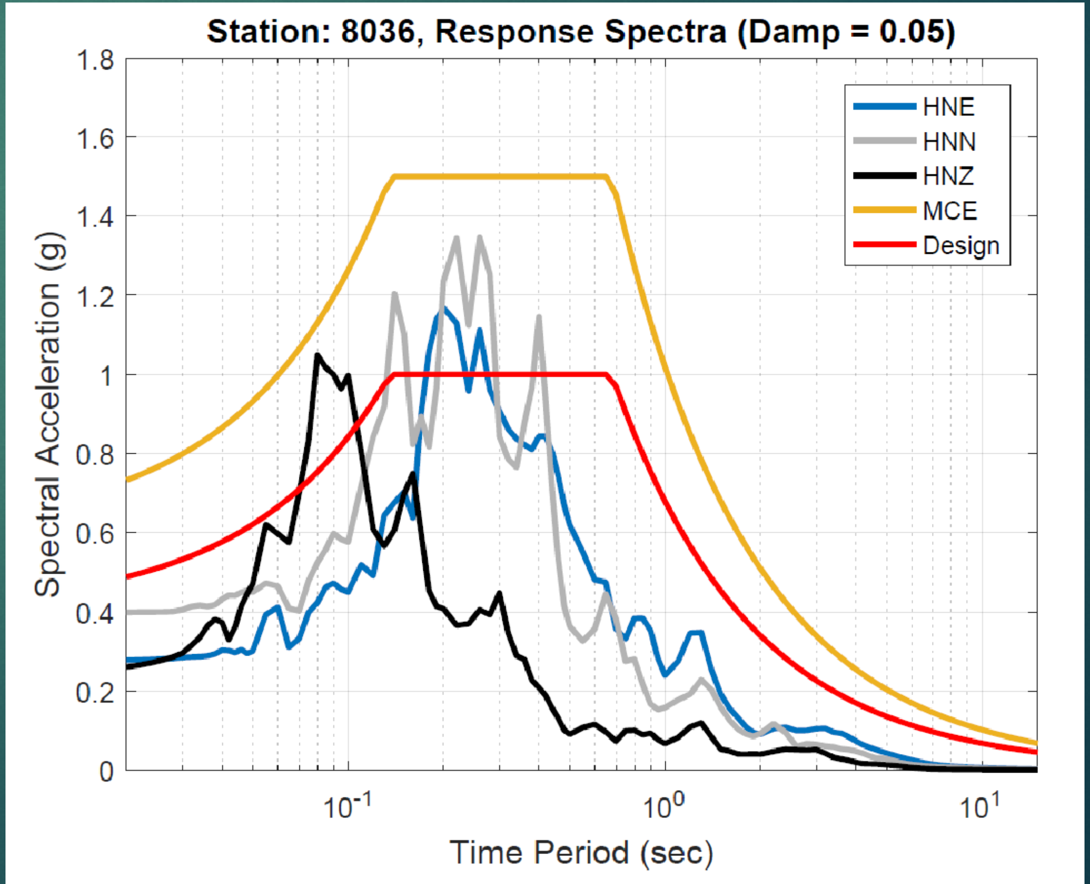
- Spectral accelerations at 1 second



Response Spectra from the 2018 Earthquake

- Station 8030 Tudor Police Station
- Station 8036 DOI Building – Lake Hood

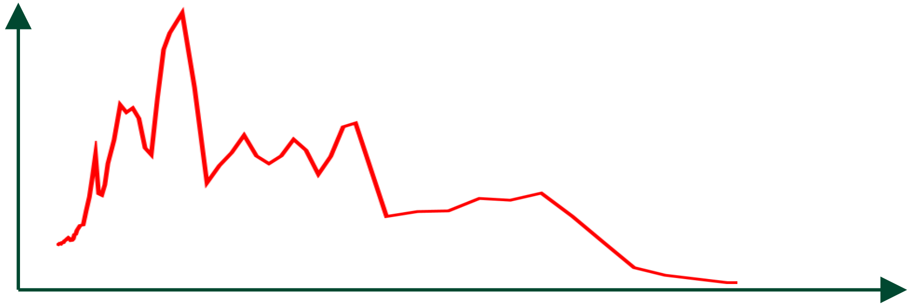




EQ Record: Time vs Period

Response Spectra

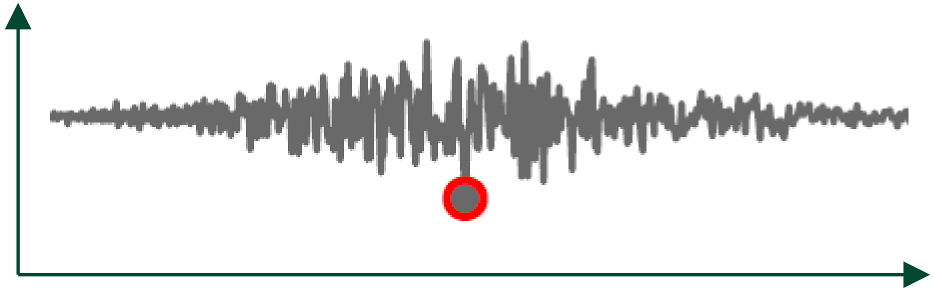
Acceleration (g)



Period (s)

Time History

Acceleration (g)

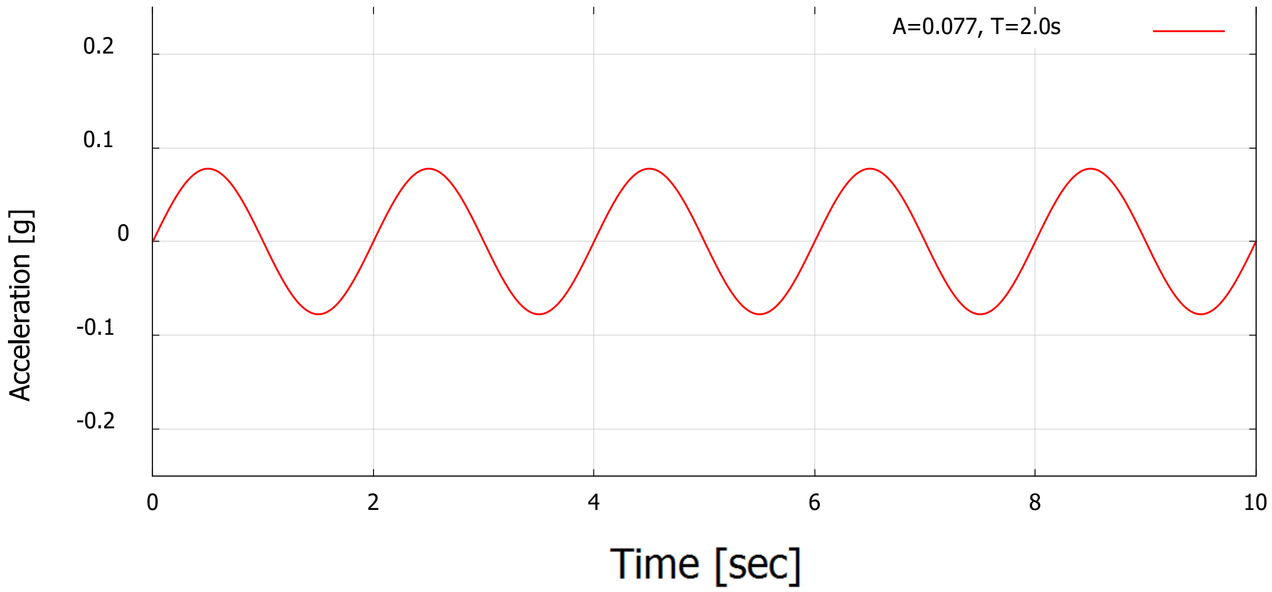


Time (s)

Slide from Scott Hamel, PhD, PE - UAA

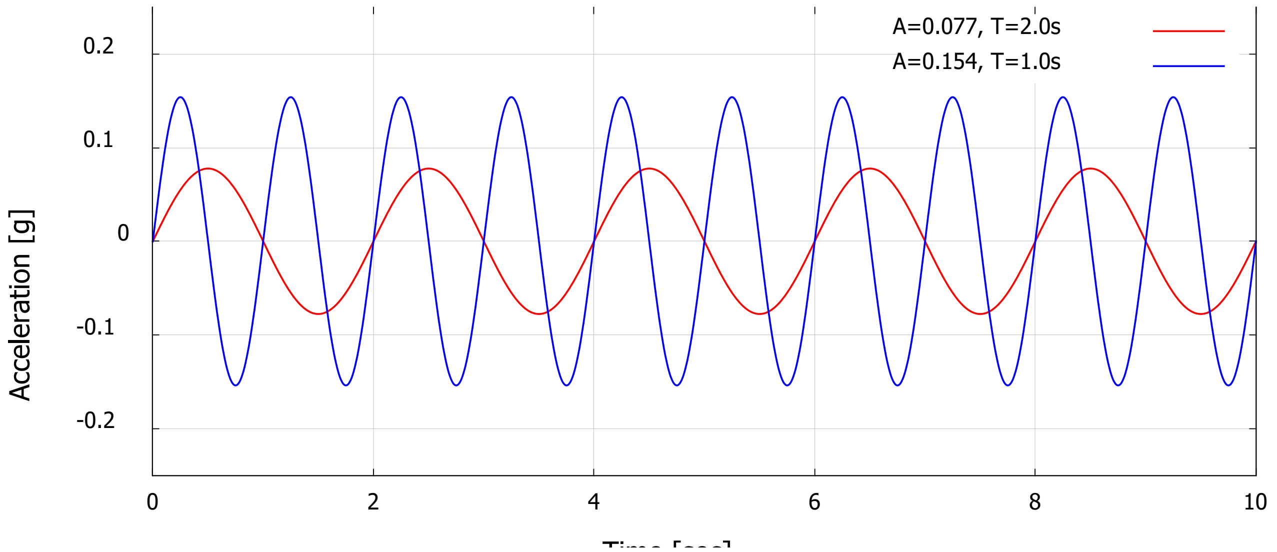
Time History of Sine

$f_{2sec}(t)$

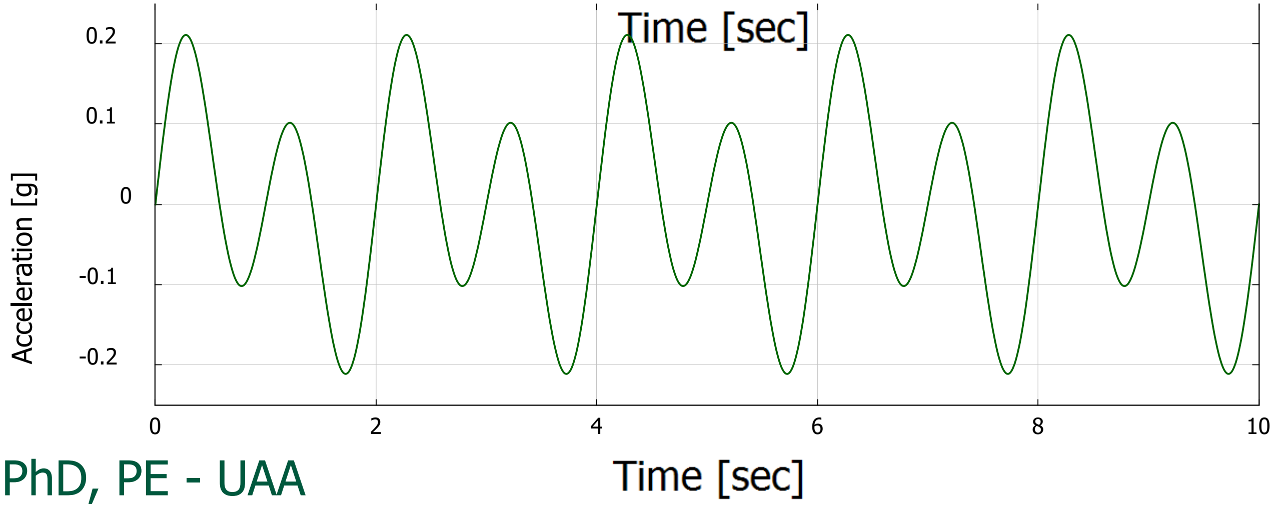


Time History of 2 Functions

$f_{2sec}(t)$,
$f_{1sec}(t)$



$f_{2sec}(t)$
+
$f_{1sec}(t)$

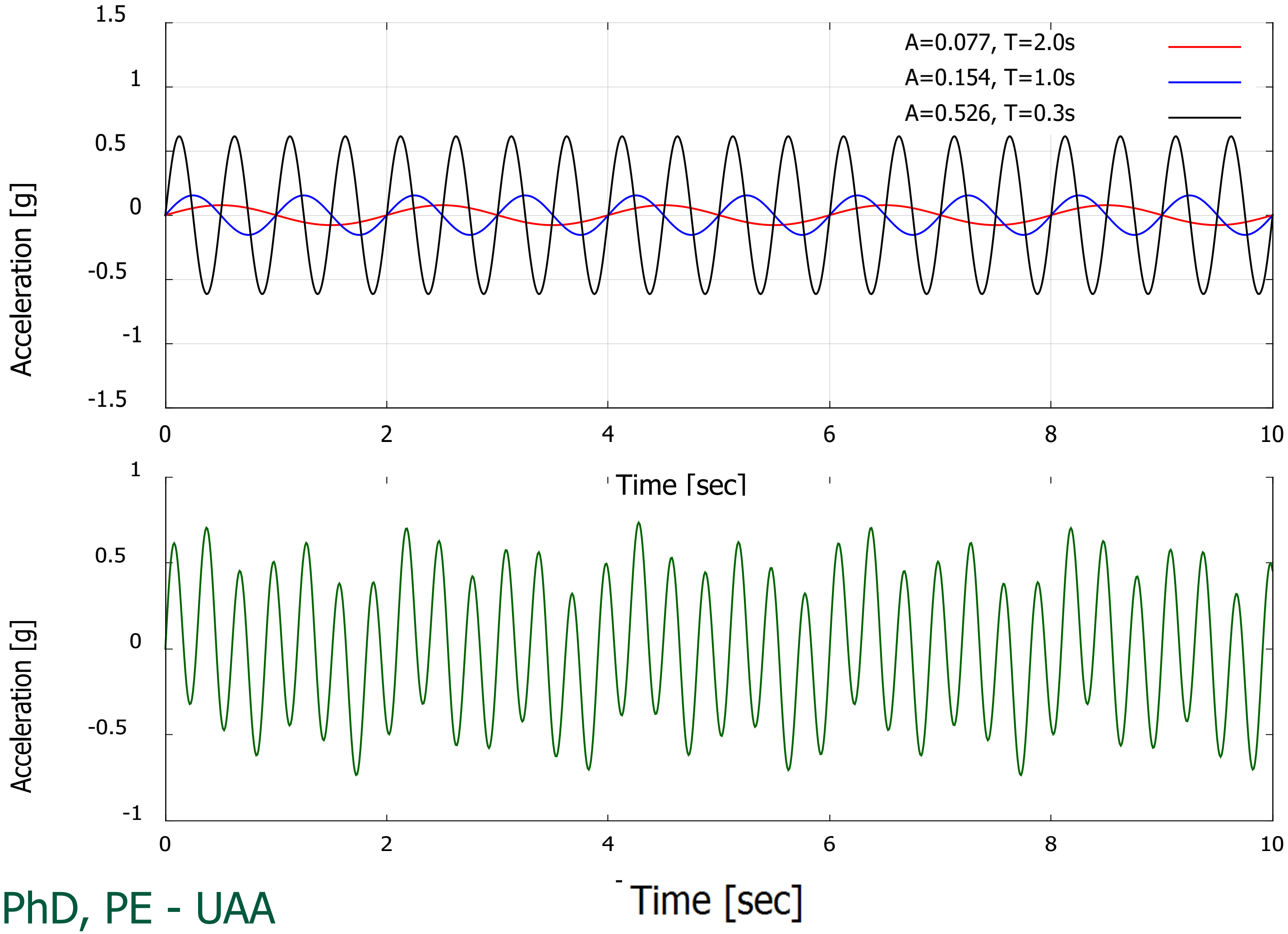


Slide from Scott Hamel, PhD, PE - UAA

Combining 3 Functions

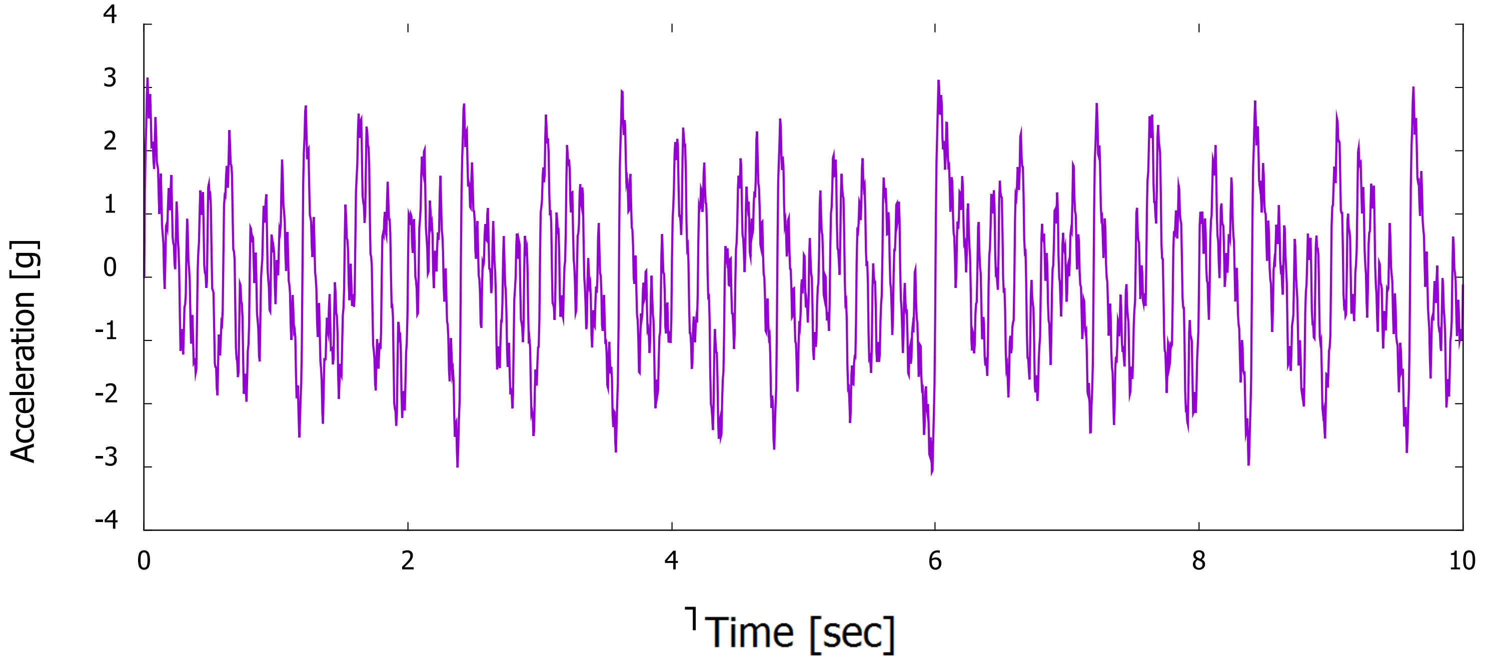
$f_{2sec}(t)$,
$f_{1sec}(t)$,
$f_{0.3sec}(t)$

$f_{2sec}(t)$
+
$f_{1sec}(t)$
+
$F_{0.3sec}(t)$



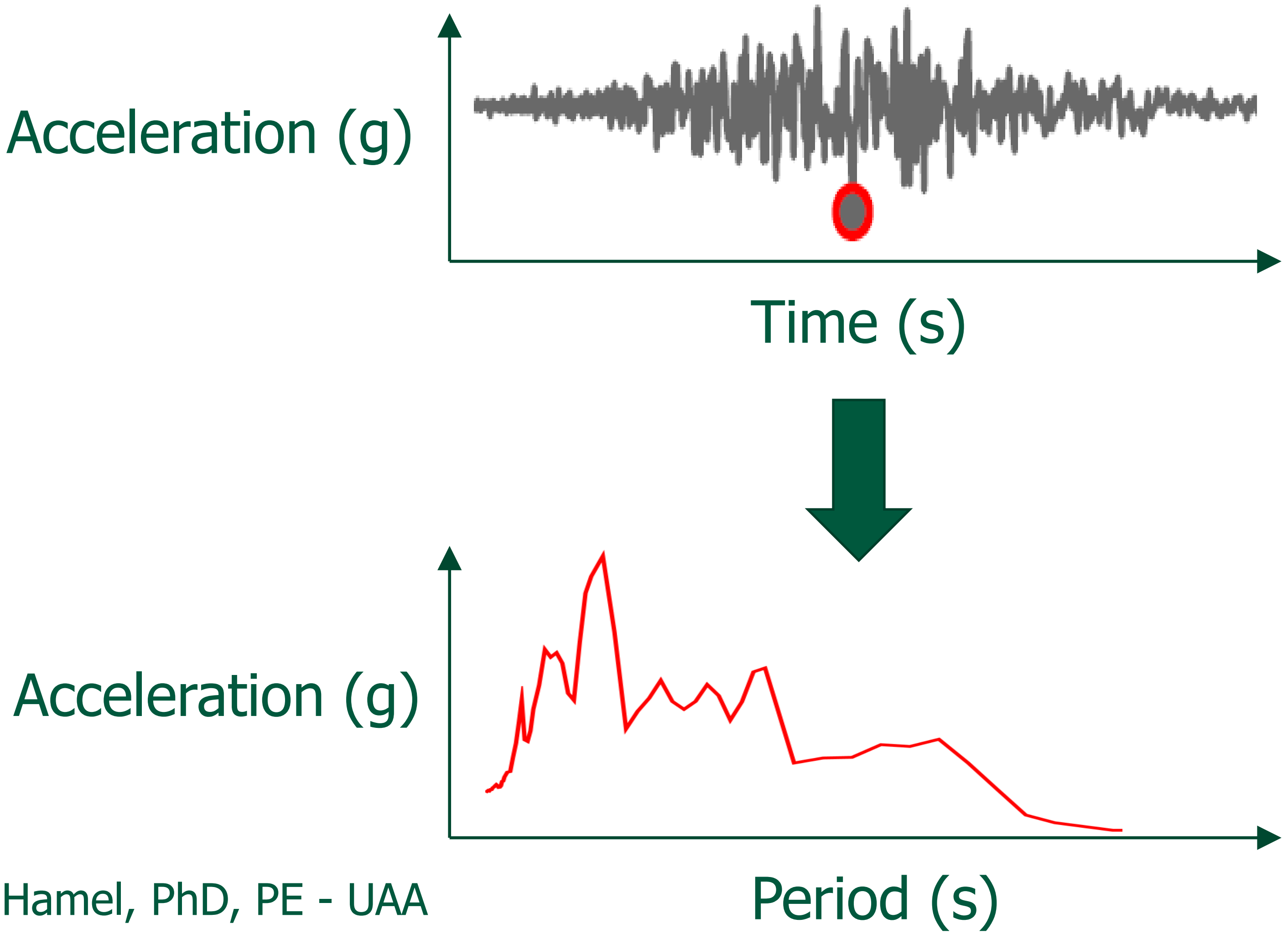
Slide from Scott Hamel, PhD, PE - UAA

14 Functions!



Period (sec)	Accel. (g)
0.02	0.247
0.04	0.259
0.06	0.307
0.08	0.520
0.10	0.493
0.15	0.630
0.20	0.889
0.30	0.526
0.40	0.566
0.50	0.616
0.75	0.381
1.00	0.154
1.50	0.125
2.00	0.078

Going the Other Way…



That Pesky Geotechnical Layer

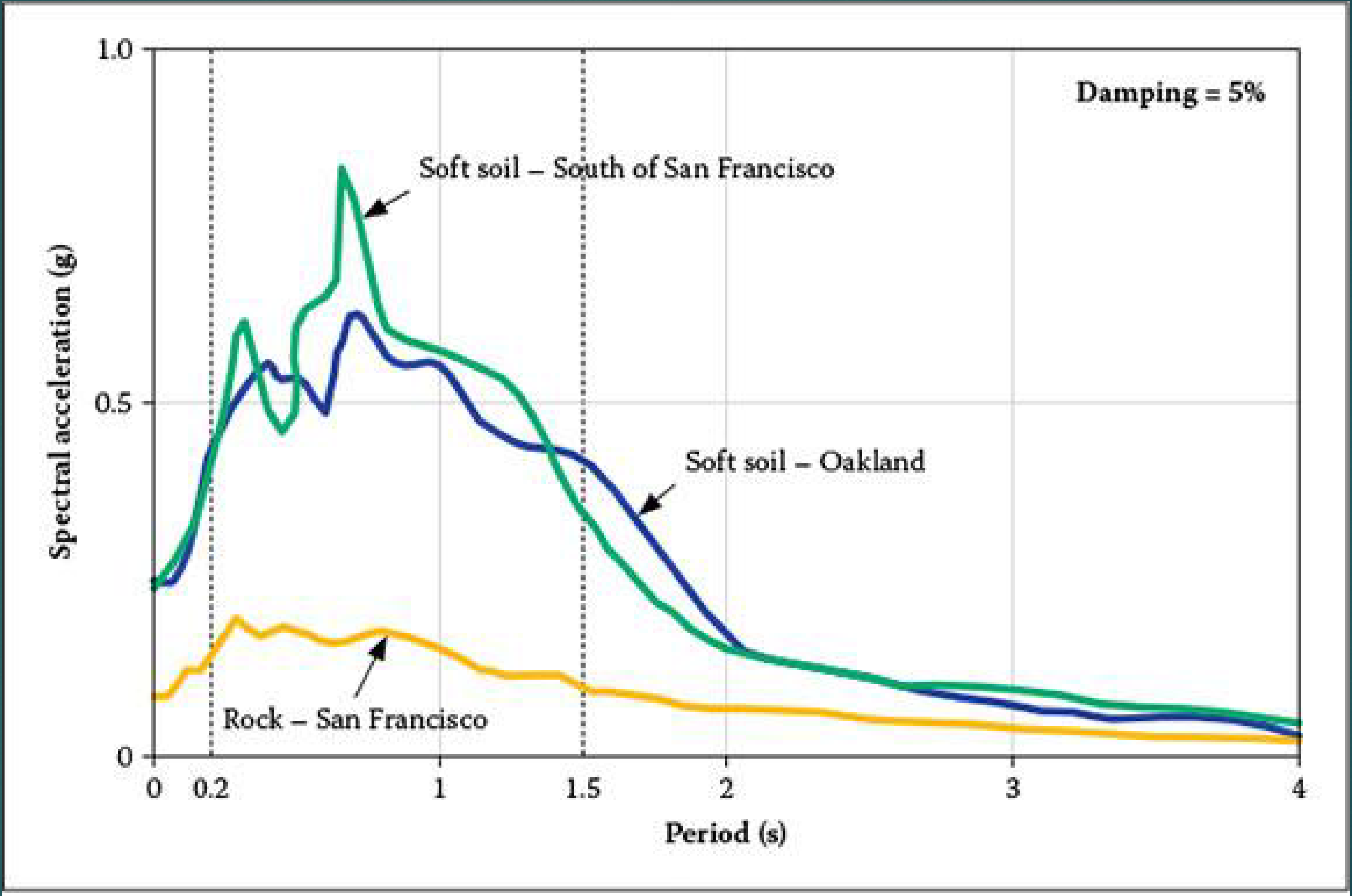
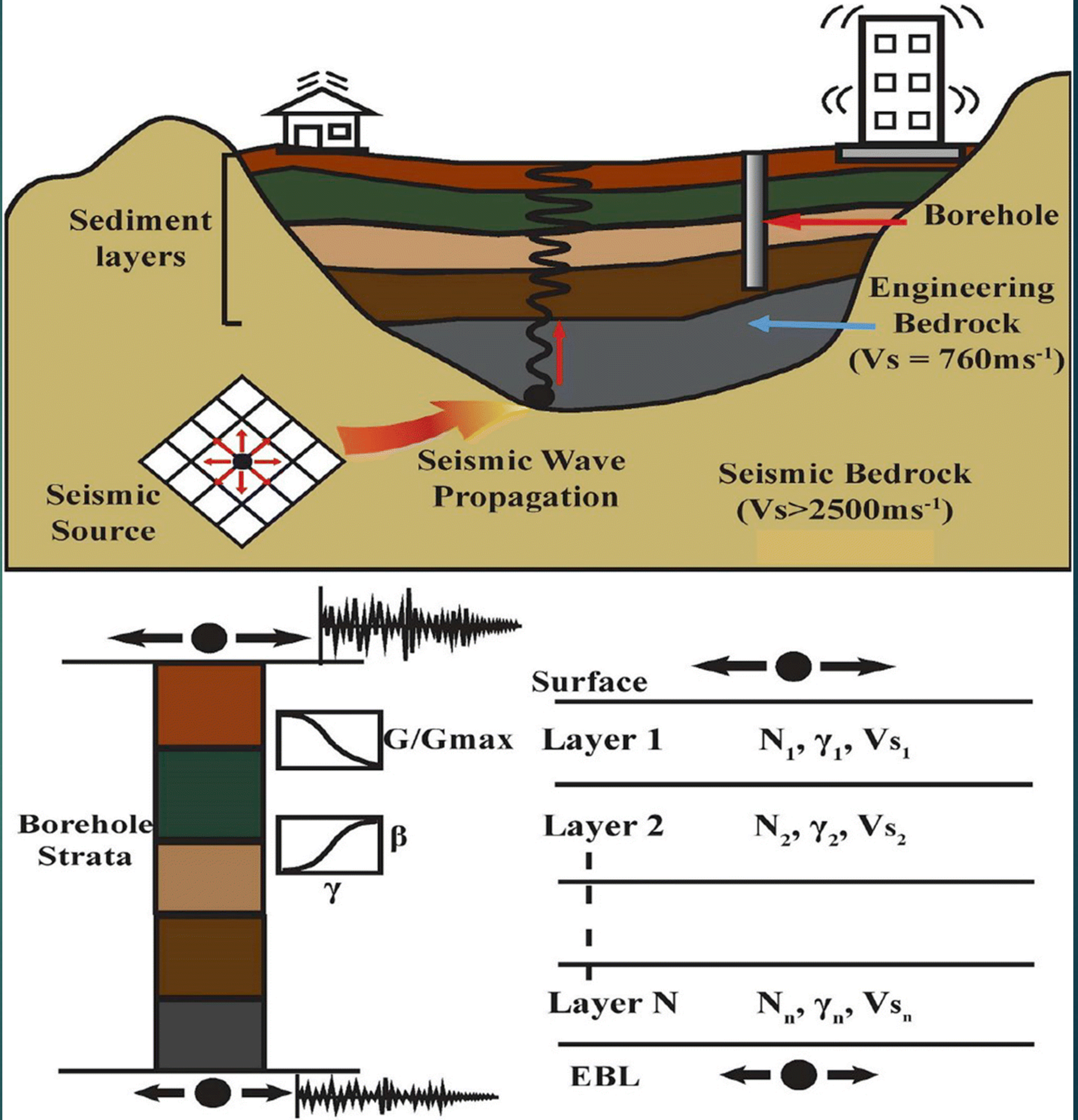


Figure 12 Average soil-site spectra in Oakland and San Francisco areas with average rock-site spectra in the region during the 1989 Loma-Prieta earthquake (Dobry *et al* 2000; Dobry & Susumu 2000)

Shear Waves

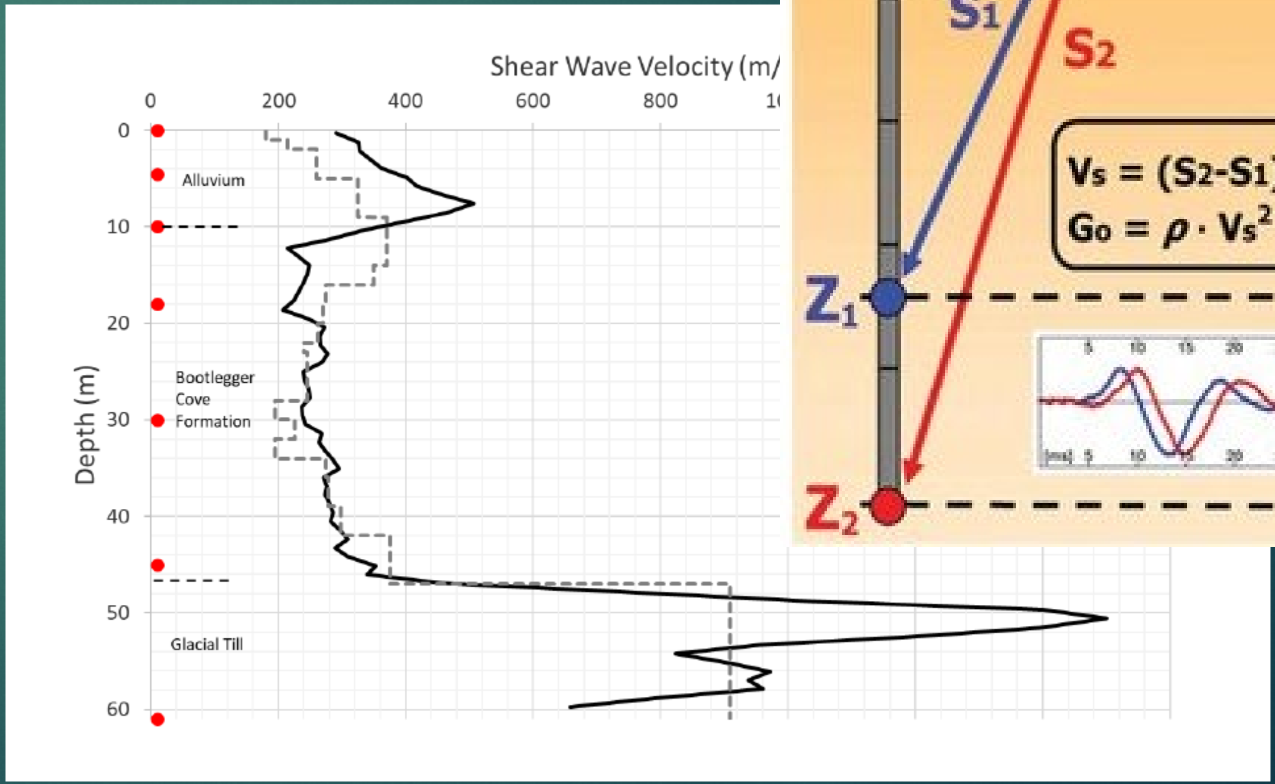
- Vertically propagating
- Imposes lateral loading on structures
- Shear wave velocity is a fundamental characteristic of a soil or rock mass

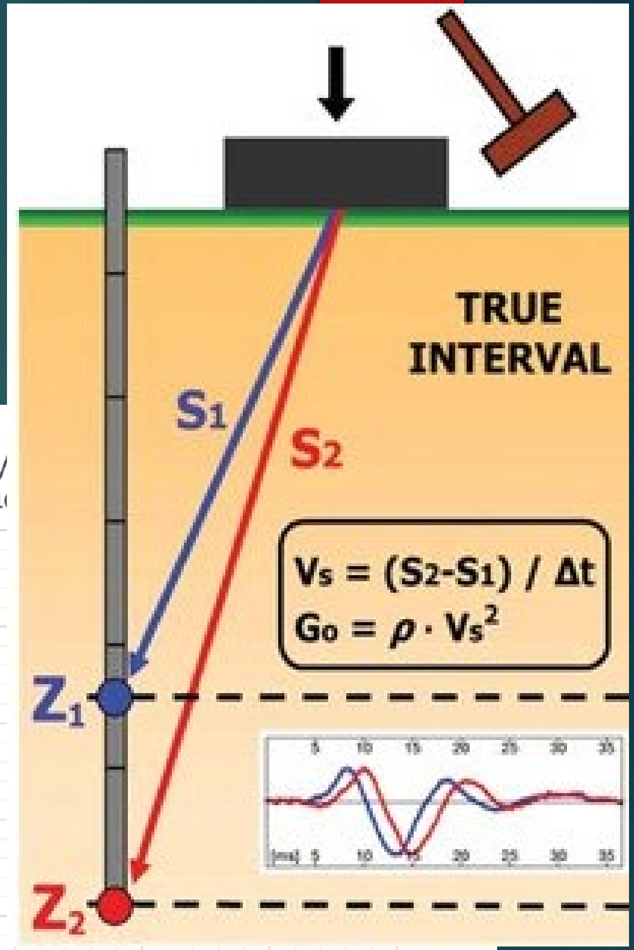


https://link.springer.com/article/10.1007/s40098-020-00417-3/figures/1

Measuring Shear Wave Velocity

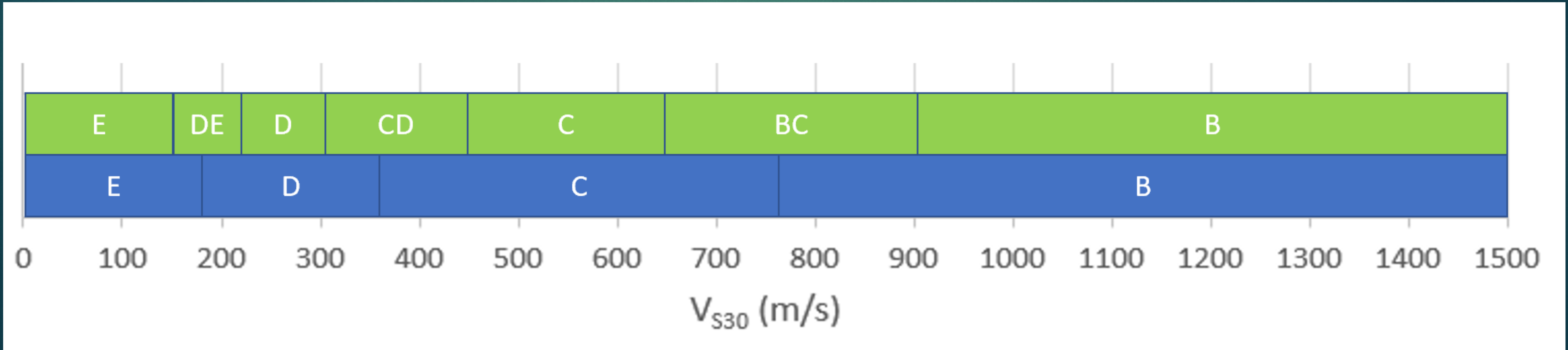
- In-Situ
  - Downhole
    - Cased hole
    - Suspension logging
    - Cone Penetration Testing
    - Cross-hole
- Surface
  - MASW, SASW
  - Seismic reflection/refraction



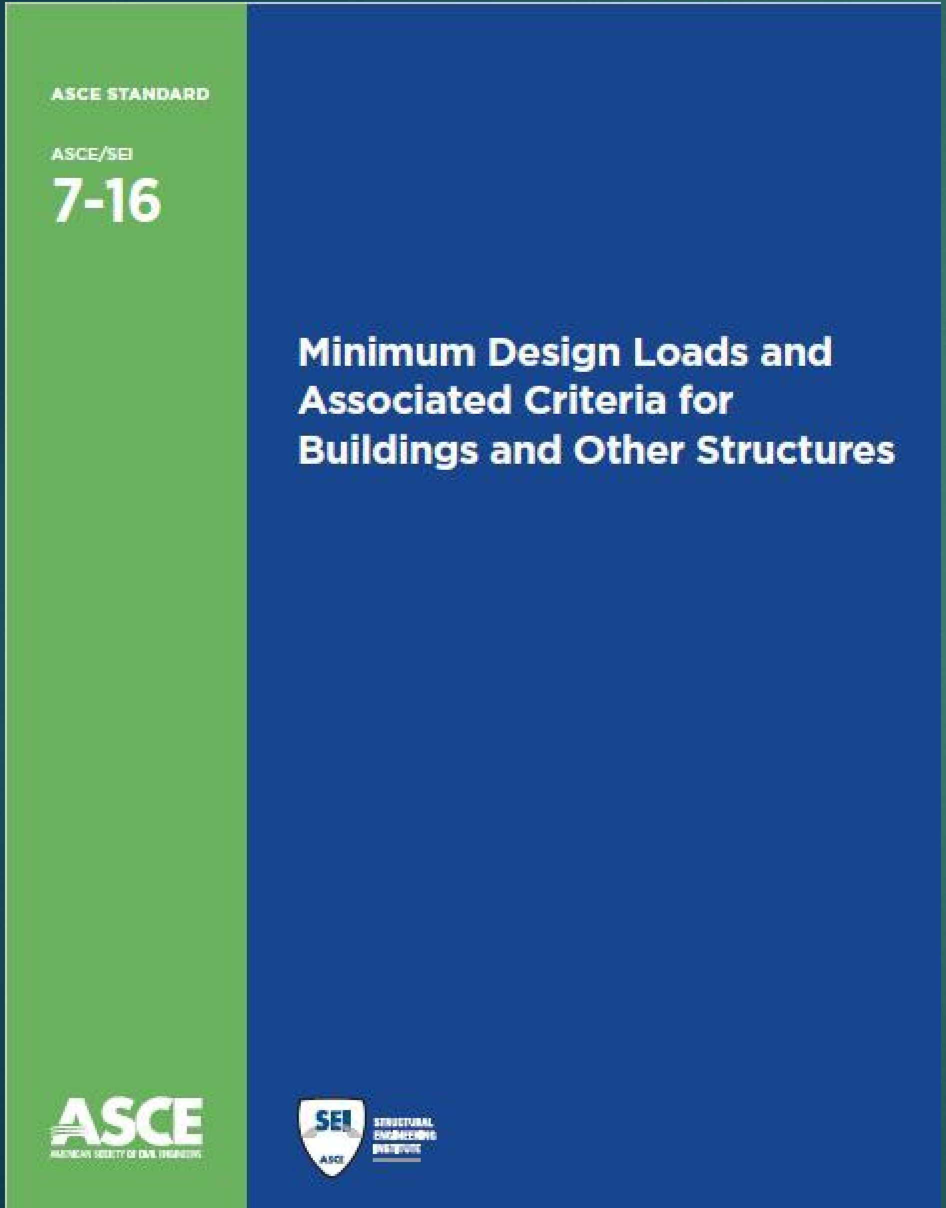


V_{S30} Current and Future

- Seismic Site Classes divided by ranges of shear wave velocity
- Rock and stiffer soils behave differently than softer soil sites
- Blue Band is current ASCE/IBC designations
- ASCE 7-22/2024 IBC is going to have the green band



A Dive into the Building Code - Present



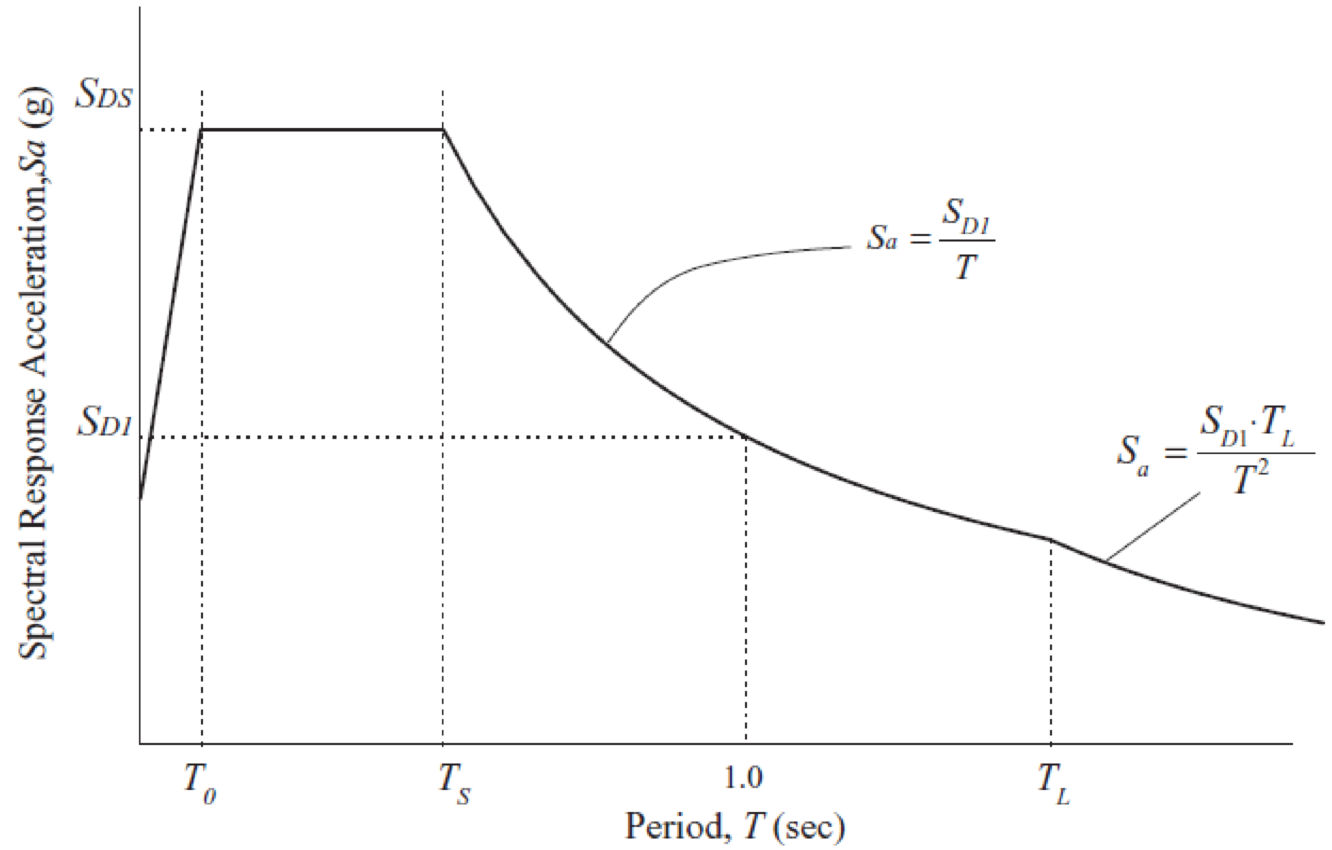
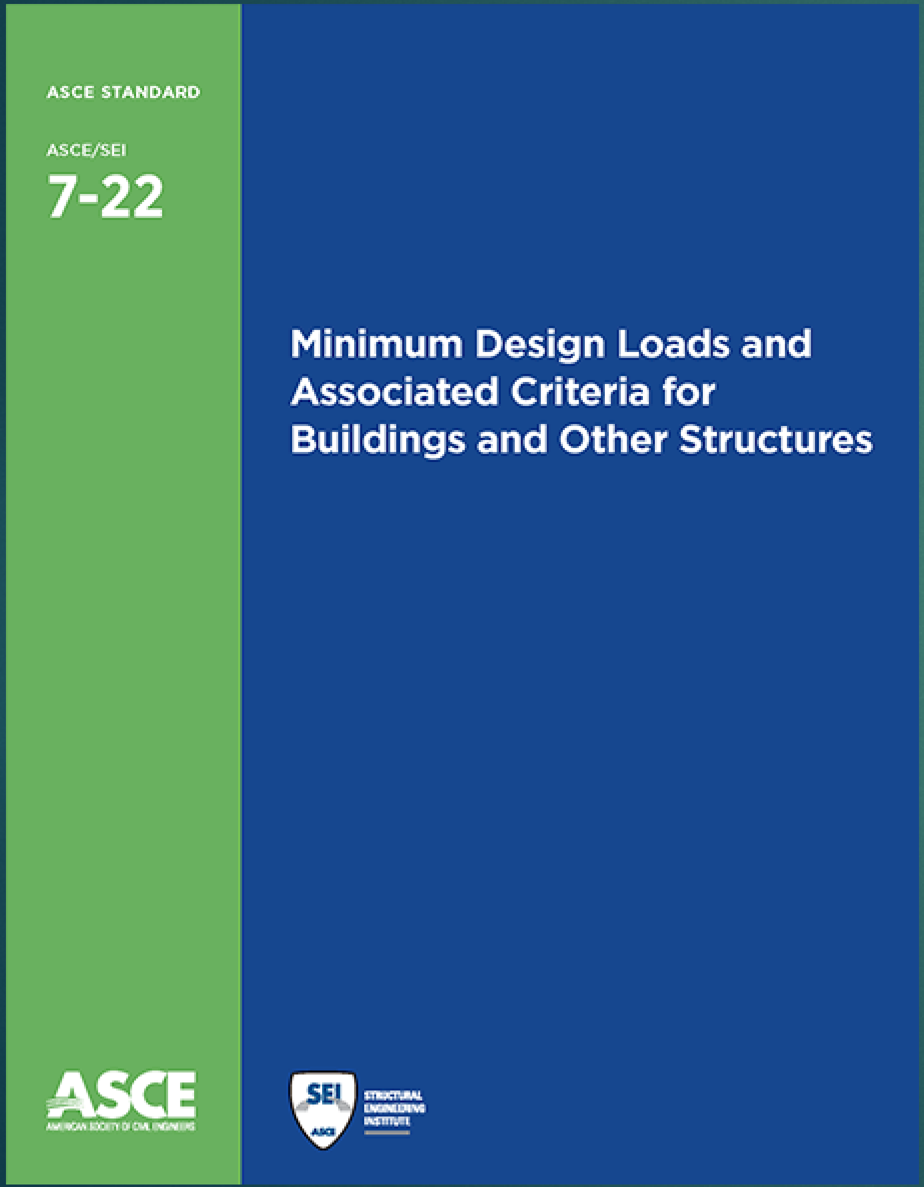
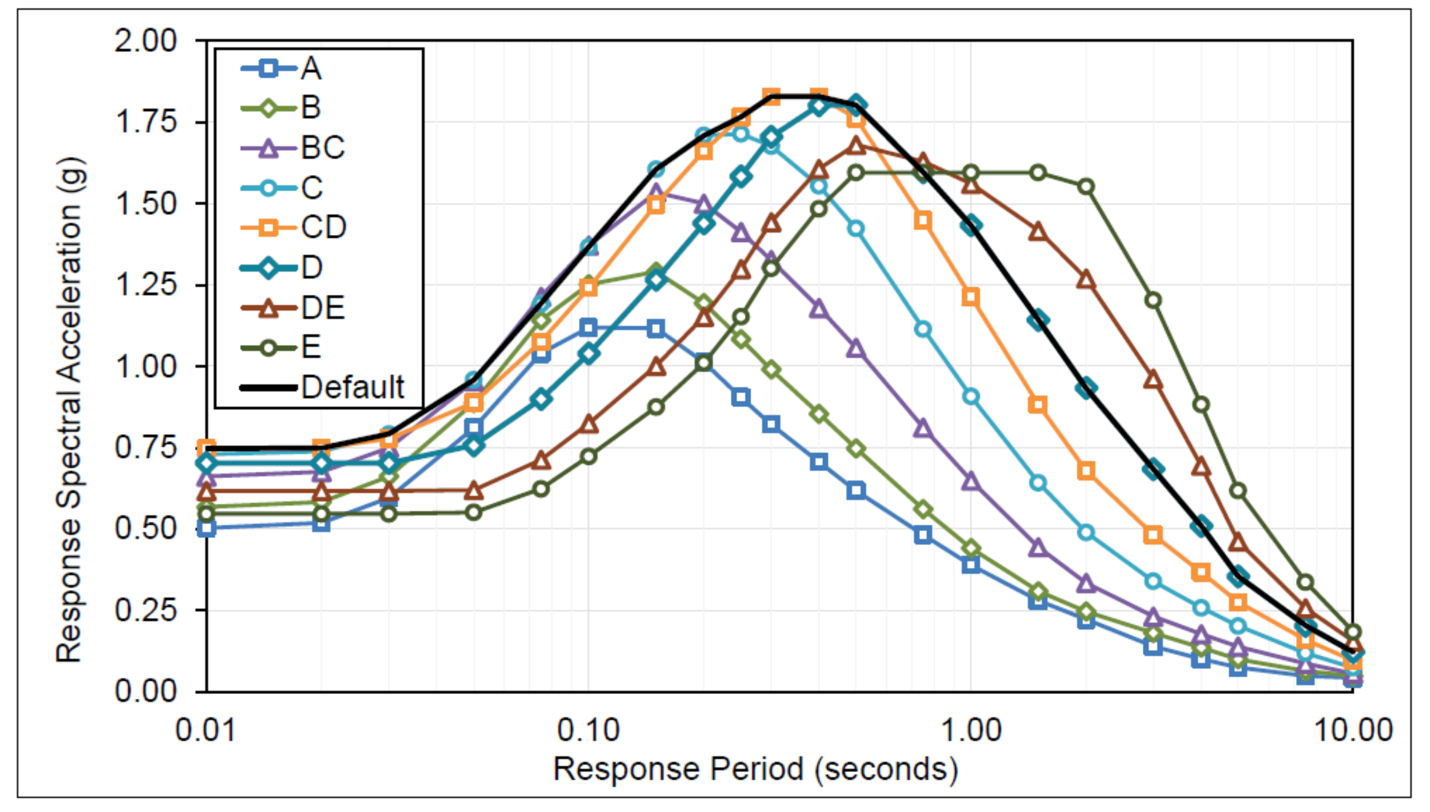


Figure 11.4-1. Two-period design response spectrum.

A Dive into the Building Code - Future





Design Response Spectrum ASCE 7-22

11.4.5 Design Response Spectrum Where a design response spectrum is required by this standard, the design response spectrum shall be determined in accordance with the requirements of Section 11.4.5.1.

EXCEPTIONS:

1. Where a site-specific ground motion analysis is performed in accordance with Section 11.4.7, the design response spectrum shall be determined in accordance with Section 21.3.
2. Where values of the multi-period 5%-damped MCE_R response spectrum are not available from the USGS Seismic Design Geodatabase, the design response spectrum shall be permitted to be determined in accordance with Section 11.4.5.2.

Multi-Period Response Spectra

11.4.5.1 Multi-Period Design Response Spectrum The multi-period design response spectrum shall be developed as follows:

1. At discrete values of period, T, equal to 0.0 s, 0.01 s, 0.02 s, 0.03 s, 0.05 s, 0.075 s, 0.1 s, 0.15 s, 0.2 s, 0.25 s, 0.3 s, 0.4 s, 0.5 s, 0.75 s, 1.0 s, 1.5 s, 2.0 s, 3.0 s, 4.0 s, 5.0 s, 7.5 s, and 10 s, the 5%-damped design spectral response acceleration parameter, S_a, shall be taken as 2/3 of the multi-period 5%-damped MCE_R response spectrum from the USGS Seismic Design Geodatabase for the applicable site class.

Anchorage Spectra

Procedures for Developing Multi-Period Response Spectra at Non-Conterminous United States Sites

FEMA P-2078/ August 2020

FEMA nehrp USGS science for a changing world

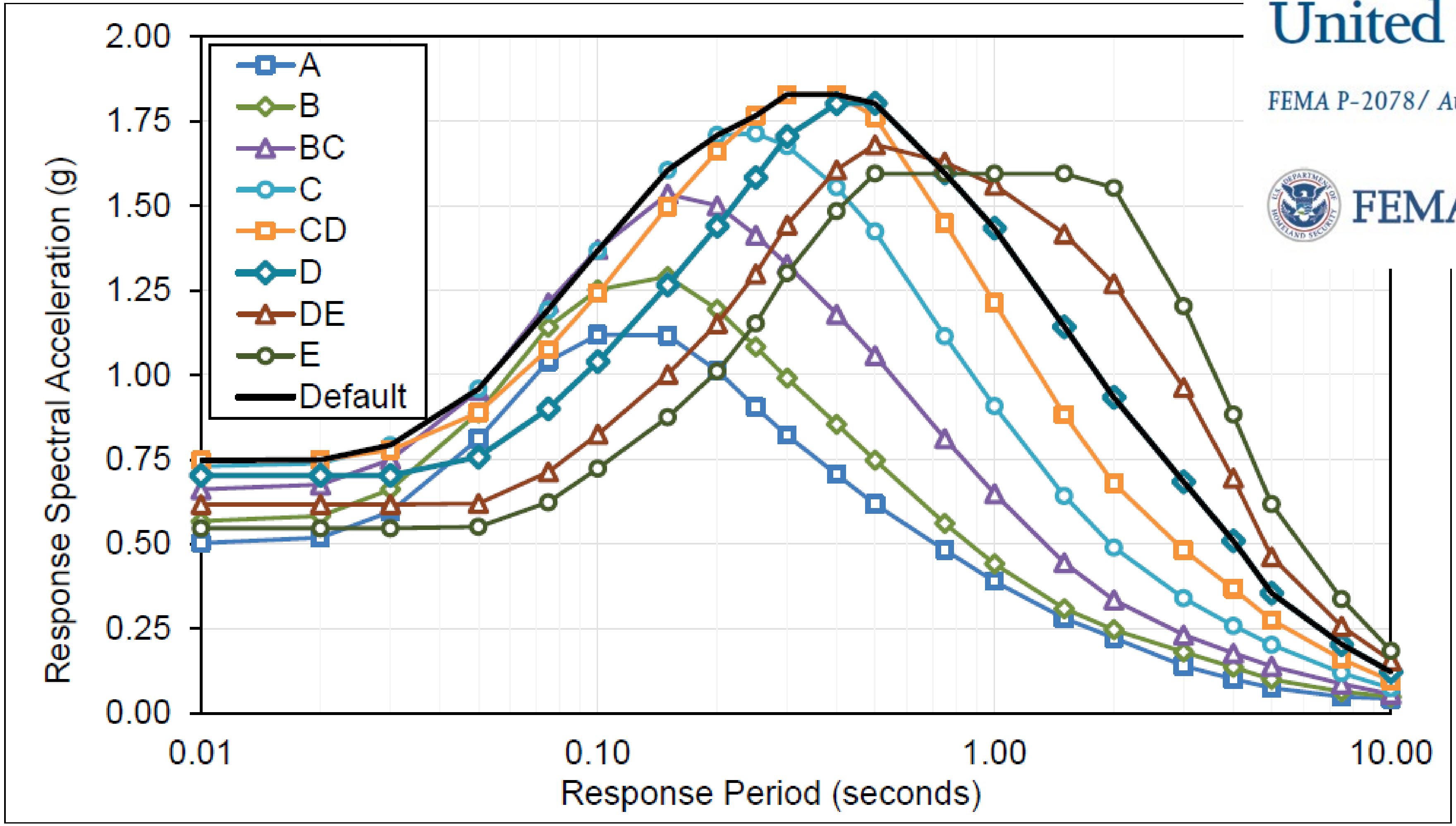


Figure 7.3-3 Plots of derived MPRS for Anchorage, Alaska.

Site Class – ASCE 7-22

Table 20.2-1. Site Classification.

Site Class	$\bar{v}_s$ Calculated Using Measured or Estimated Shear Wave Velocity Profile (ft/s)
A. Hard rock	>5,000
B. Medium hard rock	>3,000 to 5,000
BC. Soft rock	>2,100 to 3,000
C. Very dense sand or hard clay	>1,450 to 2,100
CD. Dense sand or very stiff clay	>1,000 to 1,450
D. Medium dense sand or stiff clay	>700 to 1,000
DE. Loose sand or medium stiff clay	>500 to 700
E. Very loose sand or soft clay	≥500
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.2.1

Note: For SI: 1 ft = 0.3048 m; 1 ft/s = 0.3048 m/s.

How is Site Class Determined?

- We will unpack this thing a little bit
- Commonly called V_{S30} for the average shear wave velocity in the upper 30 meters or 100 feet
- V_{S30} is aimed at taking into account that pesky geotechnical layer

20.1 SITE CLASSIFICATION

The site soil shall be classified in accordance with Table 20.2-1 and Section 20.2 based on the average shear wave velocity parameter, $\bar{v}_s$, which is derived from the measured shear wave velocity profile from the ground surface to a depth of 100 ft (30 m). Where shear wave velocity is not measured, appropriate generalized correlations between shear wave velocity and standard penetration test (SPT) blow counts, Cone Penetration Test (CPT) tip resistance, shear strength, or other geotechnical parameters shall be used to obtain an estimated shear wave velocity profile, as described in Section 20.3. Where site-specific data (measured shear wave velocities or other geotechnical data that can be used to estimate shear wave velocity) are available only to a maximum depth less than 100 ft (30 m), $\bar{v}_s$ shall be estimated as described in Section 20.3. Where the soil properties are not known in sufficient detail to determine the site class, the most critical site conditions of Site Class C, Site Class CD and Site Class D, as defined in Section 11.4.2, shall be used unless the Authority Having Jurisdiction or geotechnical data determine that Site Class DE, E, or F soils are present at the site. Site Classes A and B shall not be assigned to a site if there is more than 10 ft (3.1 m) of soil between the rock surface and the bottom of the spread footing or mat foundation.

Shear Wave Velocity – Best Option

- Go and measure it!

- This option has some peril in Anchorage we will describe later

20.1 SITE CLASSIFICATION

The site soil shall be classified in accordance with Table 20.2-1 and Section 20.2 based on the average shear wave velocity parameter, $\bar{v}_s$, which is derived from the measured shear wave velocity profile from the ground surface to a depth of 100 ft

Shear Wave Velocity - Estimated

- Geotechnical studies
  - General correlations may work but should be evaluated
  - Caution should be used – especially with SPT

(30 m). Where shear wave velocity is not measured, appropriate generalized correlations between shear wave velocity and standard penetration test (SPT) blow counts, Cone Penetration Test (CPT) tip resistance, shear strength, or other geotechnical parameters shall be used to obtain an estimated shear wave velocity profile, as described in Section 20.3. Where site-specific data (measured shear wave velocities or other geotechnical data that can be used to estimate shear wave velocity) are available only to a maximum depth less than 100 ft (30 m), $\bar{v}_s$ shall be estimated as described in Section 20.3. Where the soil properties are not

Shear Wave Velocity – Junk Drawer

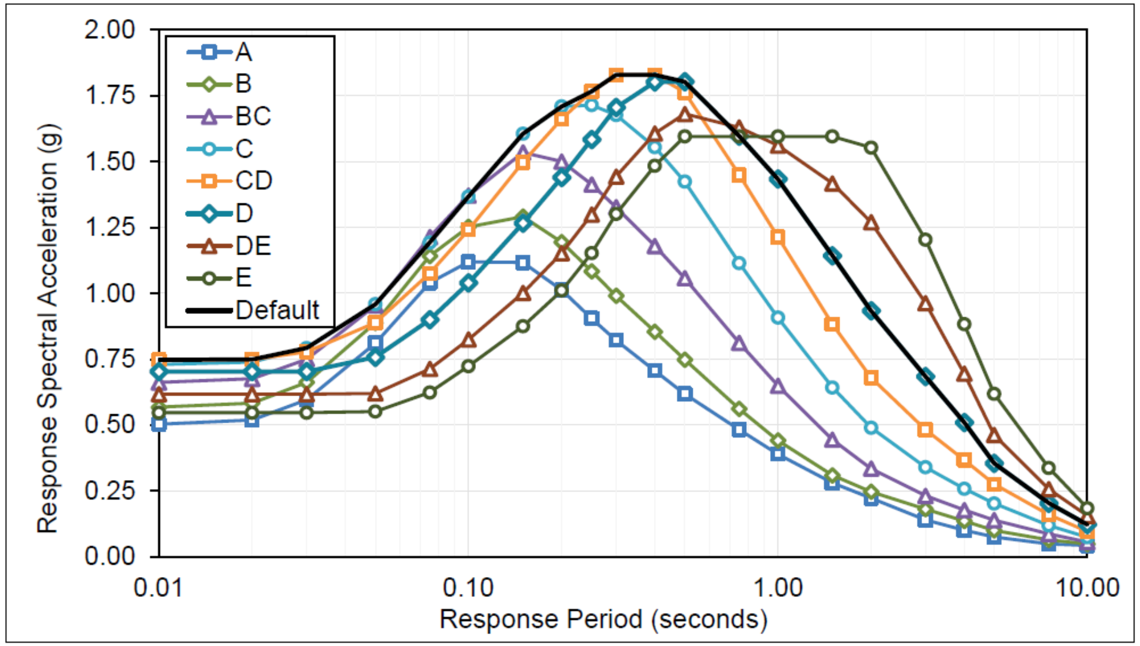
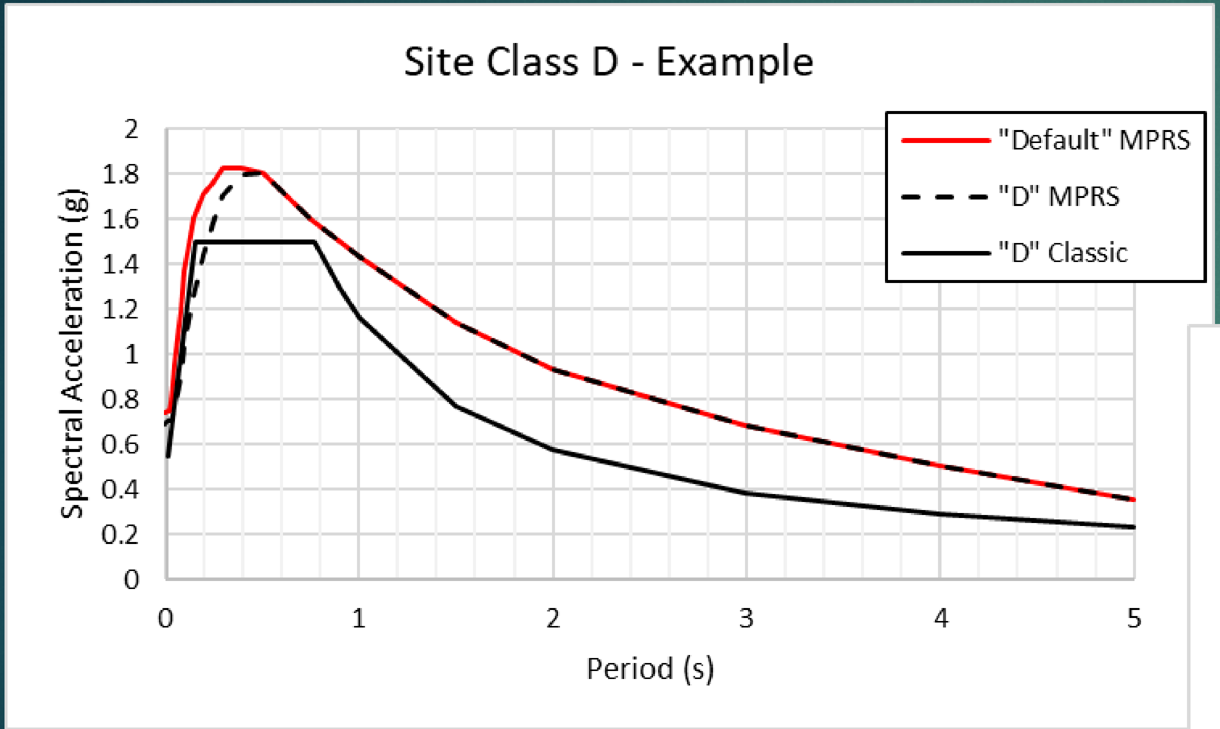
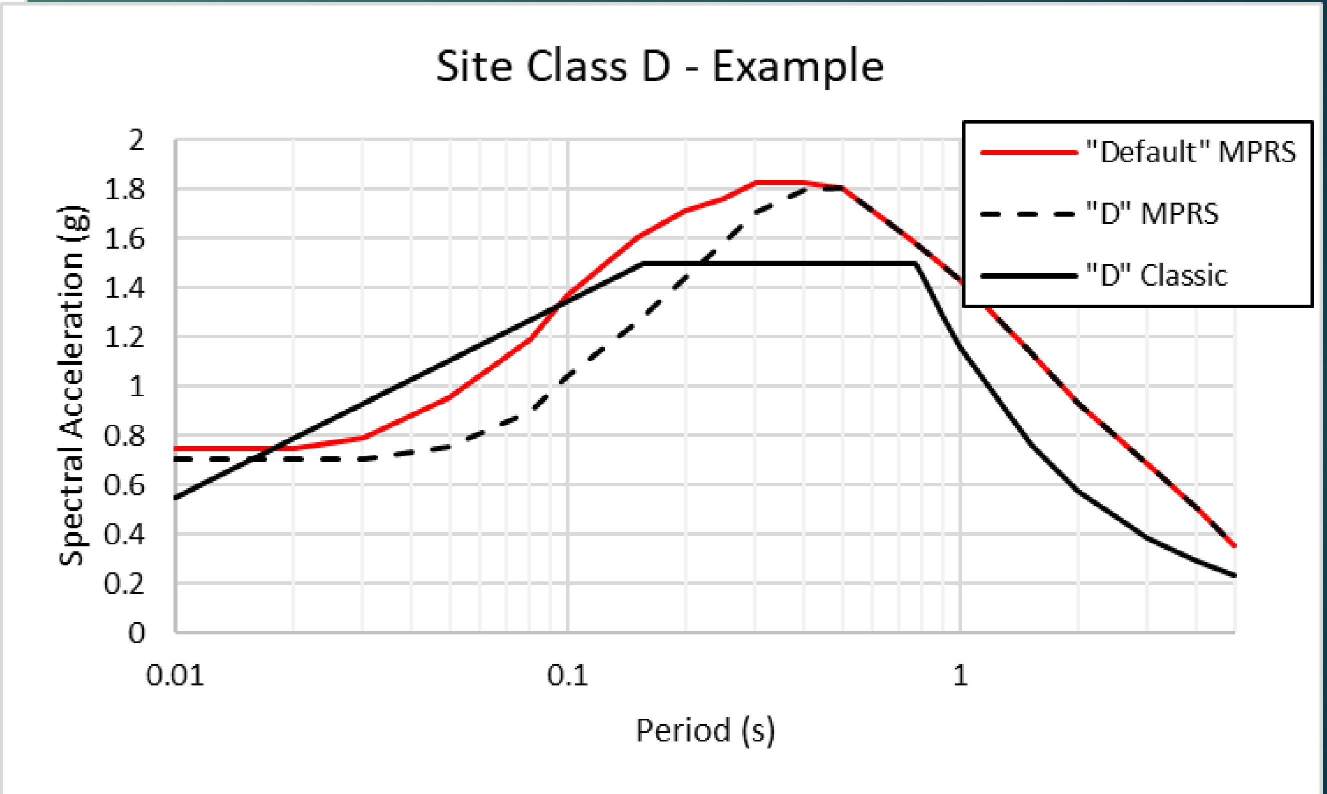


Figure 7.3-3 Plots of derived MPRS for Anchorage, Alaska.

profile, as described in Section 20.3. Where site-specific data (measured shear wave velocities or other geotechnical data that can be used to estimate shear wave velocity) are available only to a maximum depth less than 100 ft (30 m), $\bar{v}_s$ shall be estimated as described in Section 20.3. Where the soil properties are not known in sufficient detail to determine the site class, the most critical site conditions of Site Class C, Site Class CD and Site Class D, as defined in Section 11.4.2, shall be used unless the Authority Having Jurisdiction or geotechnical data determine that Site Class DE, E, or F soils are present at the site. Site

Looking at Site Class D (MCE_R)





And Now the Pitfalls

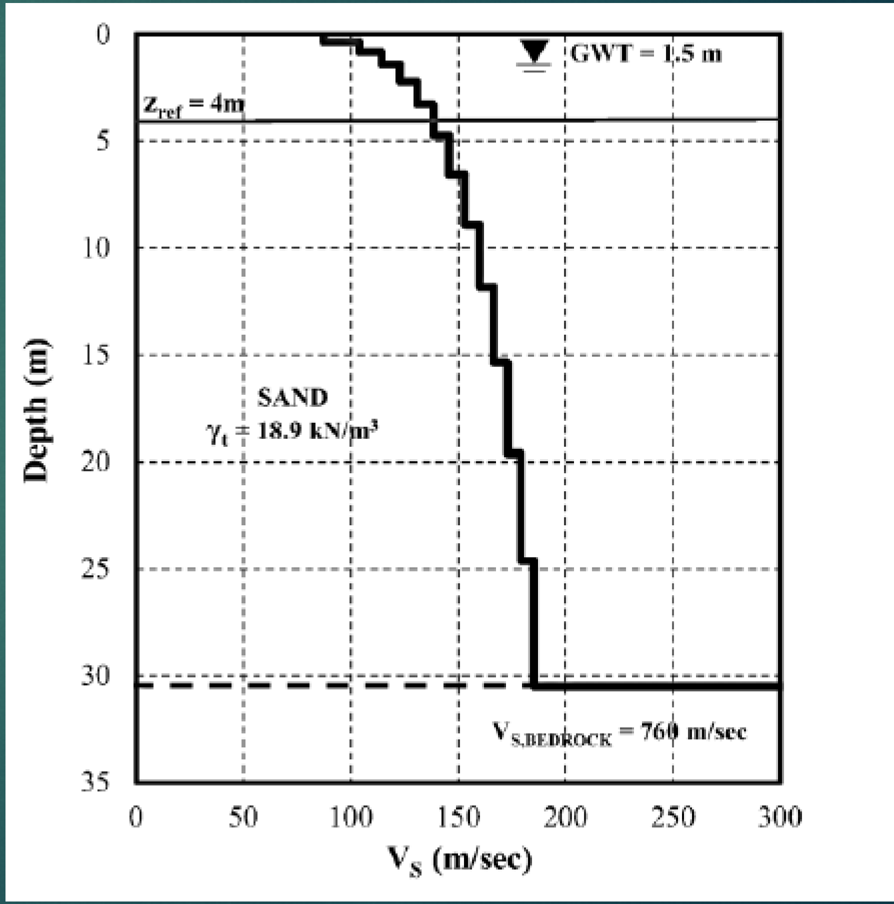
- Anchorage geology is complex

20.3 ESTIMATION OF SHEAR WAVE VELOCITY PROFILES

Where the available data used to establish the shear wave velocity profile extends to depths less than 100 ft (30 m) but more than 50 ft (15 m), and the site geology is such that soft layers are unlikely to be encountered between 50 and 100 ft, the shear wave velocity of the last layer in the profile shall be extended to 100 ft for the calculation of $\bar{v}_s$ in Equation (20.4-1). Where the data does not extend to depths of 50 ft (15 m), default site classes, as described in Section 20.1, shall be used unless another site class can be justified on the basis of the site geology.

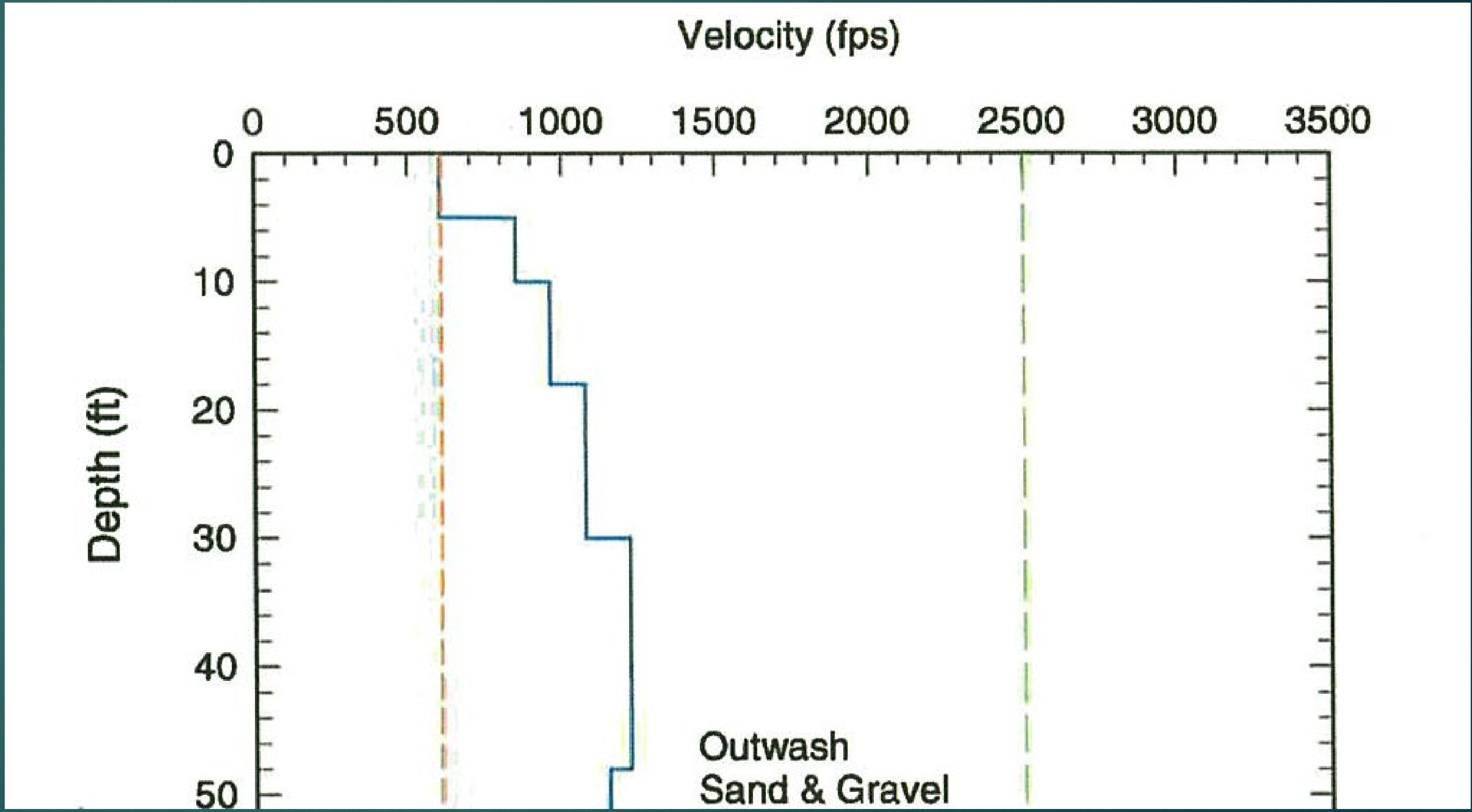
The California Example

- Shear wave velocity increases with depth
- Engineering bedrock at 30m (100ft)



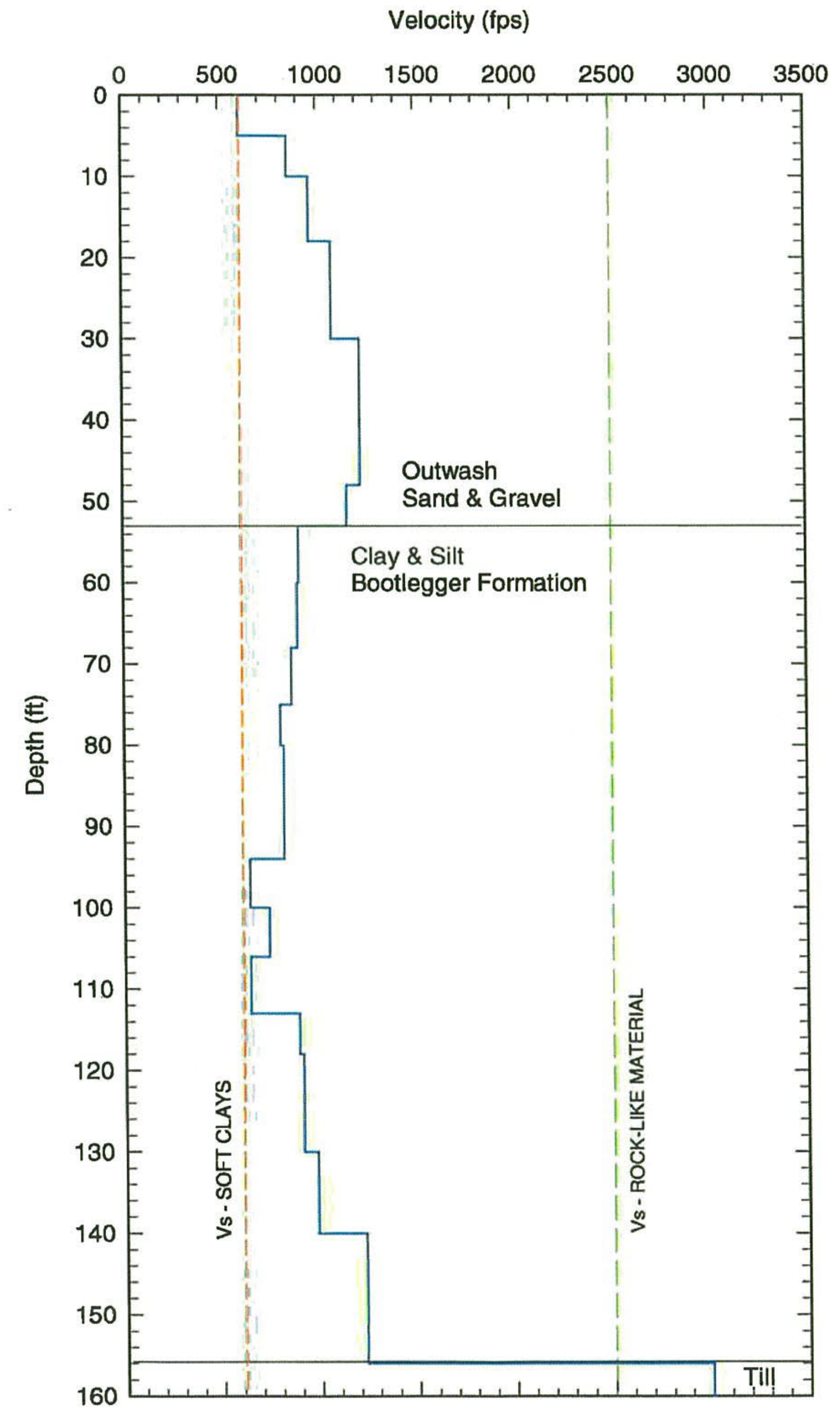
An Example Closer to Home

- Downtown Anchorage

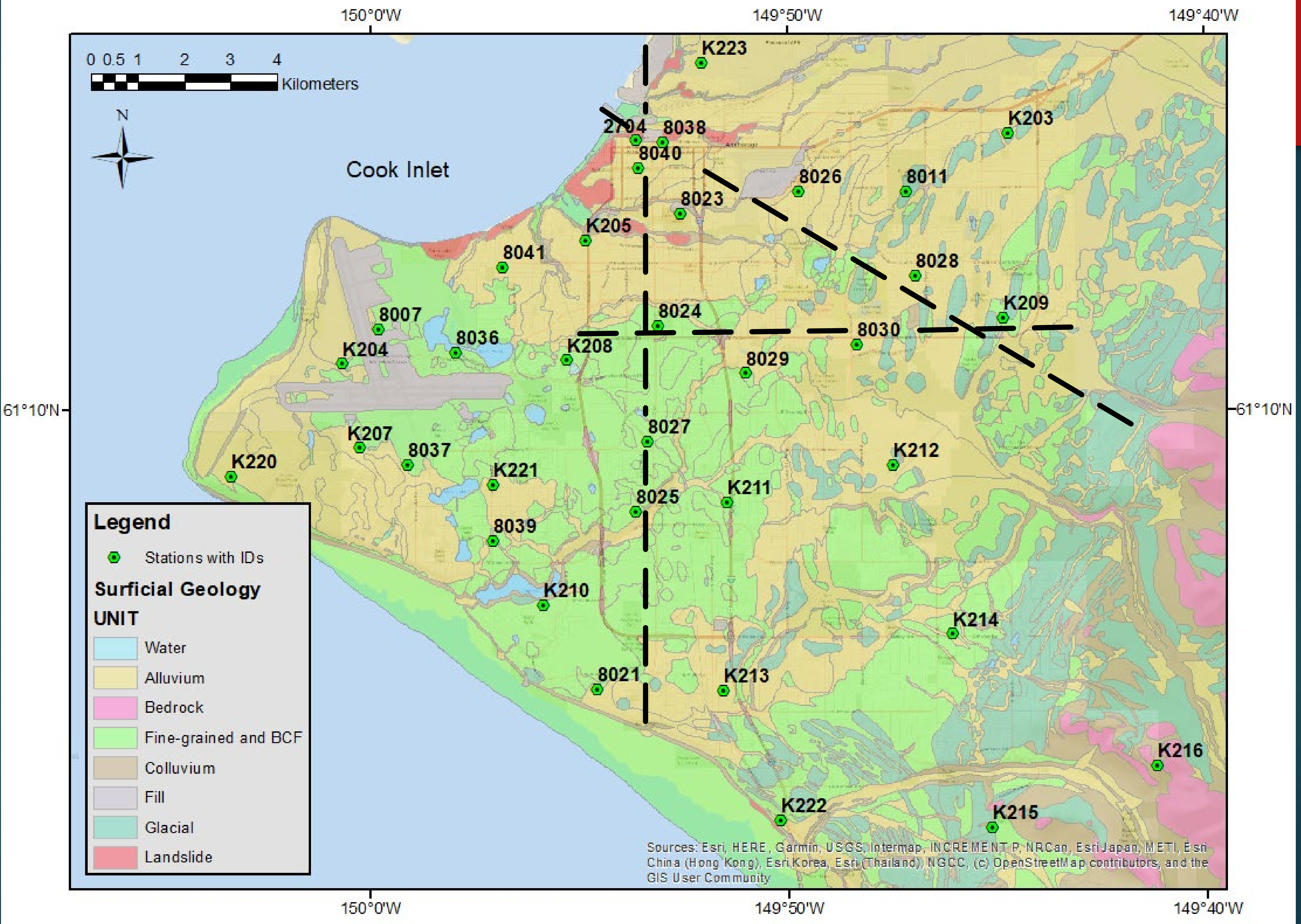


The Full Profile

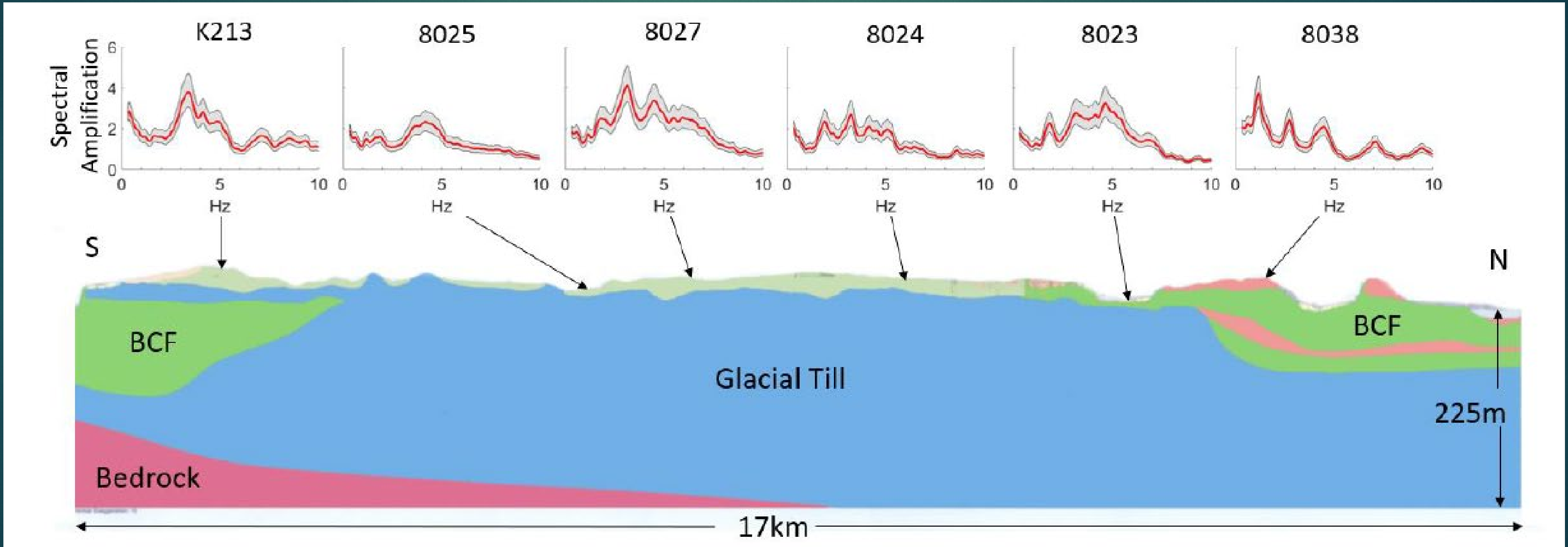
- Looking at the upper 50 feet alone would miss critical features that impact site response
- In Anchorage we see the underlying till as an "engineering" bedrock feature
- Bootlegger Cove Formation and other soft materials may be hiding at depth



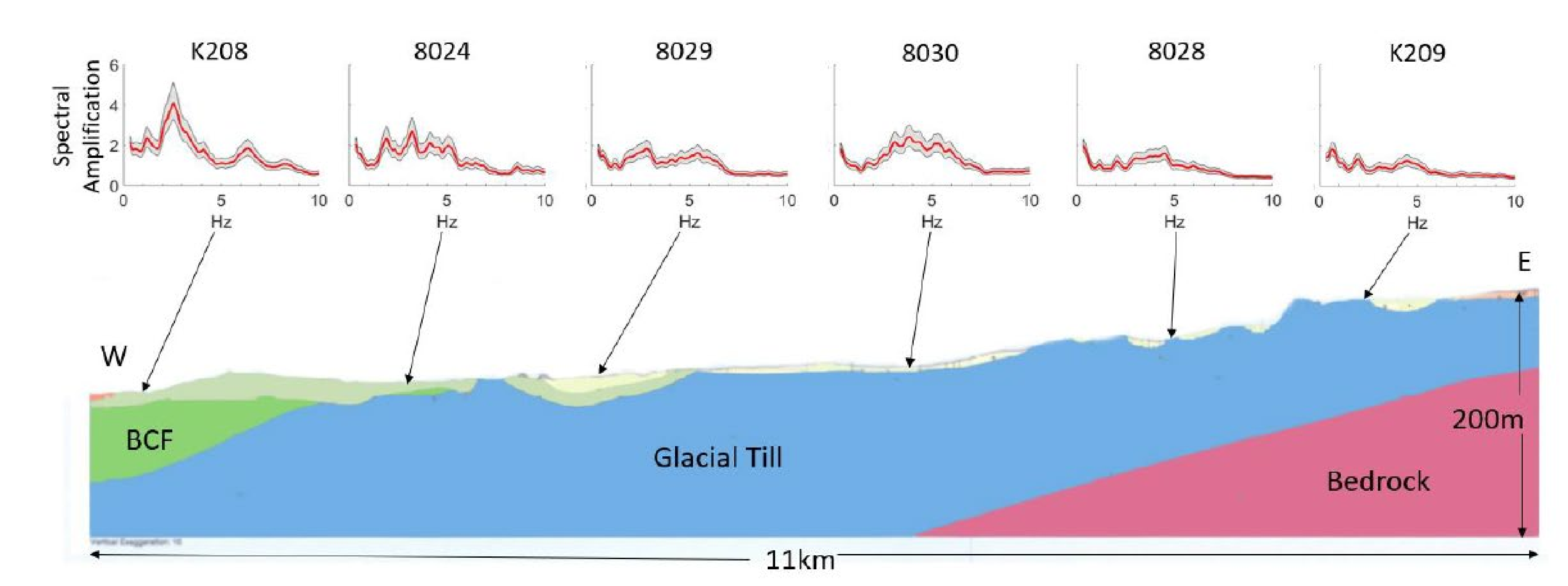
Anchorage Geology



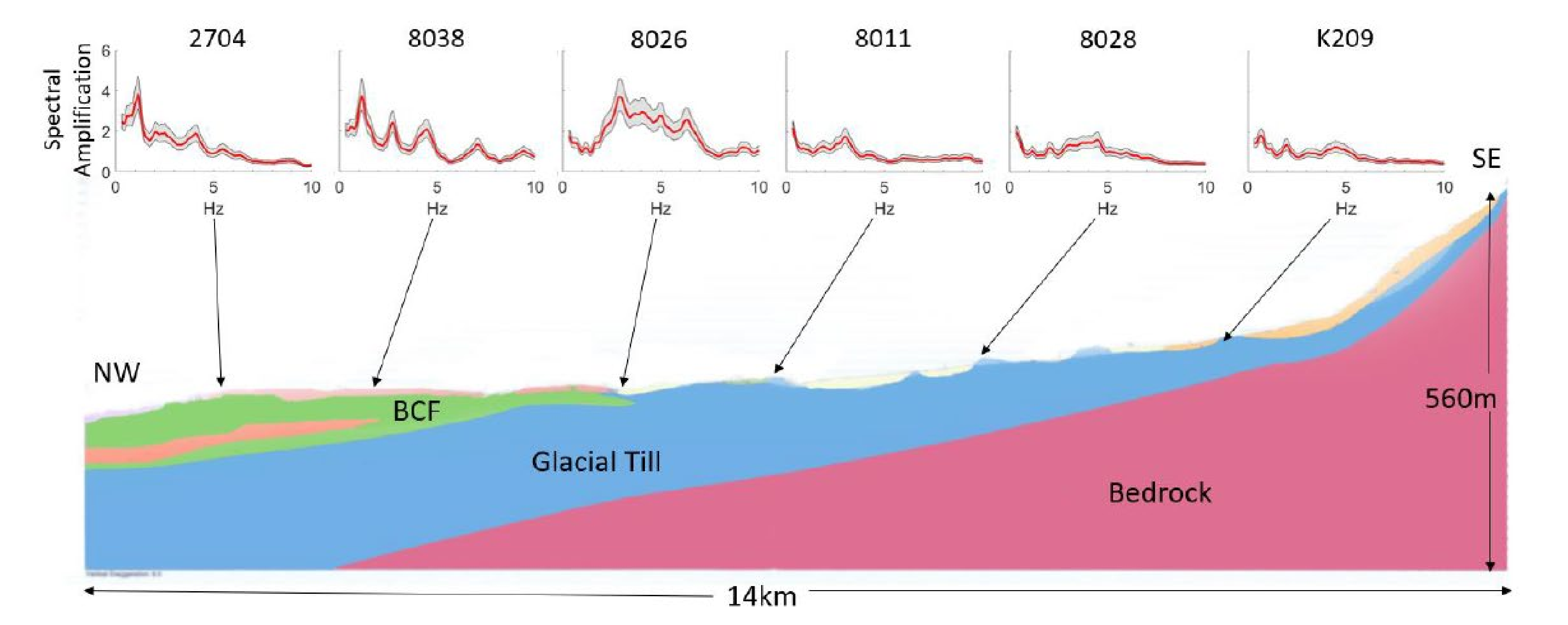
South to North Section



West to East Section

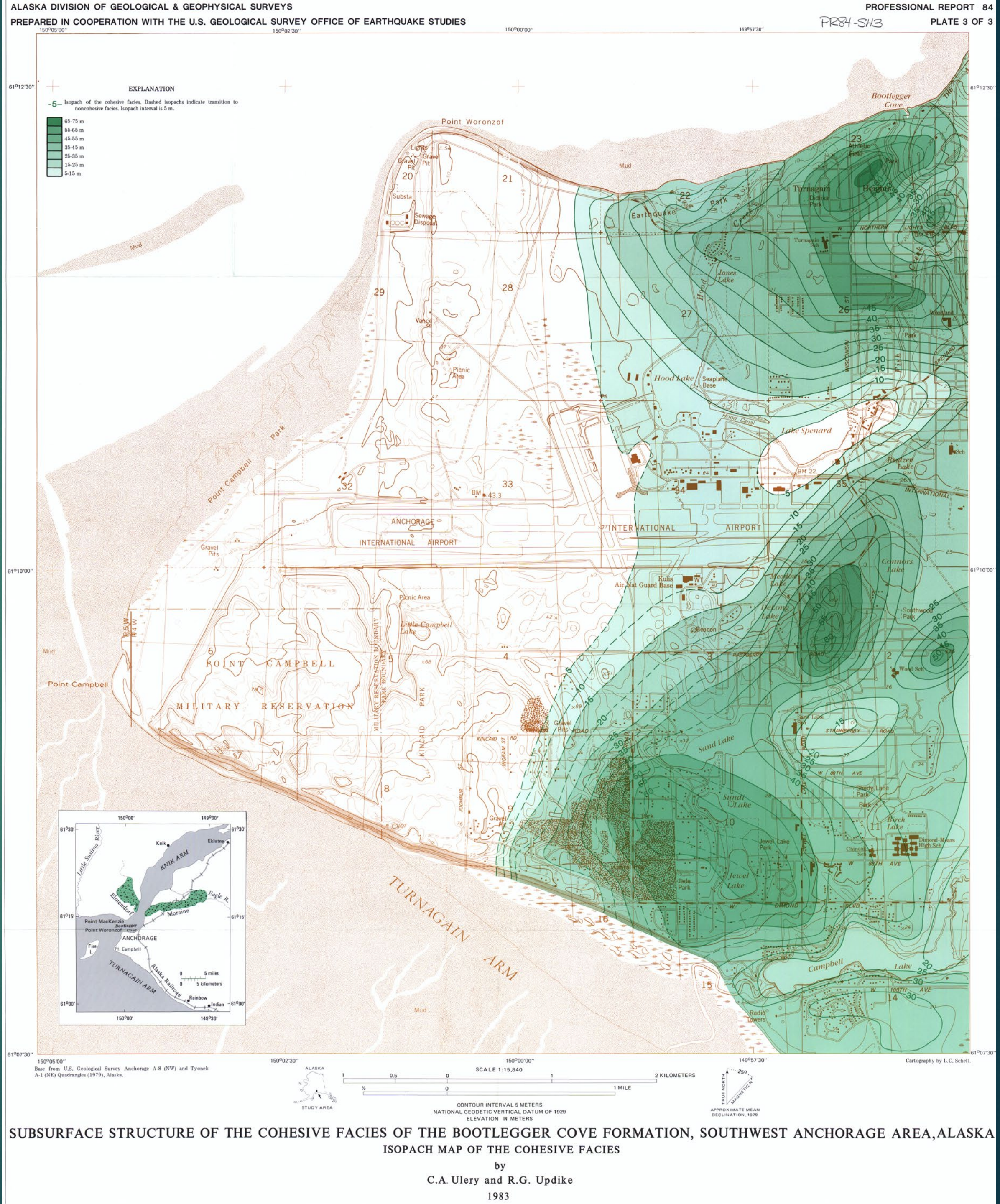


NW to SE Section

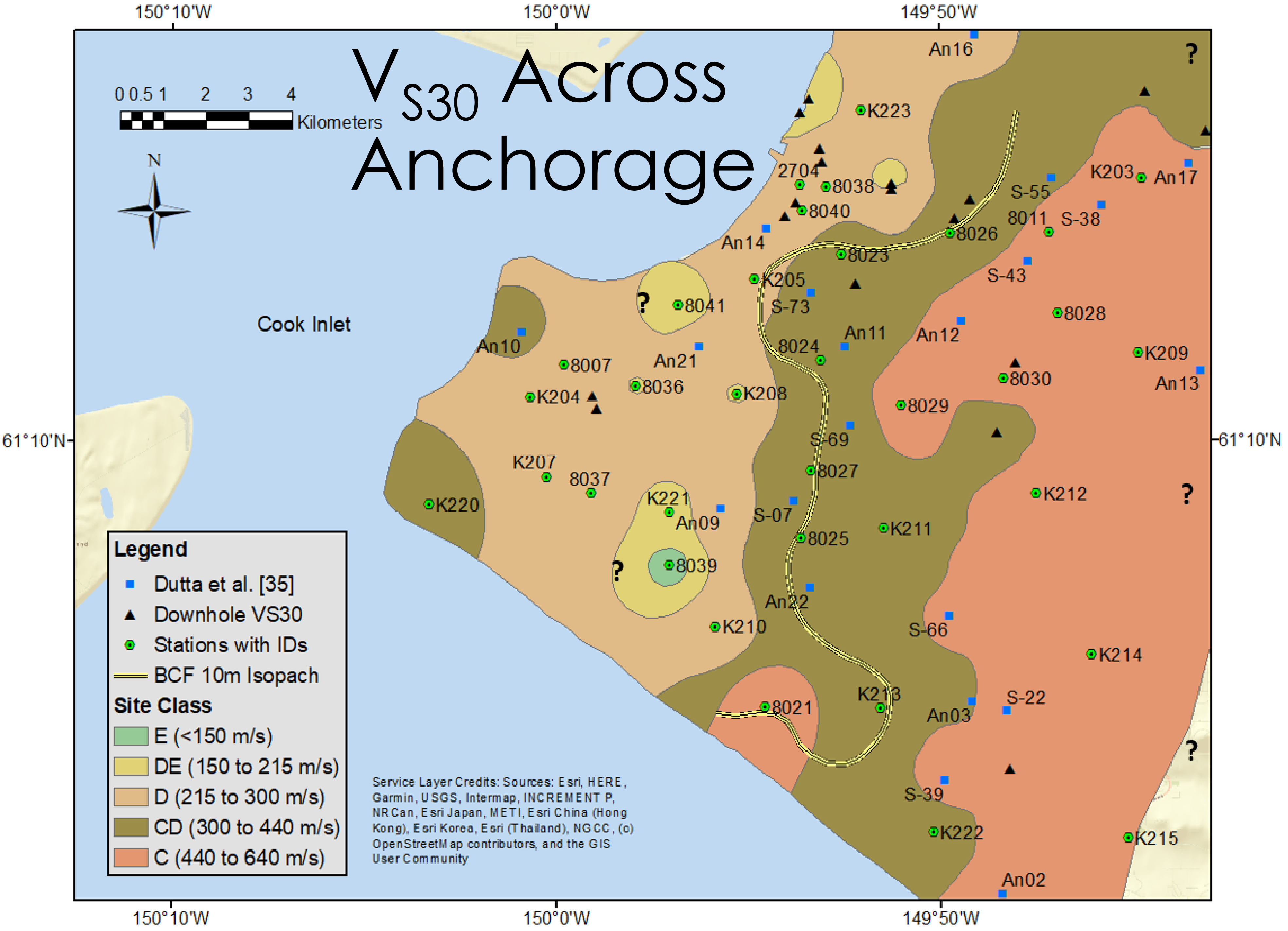


West Anchorage

- Deep Bootlegger Cove silts and clays
- Darker green indicating depths of 50m (160 feet)



- Contour Map based on:
  - Downhole
  - Surface
  - Strong-motion station estimates
- Still some work to do to tie more closely to geology



Back to the Code

- Hope for more robust geotechnical programs
- Lots of reasons only shallow geotechnical data is collected
- Given the complex nature of Anchorage geology – need to have several tools available

20.3 ESTIMATION OF SHEAR WAVE VELOCITY PROFILES

Where the available data used to establish the shear wave velocity profile extends to depths less than 100 ft (30 m) but more than 50 ft (15 m), and the site geology is such that soft layers are unlikely to be encountered between 50 and 100 ft, the shear wave velocity of the last layer in the profile shall be extended to 100 ft for the calculation of $\bar{v}_s$ in Equation (20.4-1). Where the data does not extend to depths of 50 ft (15 m), default site classes, as described in Section 20.1, shall be used unless another site class can be justified on the basis of the site geology.

Concluding Remarks

- Anchorage is located within one of the most active tectonic regions in the world
- The geologic conditions within the city are complex
- V_{S30} has some underlying assumptions
- The upcoming Building Code (IBC 2024?) will be putting more emphasis on shear wave velocity measurements/estimates
- Care needs to be taken when estimating
- V_{S30} maps of Anchorage may offer some free advice

GAC Discussion – BSSA

- The GAC is currently considering a resolution to require building permit process throughout the Municipality
- Only required within the Building Safety Service Area (BSSA)
- Based on observations of significant structural damage in Eagle River from the November 2018 earthquake

- Several Groups including FEMA and EERI have made recommendations for Building Code enforcement throughout Anchorage

Eagle River Damage Comparison

Earthquake Resiliency and Building Code Enforcement
Is there a connection?

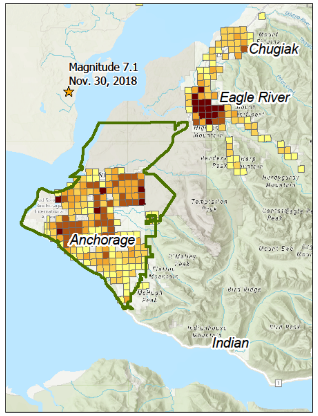
David Askov and Amanda Siok, FEMA
Ross Noffisinger and Tina Miller, Municipality of Anchorage
John Thornley, Golder Associates, Inc.

The Anchorage Building Safety Service Area (ABSSA)

Building Code Enforcement: The *"Anchorage Building Safety Service Area" (ABSSA)* primarily consists of the Anchorage Bowl. Building permits within the ABSSA require a plan review and a building inspection with a municipal inspector.

Outside the ABSSA: The Municipality of Anchorage does not require plan reviews and municipal inspections for construction outside of the ABSSA, including the communities of Eagle River, Chugiak, Indian, and Girdwood.

Distribution of the Damage



November 30, 2018: A magnitude 7.1 earthquake caused significant shaking in the communities of Anchorage, Eagle River, and Chugiak. The State of Alaska received thousands of requests for Individual Assistance, including residents of the Municipality of Anchorage.

- Earthquake Epicenter
- ABSSA Boundary

State of Alaska Individual Assistance Applicants per 1km Grid Cell
- 4 - 10 (<4 not shown)
- 11 - 25
- 26 - 50
- 51 - 100
- Over 100

Despite the less urban composition of Eagle River and Chugiak, their applicant densities are quite high, especially in Eagle River.

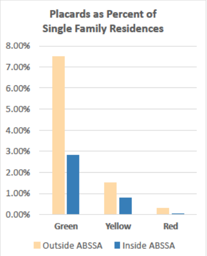
A Quick Look at the Placard Assignments

Municipality of Anchorage inspectors assigned a placard color to each inspection performed per the ATC-20 process:
- Green - Safe to inhabit, may require repairs[1]
- Yellow - Hazardous condition restricts use/occupancy
- Red - Extreme hazard, unsafe for occupancy

The table (below) and graph (right) show the placard color assignments for all single-family residences in the communities of Anchorage[2], Eagle River, and Chugiak.

TOTALS	None	Green	Yellow	Red	Inspections	Total
Inside ABSSA	43505	1272	367	8	1647	45153
Outside ABSSA	9721	804	163	34	1001	10722
PERCENTAGES	**None**	**Green**	**Yellow**	**Red**	**Inspections**	
Inside ABSSA	96.35%	2.82%	0.81%	0.02%	3.65%	
Outside ABSSA	90.66%	7.50%	1.52%	0.32%	9.34%	
Ratio out/in:	**0.94**	**2.66**	**1.87**	**17.90**	**2.56**	

The bottom row shows the ratio of the rates outside the ABSSA to the rates inside. At all 3 placard colors, the areas outside the ABSSA sustained much higher rates of damage.



[1] Green generally indicates damage sustained requiring repair. This level of damage however did not warrant a yellow or red placard.
[2] 99.1% of Anchorage's single family residences fall inside the ABSSA.

Building Code Enforcement

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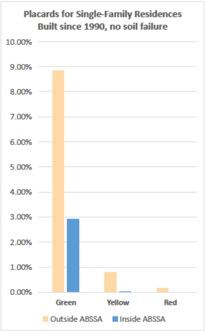
Some of the earthquake damage was caused by soil failure under these houses. Because the building codes and inspections would not have predicted that, those inspections were also removed from this analysis.

TOTALS	None	Green	Yellow	Red	Inspections	Total
Inside ABSSA*	10772	324	1	0	325	11097
Outside ABSSA	3755	369	33	6	408	4163
Eagle River	2720	326	30	4	360	3080
Chugiak	836	38	3	1	42	878
Anchorage*	199	5	0	1	6	205
PERCENTAGES	**None**	**Green**	**Yellow**	**Red**	**Inspections**	
Inside ABSSA*	97.07%	2.92%	0.01%	0.00%	2.93%	
Outside ABSSA	90.20%	8.86%	0.79%	0.14%	9.80%	
Eagle River	88.31%	10.58%	0.97%	0.13%	11.69%	
Chugiak	95.22%	4.33%	0.34%	0.11%	4.78%	
Anchorage*	97.07%	2.44%	0.00%	0.49%	2.93%	
Ratio out/in:	**0.93**	**3.04**	**87.97**	**---**	**3.35**	

* In the community boundary of Anchorage, this analysis includes 11,097 residences *inside* the ABSSA and 205 *outside*.

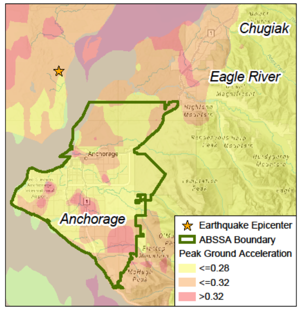


Analyzing only homes built since 1990 and not experiencing soil failure, both inside and outside the ABSSA show decreased rates of damage. That said, the inspections **inside the ABSSA experienced much lower rates of damage**, with only one yellow placard and **no red placards**.

Breakdown by Levels of Shaking

Peak ground acceleration (PGA) measures the intensity of the ground motion experienced during the earthquake, with higher values indicating more intense ground motion. The International Building Code requires buildings in Anchorage to resist a minimum PGA level of 0.5g. Only isolated locations in the Municipality reached that level of ground motion, with most residences experiencing only 60% or less of that.

This map originated from the USGS ShakeMap PGA and was augmented with a map from Golder Associates interpolating sensor data available in the most populated parts of Anchorage.



ShakeMap PGA ≤0.28	None	Green	Yellow	Red	Inspections	None	Green	Yellow	Red
Inside ABSSA	5849	191	0	0	191	96.84%	3.16%	0.00%	0.00%
Outside ABSSA	1000	104	7	0	111	90.01%	9.36%	0.63%	0.00%
Anchorage	58	2	0	0	2	96.67%	3.33%	0.00%	0.00%
Chugiak	105	9	0	0	9	92.11%	7.89%	0.00%	0.00%
Eagle River	837	93	7	0	100	89.33%	9.93%	0.75%	0.00%
					Ratio out/in:	**0.93**	**2.96**	---	---

ShakeMap PGA ≤0.32	None	Green	Yellow	Red	Inspections	None	Green	Yellow	Red
Inside ABSSA	3554	100	1	0	101	97.24%	2.74%	0.03%	0.00%
Outside ABSSA	2226	206	23	5	234	90.49%	8.37%	0.93%	0.20%
Anchorage	123	3	0	1	4	96.85%	2.36%	0.00%	0.79%
Chugiak	731	29	3	1	33	95.68%	3.80%	0.39%	0.13%
Eagle River	1372	174	20	3	197	87.44%	11.09%	1.27%	0.19%
					Ratio out/in:	**0.93**	**3.06**	**34.17**	---

ShakeMap PGA >0.32	None	Green	Yellow	Red	Inspections	None	Green	Yellow	Red
Inside ABSSA	1369	33	0	0	33	97.65%	2.35%	0.00%	0.00%
Outside ABSSA	529	59	3	1	63	89.36%	9.97%	0.51%	0.17%
Anchorage	13	0	0	0	0	100.00%	0.00%	0.00%	0.00%
Chugiak	0	0	0	0	0	---	---	---	---
Eagle River	511	59	3	1	63	89.02%	10.28%	0.52%	0.17%
					Ratio out/in:	**0.92**	**4.23**	---	---

These tables show rates of damage at different levels of ground motion. Variations in the intensity of ground motion do not appear to be a significant factor in explaining the higher rate of damage experienced outside the ABSSA.

Future Directions

PGA Maps: Outside the most populated parts of Anchorage, there are fewer sensors used to create the USGS ShakeMap. Improving the detail of the ShakeMap will enable a better understanding of the effects of ground motion on residential damage.
Future Earthquakes: Because this earthquake's ground motion (PGA) only reached the building code's minimum level in a few isolated pockets, repeating this analysis in future events will add greater understanding.
Additional Factors: Analyze if other factors (e.g.: socioeconomic data, appraisal value, English proficiency, building on historical marshlands) affect the rates of damage reported.

Base Map Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community
ATC-20: https://www.atcouncil.org/atc-20
USGS ShakeMap: https://earthquake.usgs.gov/data/shakemap/
Golder Associates, Inc.: https://www.golder.com/

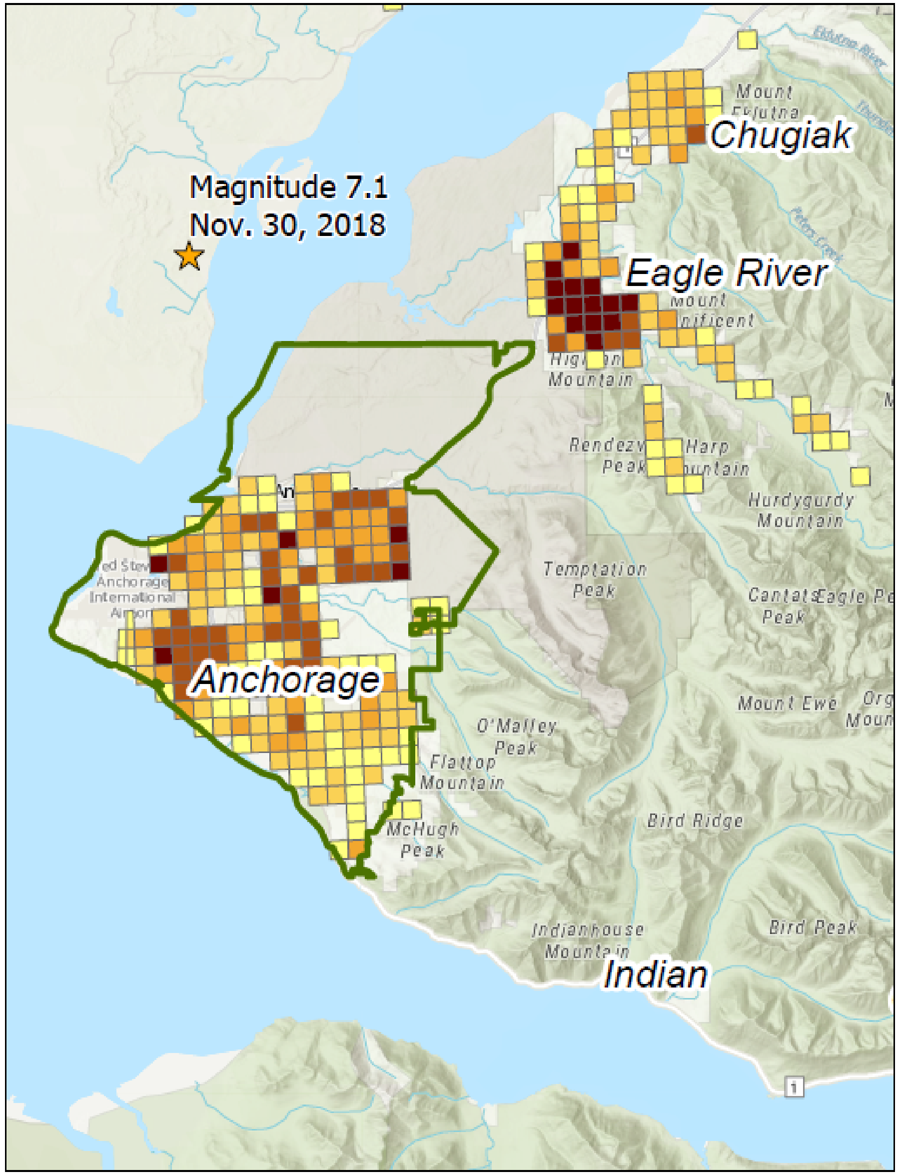
http://www.learningfromearthquakes.org/2018-11-30-anchorage-alaska/images/2019_Symposium/Anchorage_EQ_Symposium_poster-David_Askov.pdf

Damage Distribution

- Summary of the State of Alaska Individual Assistance requests

Image from Askov et al. 2019 Poster

Distribution of the Damage



November 30, 2018: A magnitude 7.1 earthquake caused significant shaking in the communities of Anchorage, Eagle River, and Chugiak. The State of Alaska received thousands of requests for Individual Assistance, including residents of the Municipality of Anchorage.

- ★ Earthquake Epicenter
- ABSSA Boundary

State of Alaska Individual Assistance Applicants per 1km Grid Cell

- 4 - 10 (<4 not shown)
- 11 - 25
- 26 - 50
- 51 - 100
- Over 100

Despite the less urban composition of Eagle River and Chugiak, their applicant densities are quite high, especially in Eagle River.

A Quick Look at the Placard Assignments

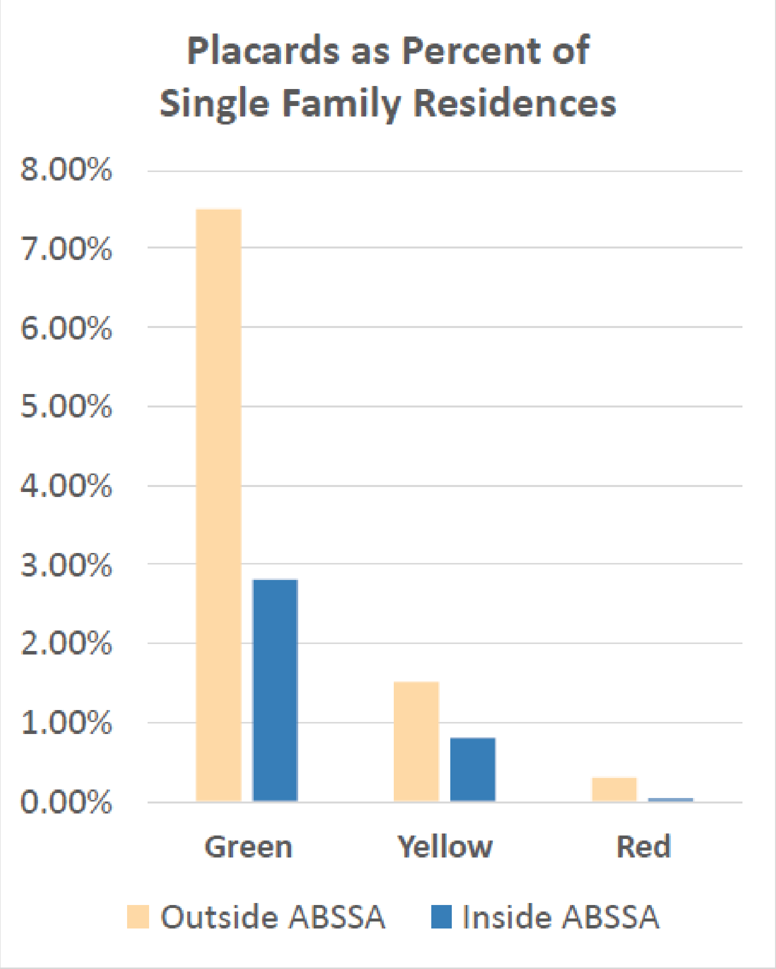
Municipality of Anchorage inspectors assigned a placard color to each inspection performed per the ATC-20 process:

- Green - Safe to inhabit, may require repairs[1]
- Yellow - Hazardous condition restricts use/occupancy
- Red - Extreme hazard, unsafe for occupancy

The table (below) and graph (right) show the placard color assignments for all single-family residences in the communities of Anchorage[2], Eagle River, and Chugiak.

TOTALS	None	Green	Yellow	Red	Inspections	Total
Inside ABSSA	43506	1272	367	8	1647	45153
Outside ABSSA	9721	804	163	34	1001	10722
PERCENTAGES	**None**	**Green**	**Yellow**	**Red**	**Inspections**	
Inside ABSSA	96.35%	2.82%	0.81%	0.02%	3.65%	
Outside ABSSA	90.66%	7.50%	1.52%	0.32%	9.34%	
Ratio out/in:	**0.94**	**2.66**	**1.87**	**17.90**	**2.56**	

The bottom row shows the ratio of the rates outside the ABSSA to the rates inside. At all 3 placard colors, the areas outside the ABSSA sustained much higher rates of damage.



[1] Green generally indicates damage sustained requiring repair. This level of damage however did not warrant a yellow or red placard.

[2] 99.1% of Anchorage's single family residences fall inside the ABSSA.

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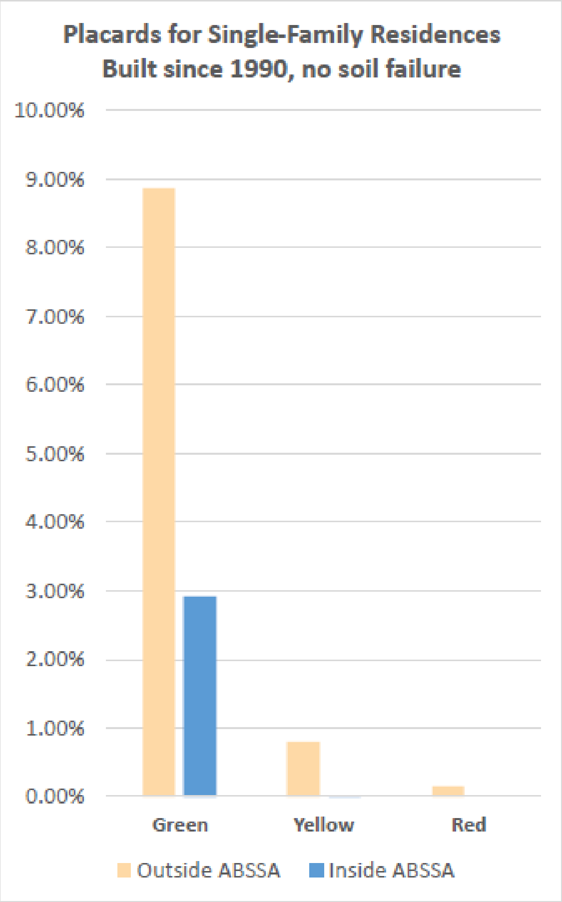

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Questions?