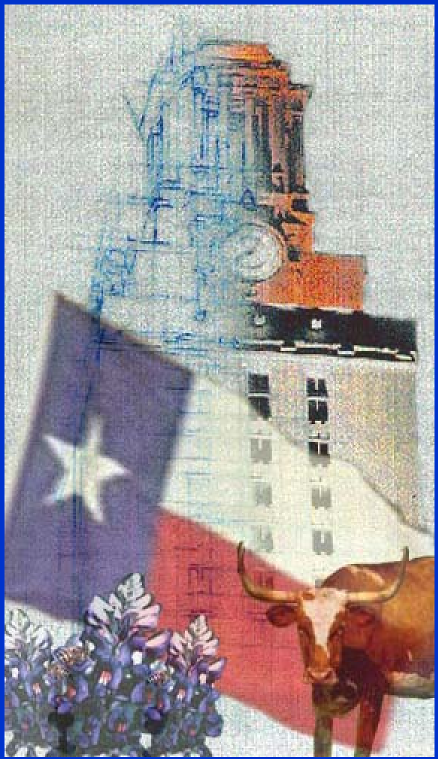
Soil Amplification and Topographic Effects



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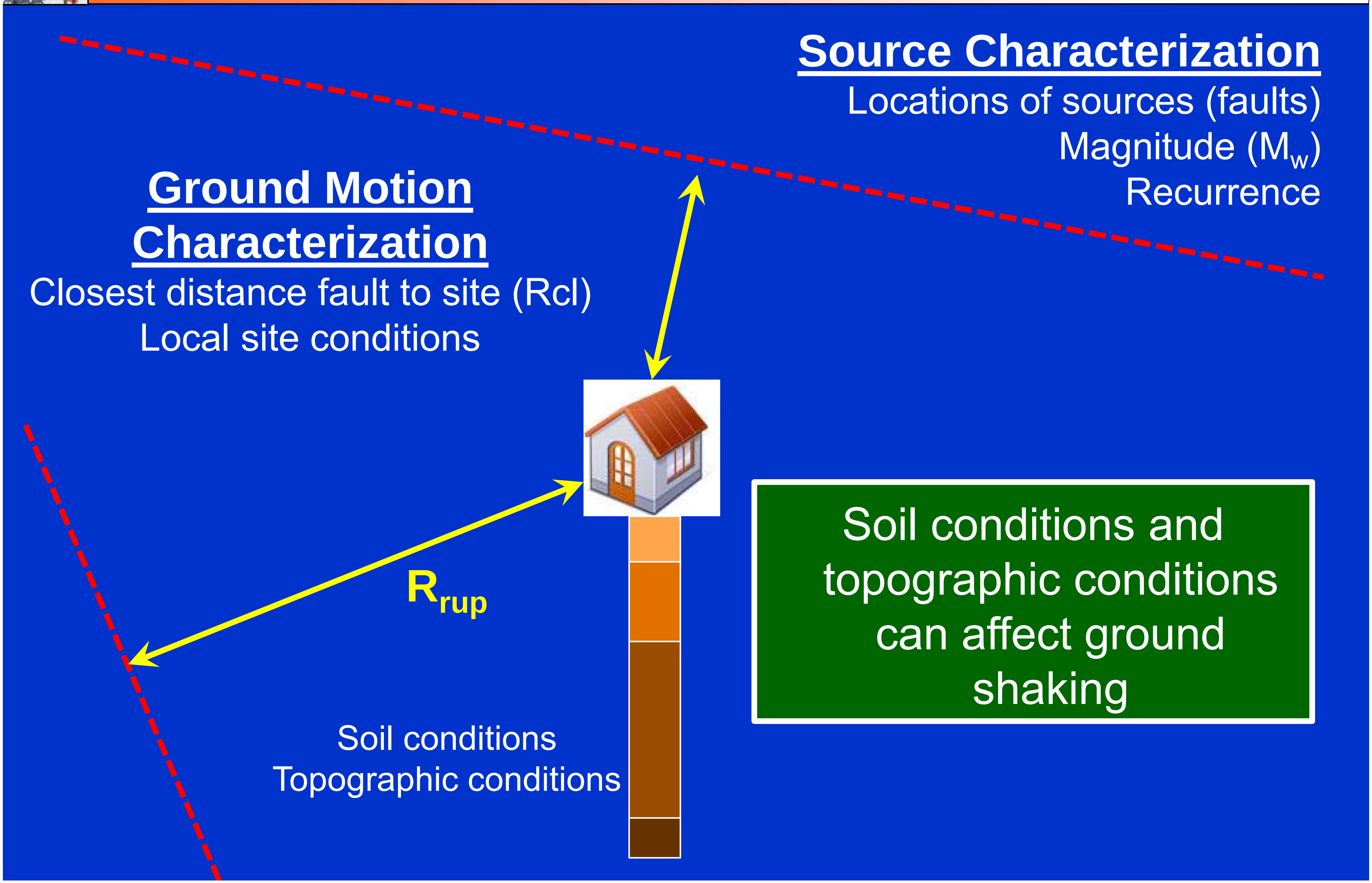
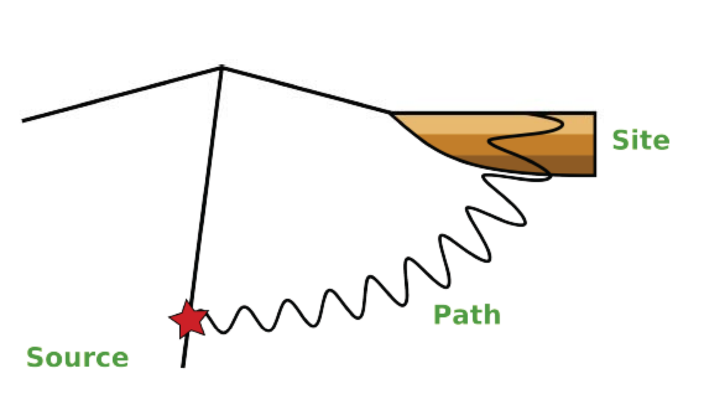
18 November 2010

Seismic Design Framework

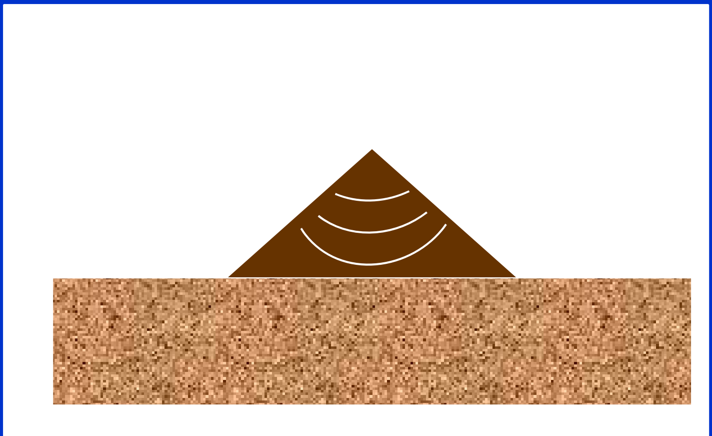


Local Effects

- Soil Amplification
  - Increase in ground motion intensity due to dynamic response of local soil layers



- Topographic Amplification
  - Increase in ground motion intensity due to focusing of waves within hillsides

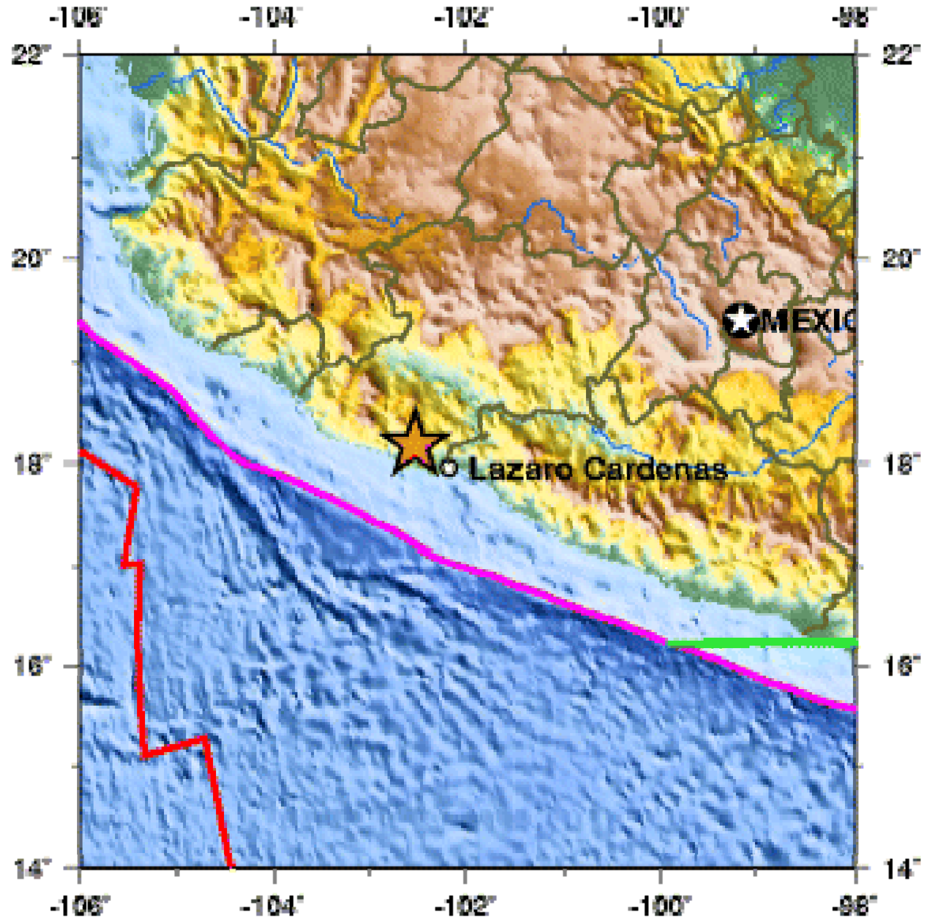


These effects typically applied to "rock" ground motions defined by seismic hazard assessment

1985 Michoacan Earthquake

Example of soil amplification ("Site effects")

- M_w 8 along coastal subduction zone
- ~300 km west of Mexico City

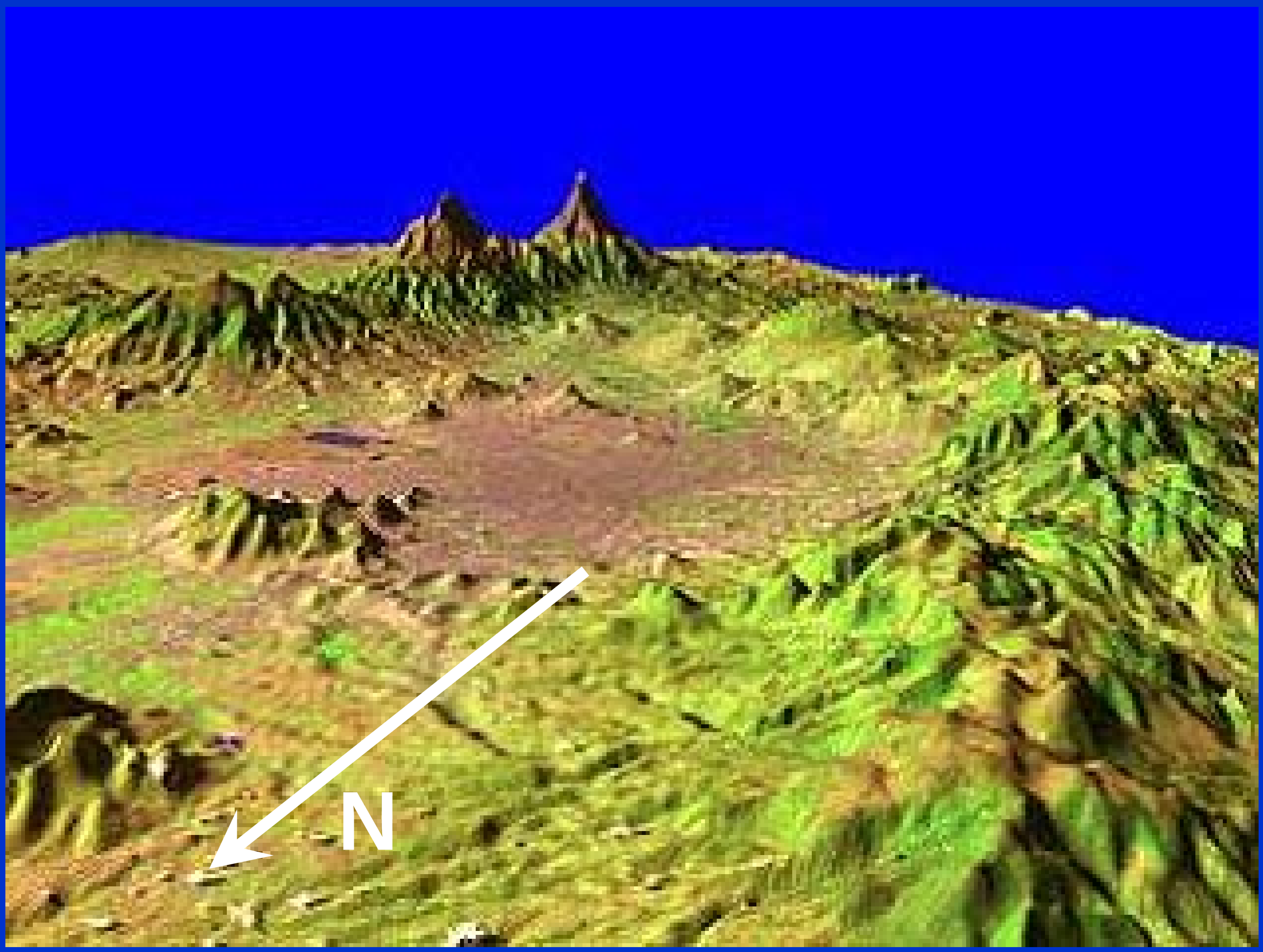


Michoacan, Mexico

Damage Patterns

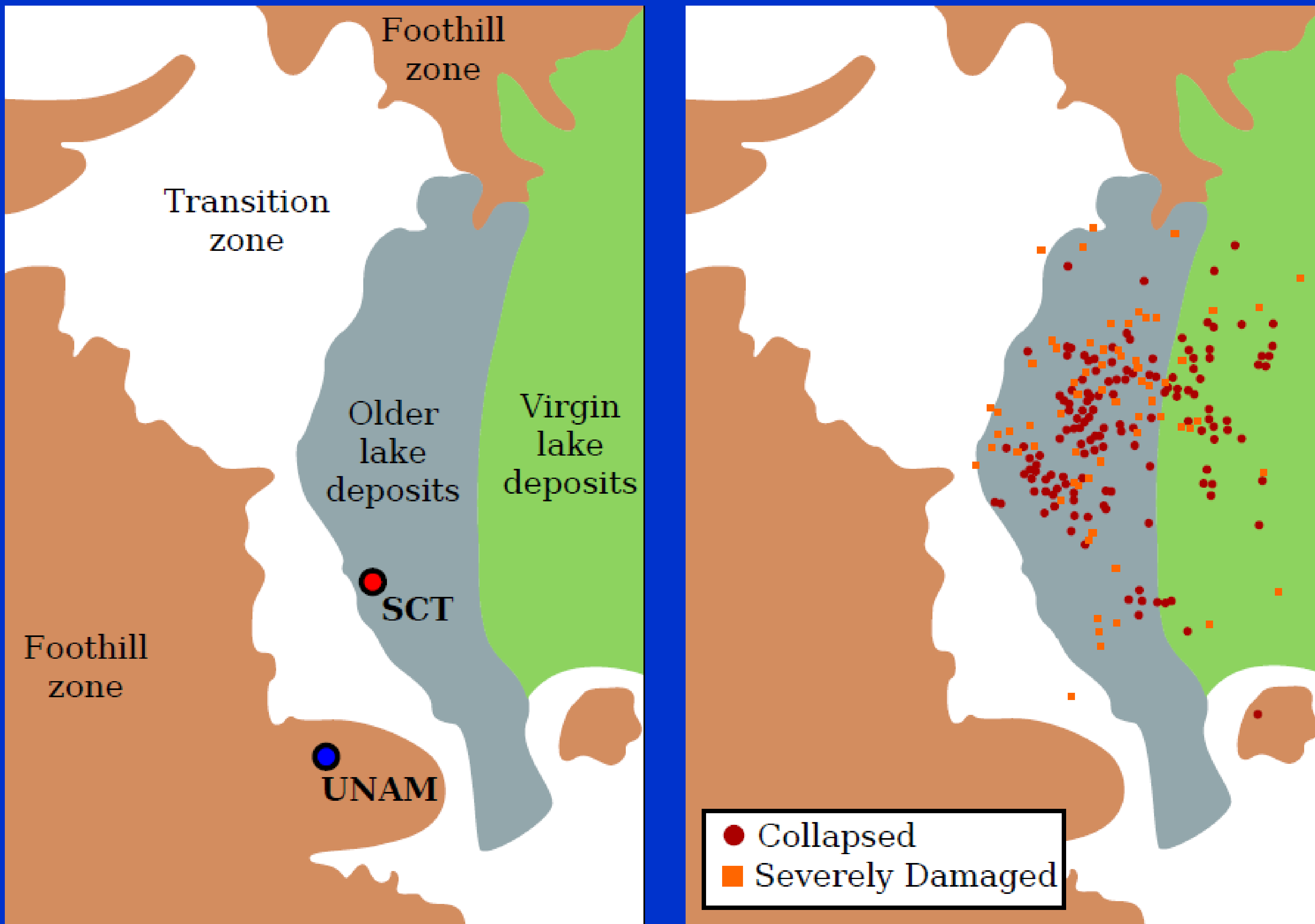
- Some damage near coast
- Most damage in Mexico City
  - Unusual to have severe damage 300 km from earthquake
- Ground shaking was significantly affected by soil conditions in Mexico City
  - Mexico City built on ancient lake bed
  - Very soft clays underlie much of the city

Mexico City

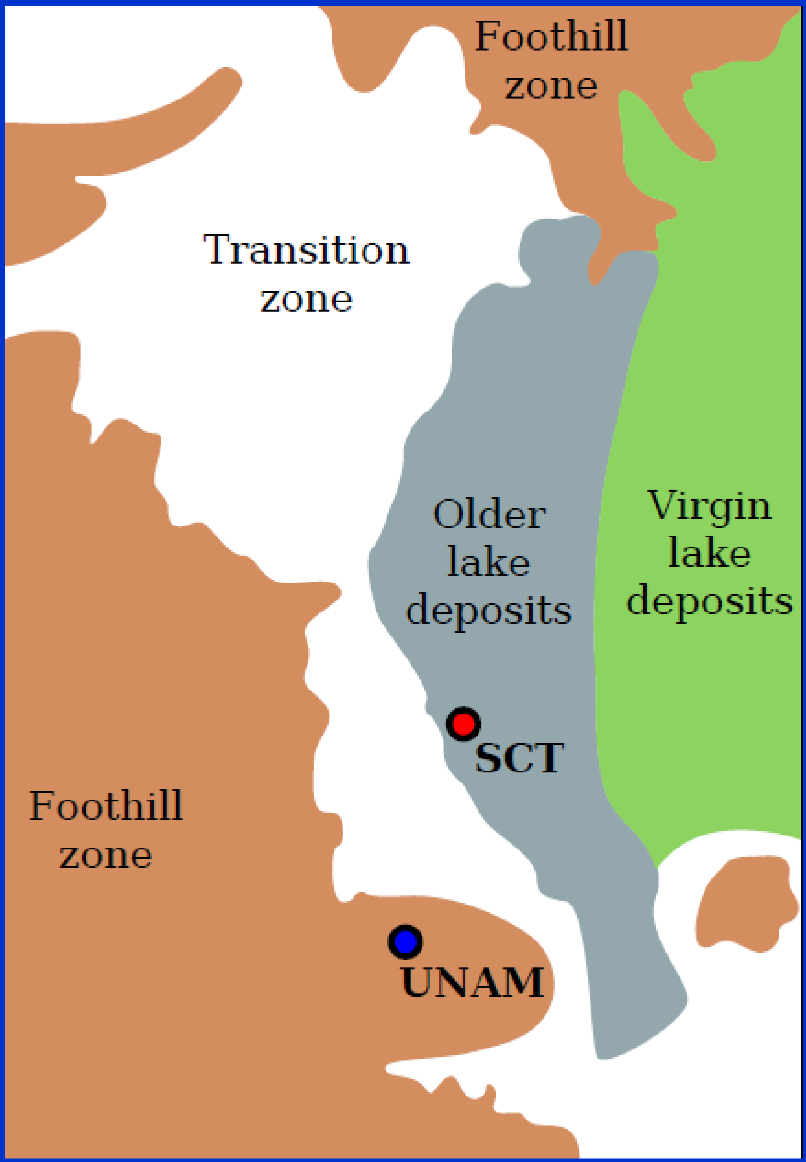


EQ waves

Mexico City


Foothill zone
Transition zone
Older lake deposits
Virgin lake deposits
SCT
Foothill zone
UNAM
Collapsed
Severely Damaged

Mexico City



Foothill zone
Transition zone
Older lake deposits
Virgin lake deposits
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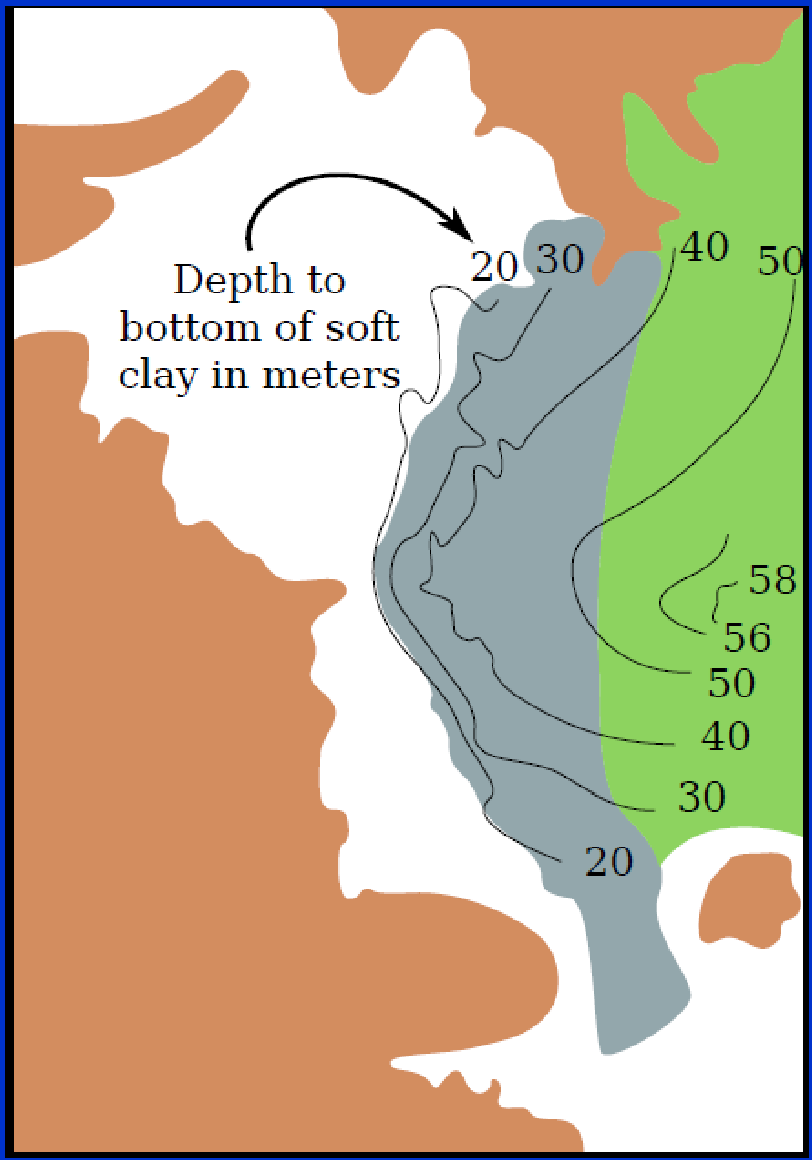
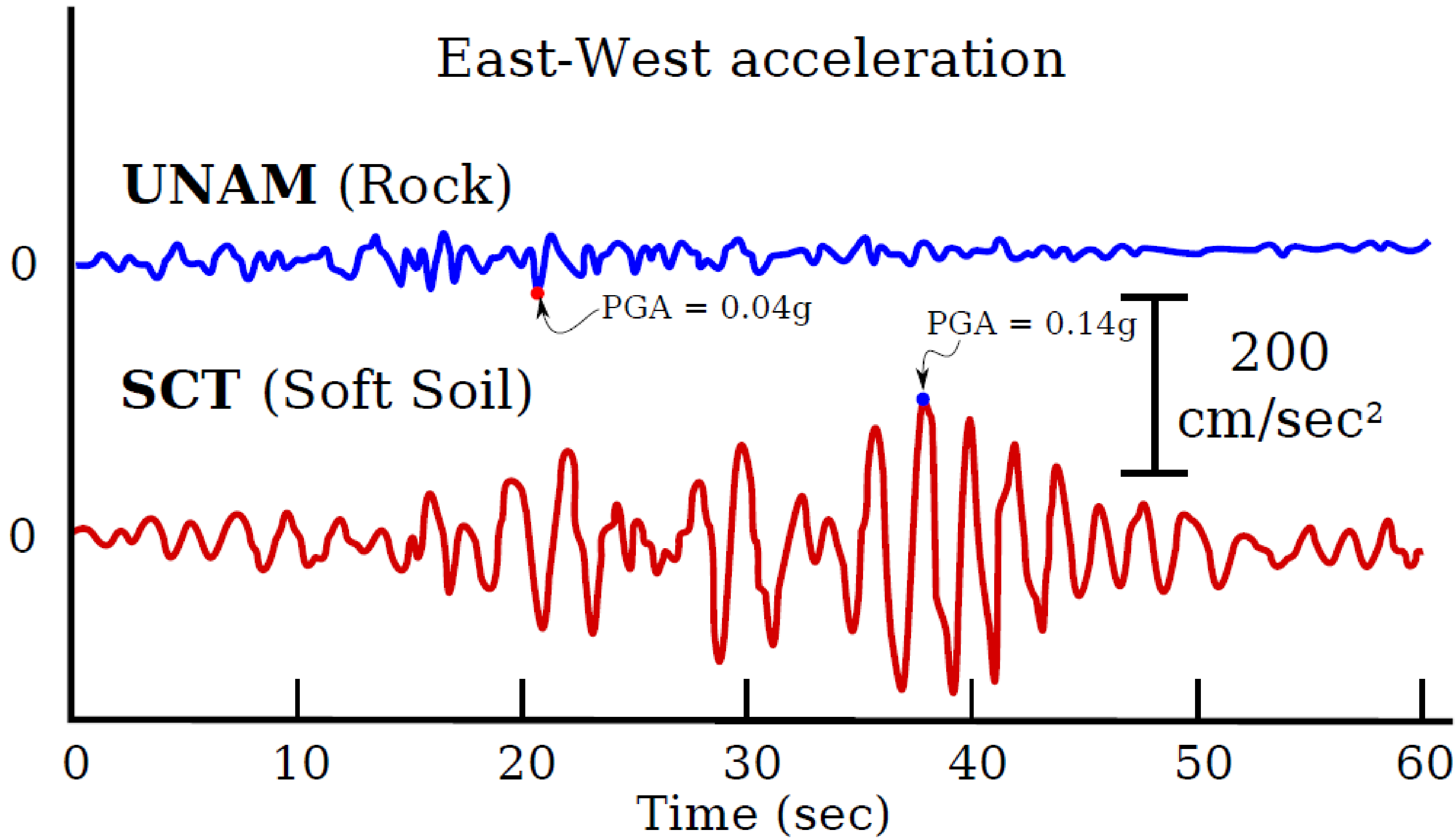
UNAM

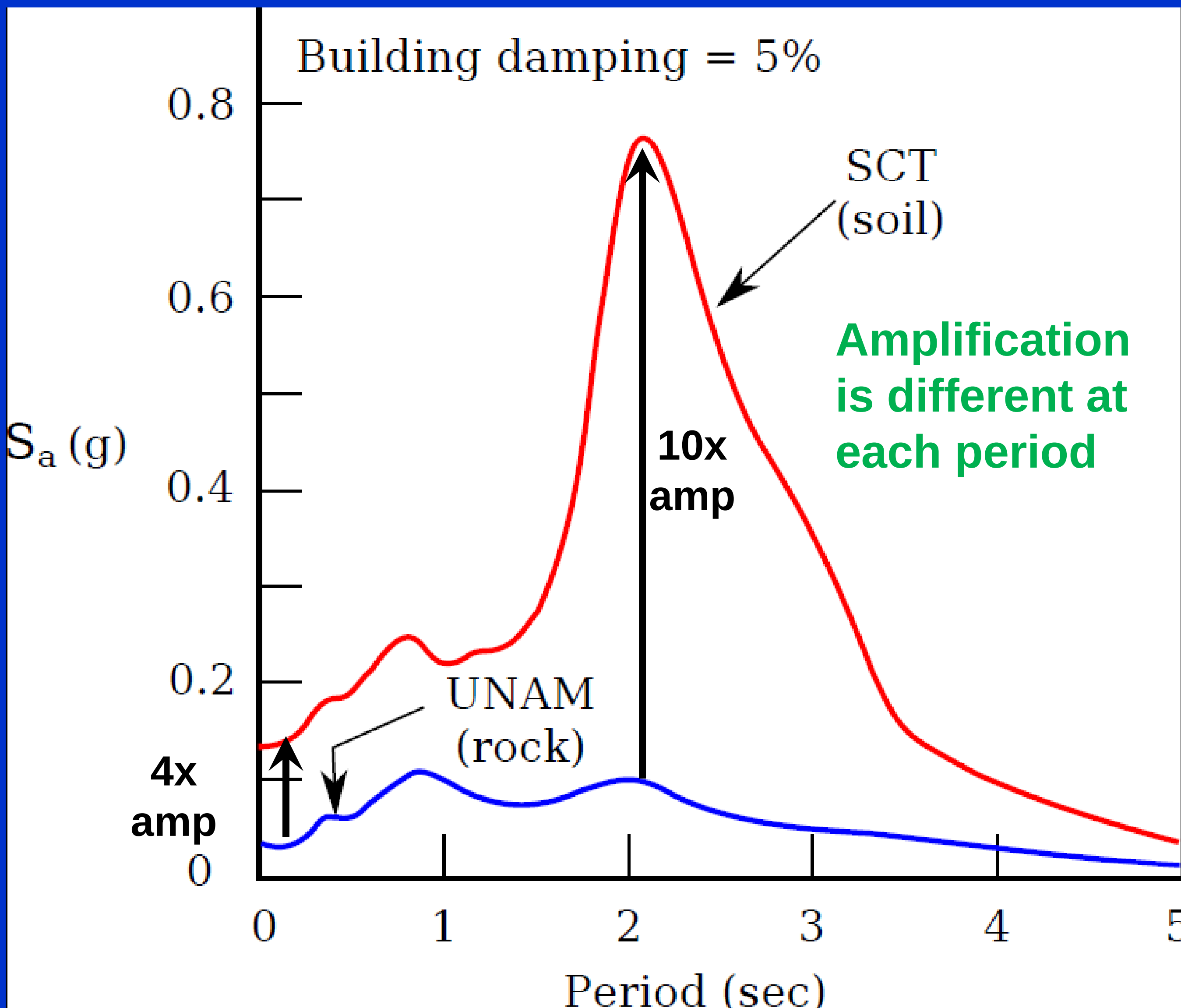


Depth to bottom of soft clay in meters
20
30
40
50
58
56
50
40
30
20

Ground Shaking



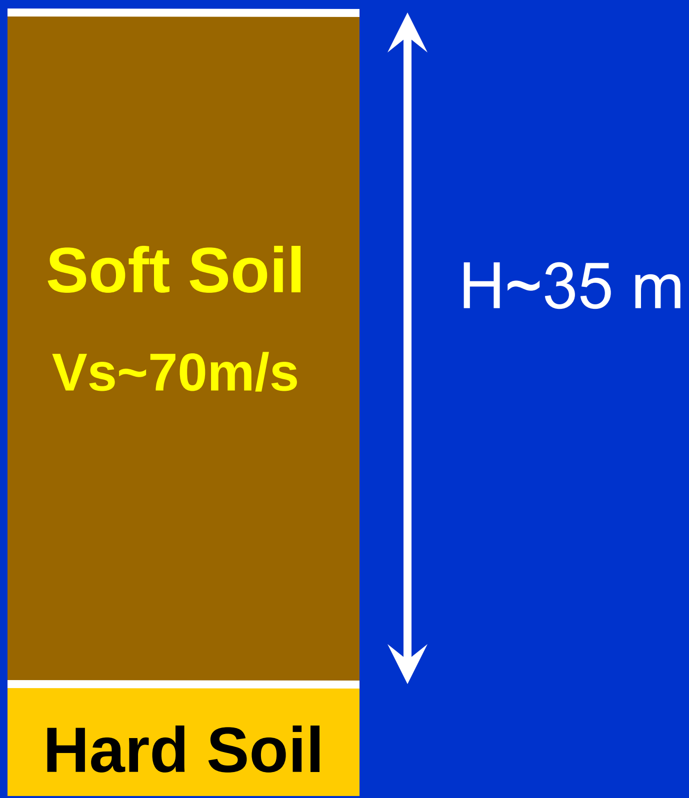
Ground Shaking



Selective Building Damage

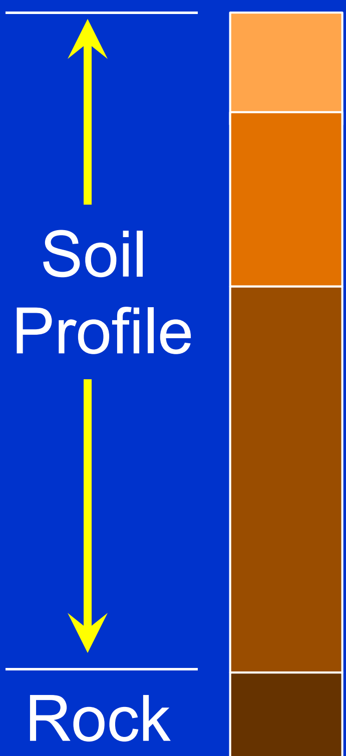
- Dynamic soil response in damaged areas
  - Soil site period, $T_s \sim 2$ s
  - $T_s = 4 H / Vs$

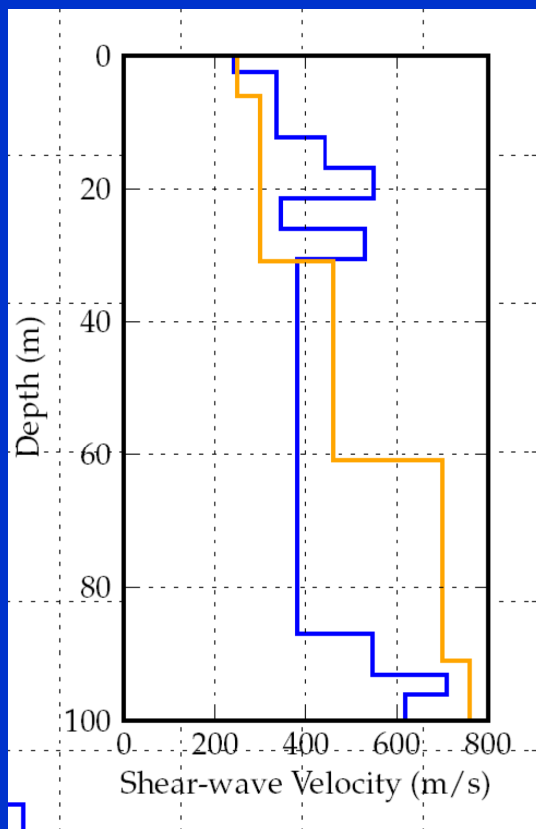
    $= 4(35\ m)/70\ m/s = 2$ s
- Damaged Buildings
  - Mostly taller buildings
  - $T_{bldg} \sim 2$ s
- Areas east with deeper soil, $T_s >> T_{bldg}$

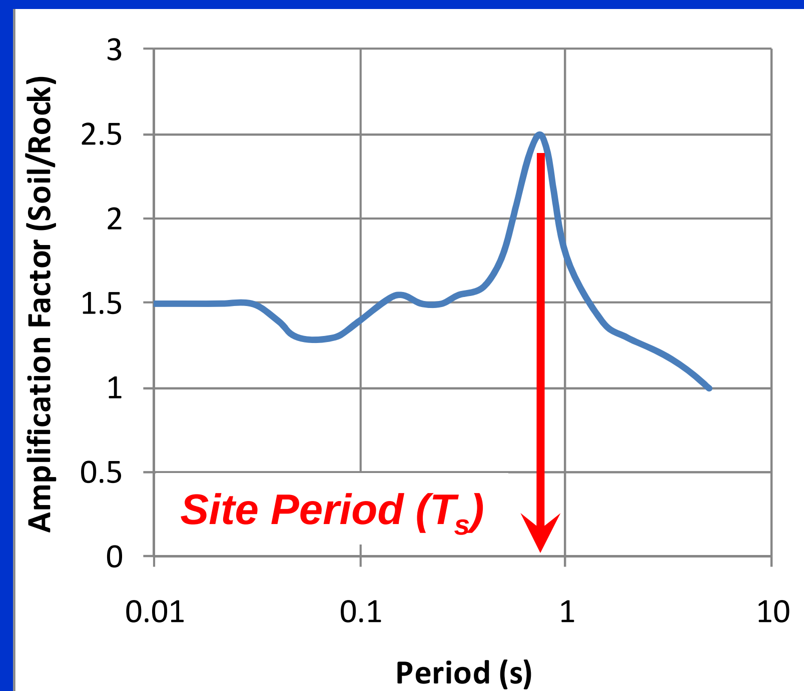


Soil Amplification

- Amplification Factor (AF) = Sa,soil / Sa,rock



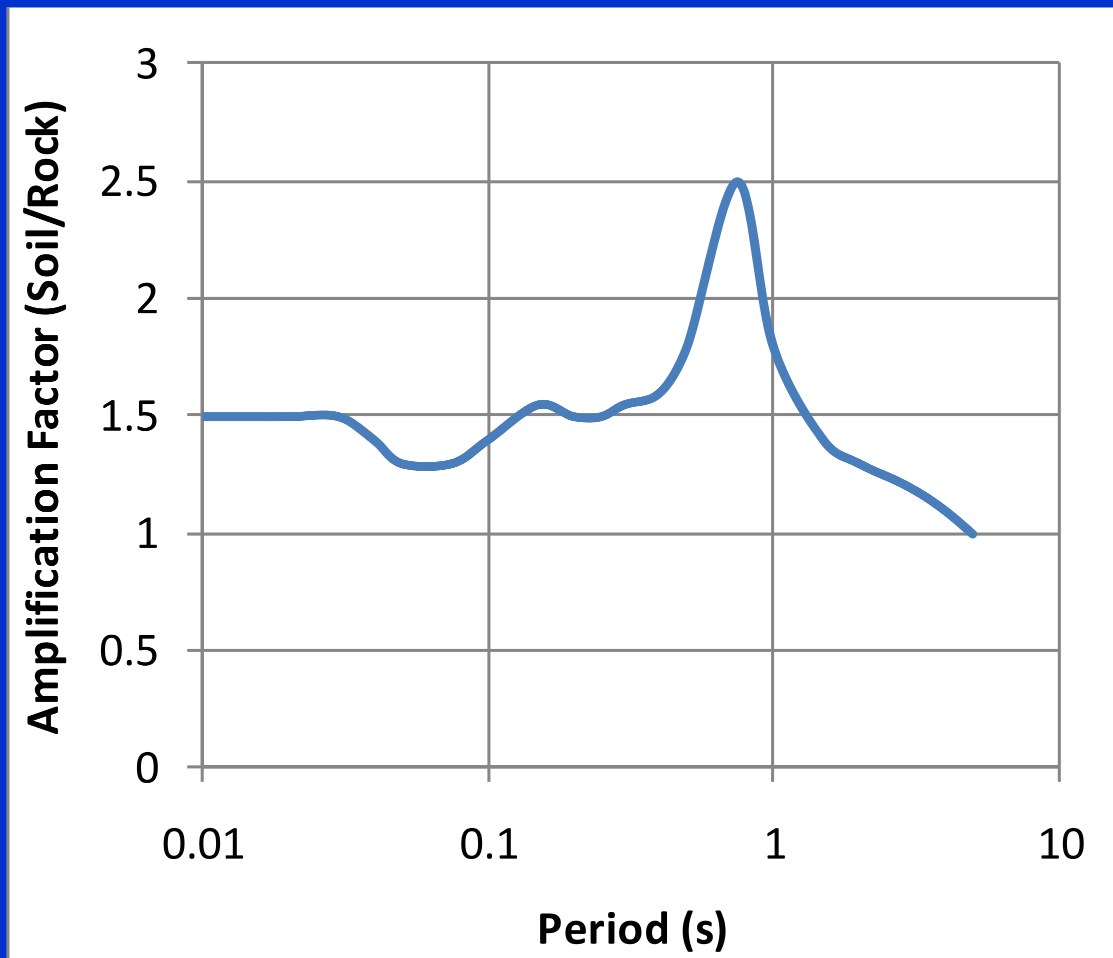




T_S = 4 H / Vs
H: thickness of soil
Vs: avg Vs over H

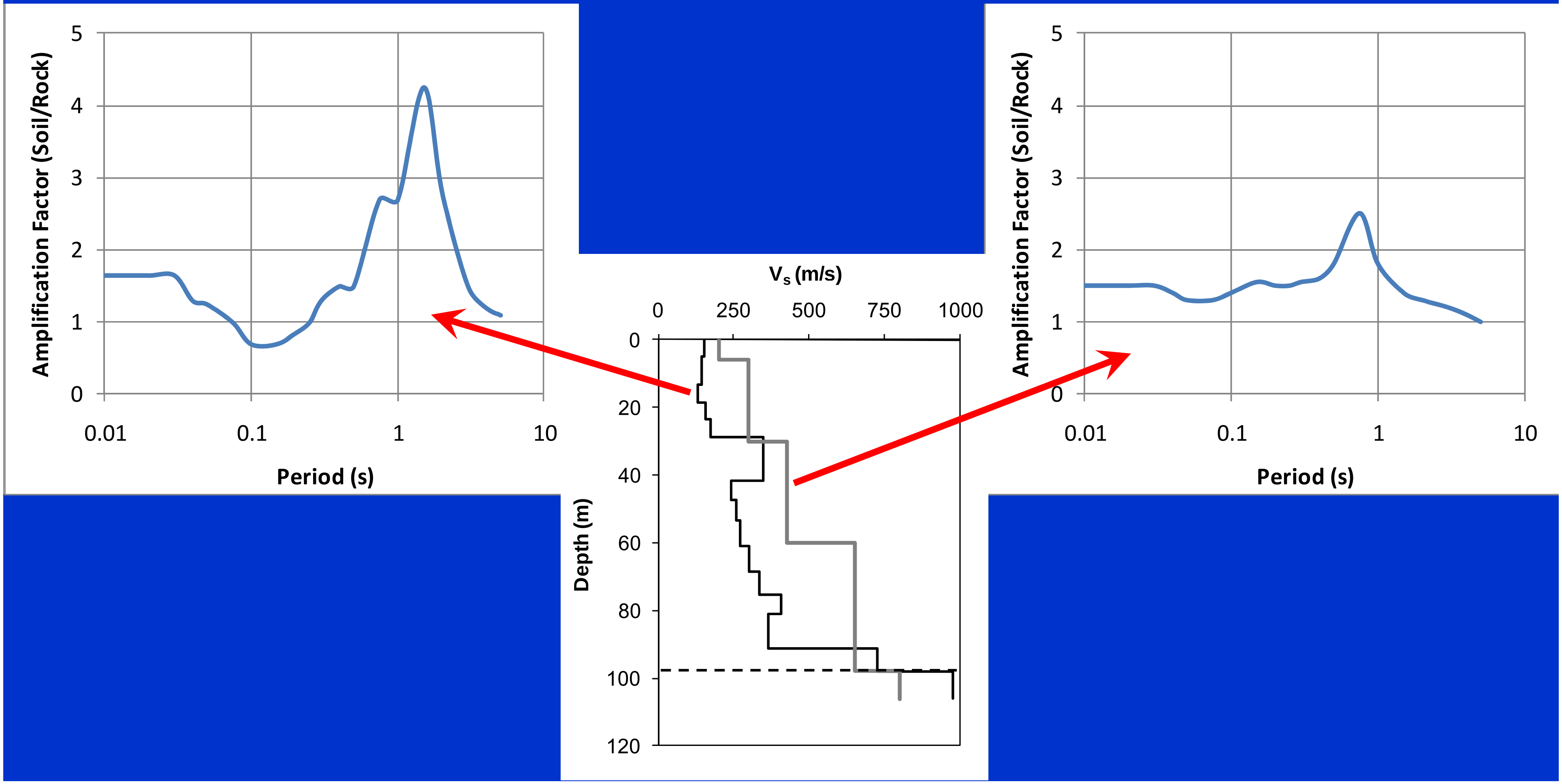
Soil Amplification

- AF's are period dependent



Soil Amplification

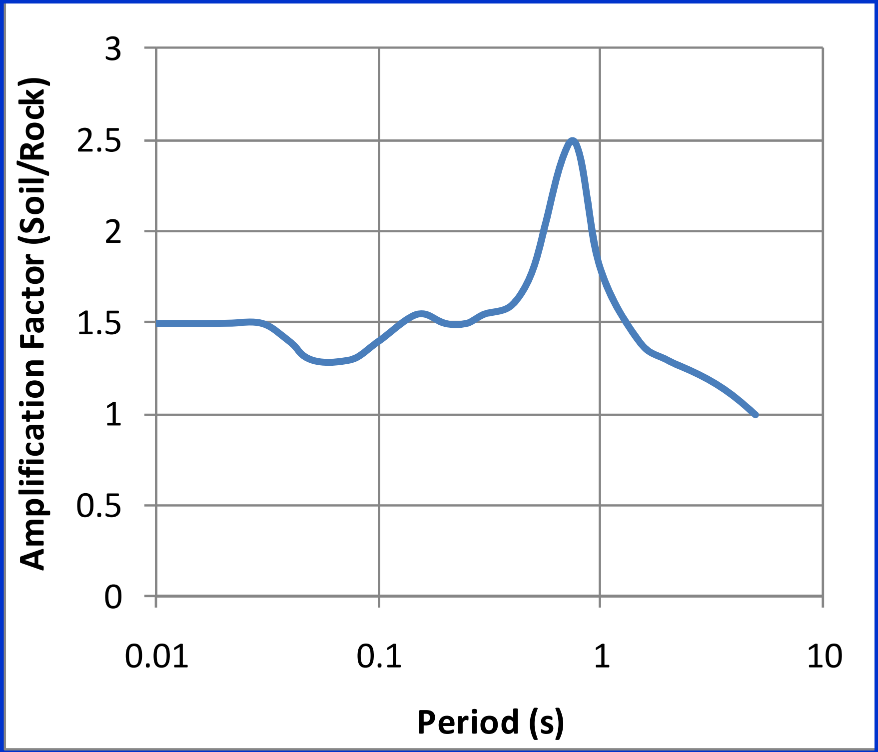
- AF’s are influenced by Vs profile
  - – Softer soil (smaller Vs) → larger AF (generally)



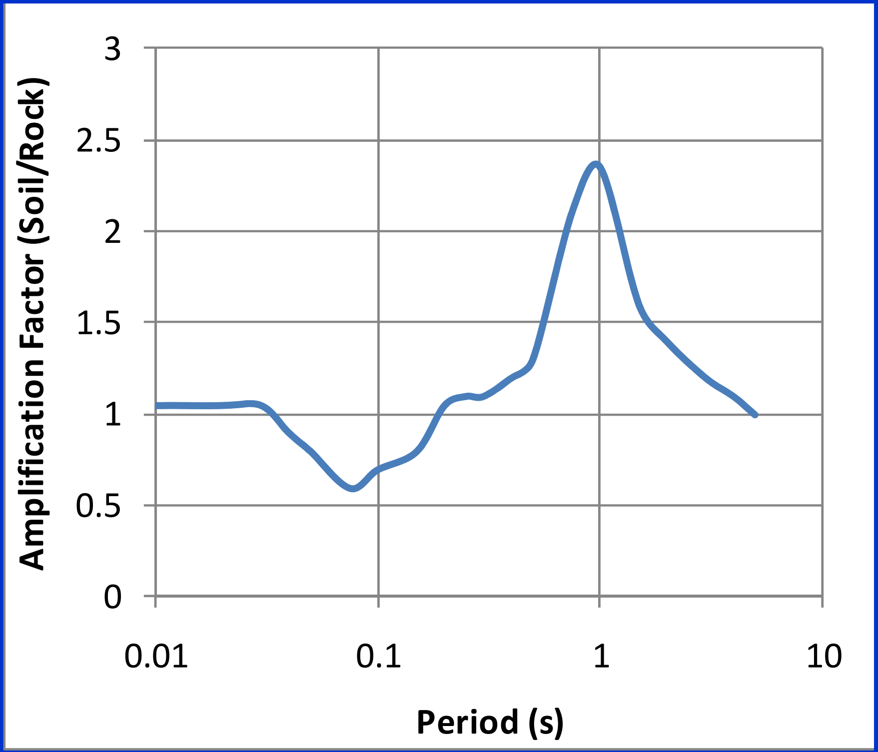
Soil Amplification

- AF's are influenced by level of rock motion
  - Soil is nonlinear

PGArock = 0.1 g



PGArock = 0.4 g



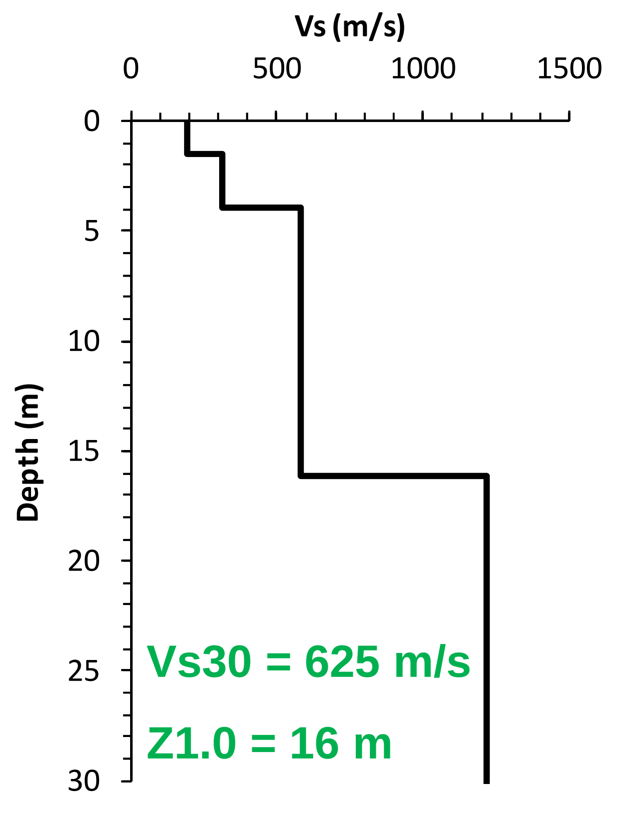
Accounting for Site Effects

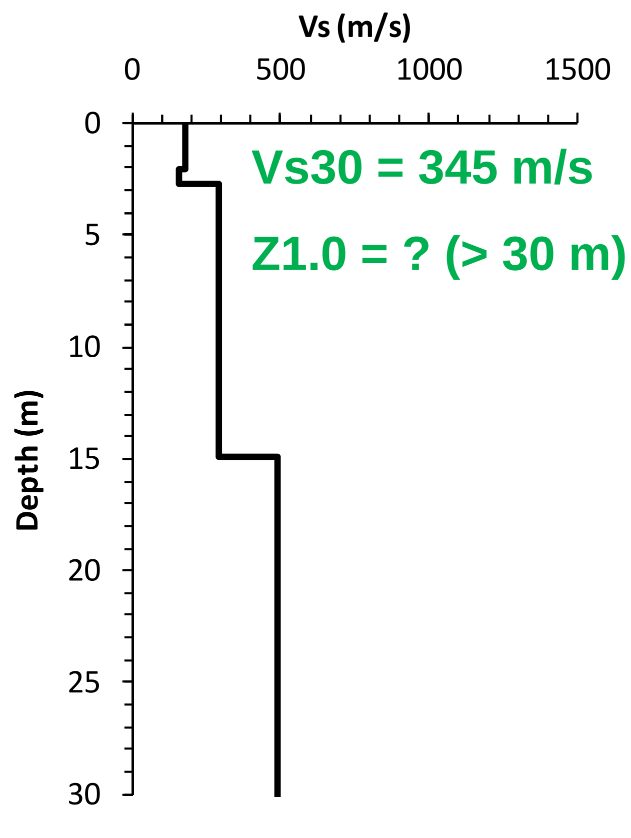
- Simplified Methods
  - Quantify site conditions based on simple parameters (e.g. Vs30)
  - Develop estimates for amplification based on these parameters
- Wave Propagation Analysis (Site Response)
  - Model full Vs profile of soil from bedrock (Vs~760 m/s) to the ground surface
  - Apply motions at base of soil and compute expected amplification at ground surface

Both methods assume a one-dimensional soil profile

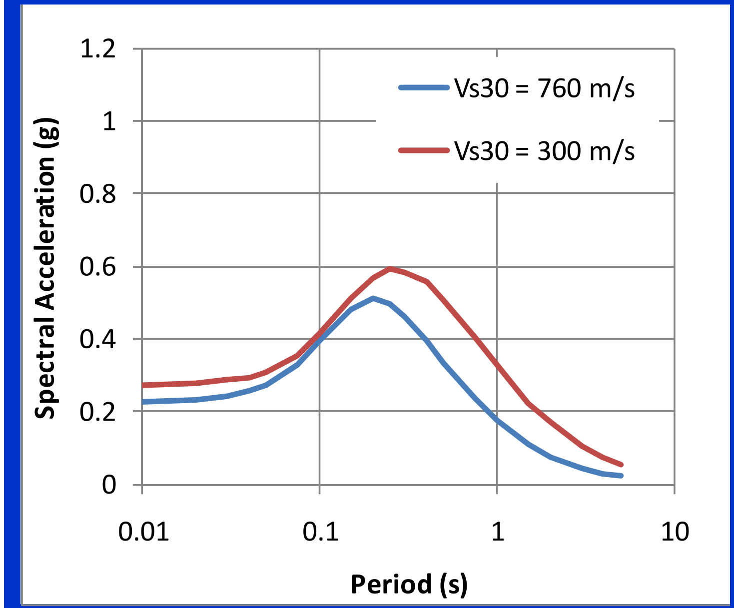
Simplified Methods

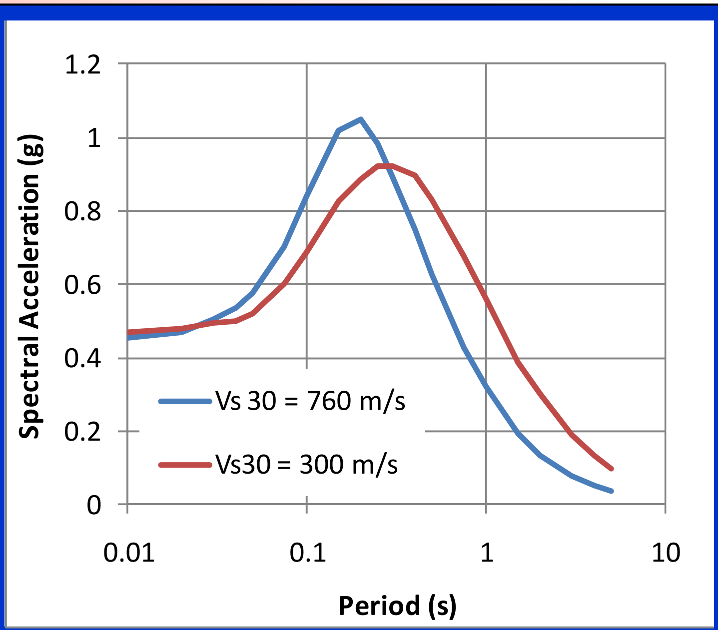
- Parameters
  - Vs30: average Vs over top 30 m
  - Z1.0: depth to Vs=1.0 km/s





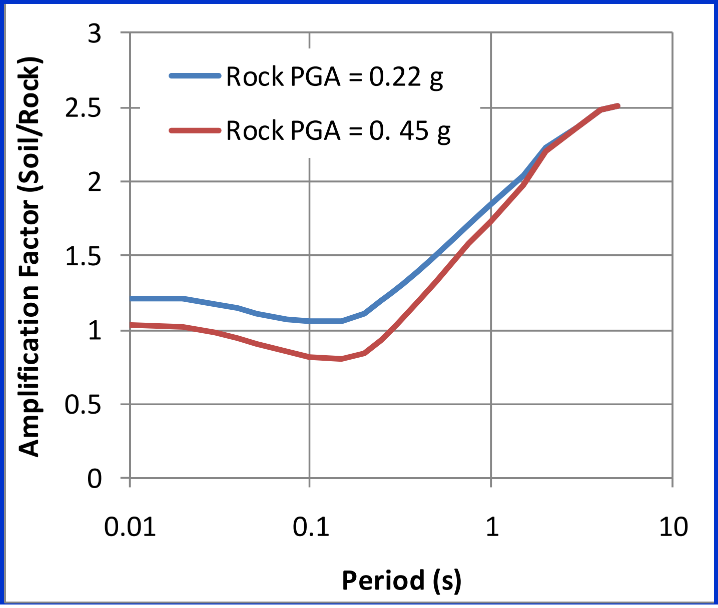
Influence of Vs30: GMPEs



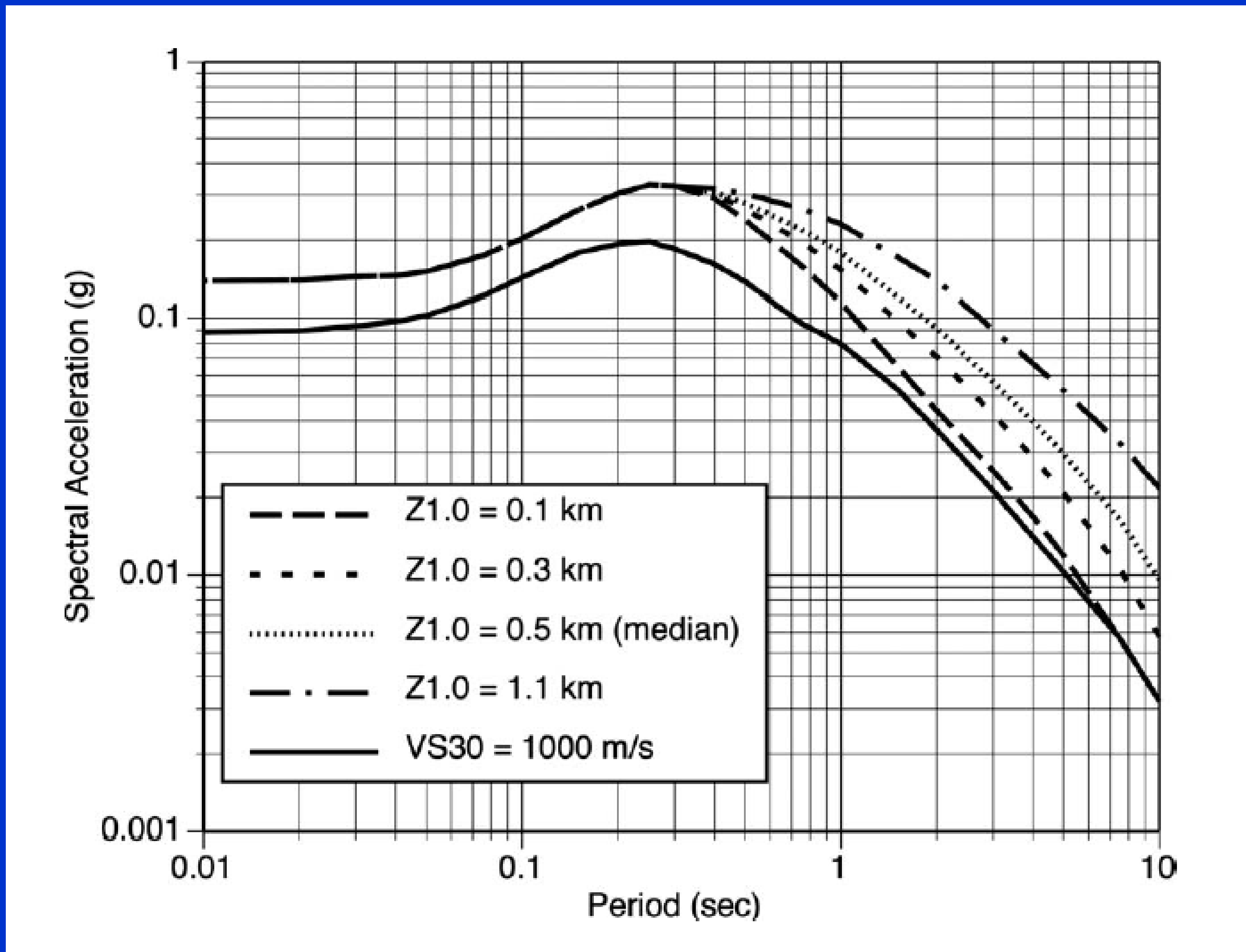


Moderate Rock PGA

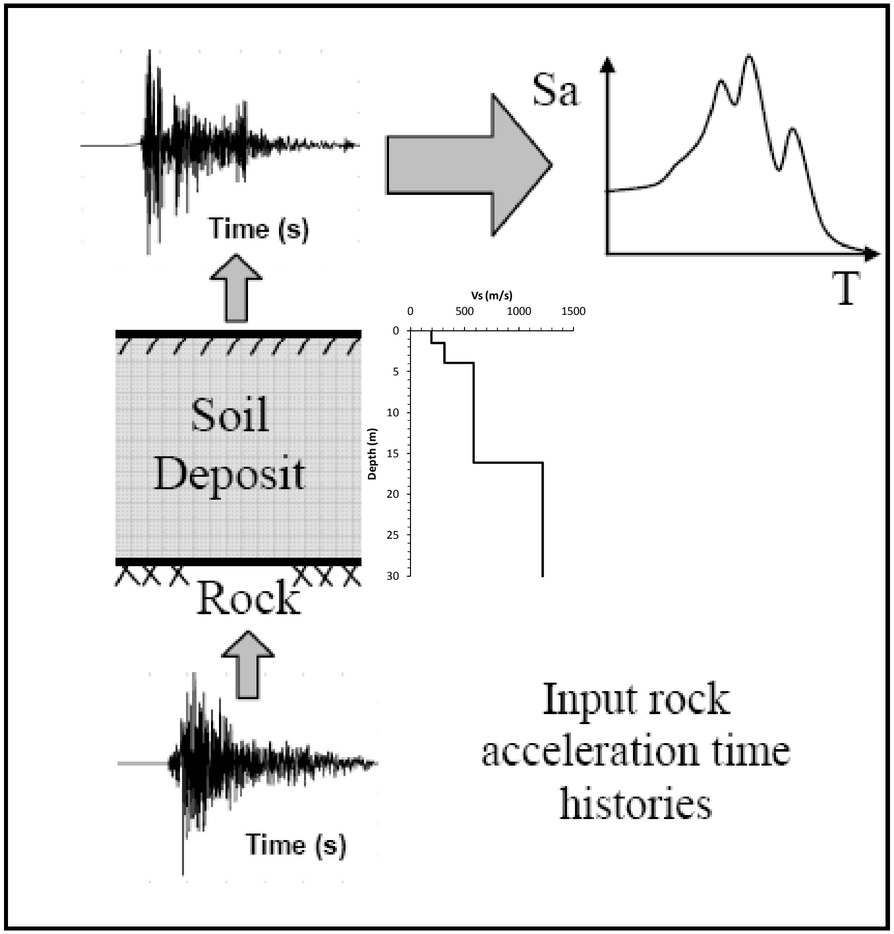
High Rock PGA



Influence of Z1.0: GMPEs



Site Response Analysis



Advantages:

- *Model detailed velocity profile*
- *Model local soil types*

Increased Complexity:

- *Measuring Vs down to bedrock*
- *Selecting input motions*
- *Defining nonlinear soil properties*

Site response program ***Strata*** available for free at:
http://nees.org/resources/strata

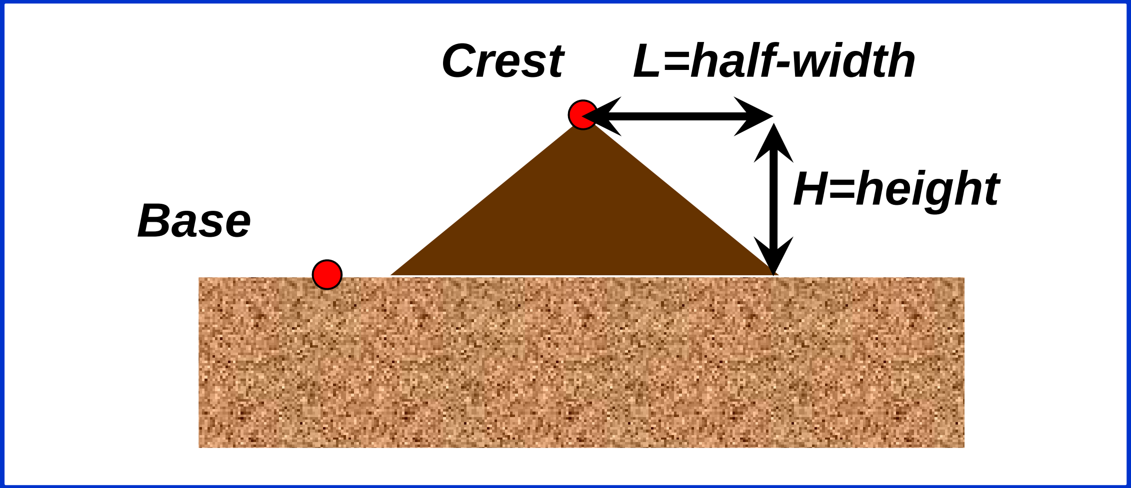
Integration with PSHA

- Define hazard in terms of an acceleration response spectrum on rock (Vs30 ~ 760 m/s)
- Apply soil amplification to rock response spectrum
  - Building code procedure
  - GMPE amplification
  - Site response analysis

Increasing Complexity

Topographic Amplification

- Increase in ground motion intensity due to focusing of waves within hillsides



Amplification = Crest Motion/ Base Motion

Shape Ratio = H / L

Topographic Amplification

- Amplification increases with increasing Shape Ratio

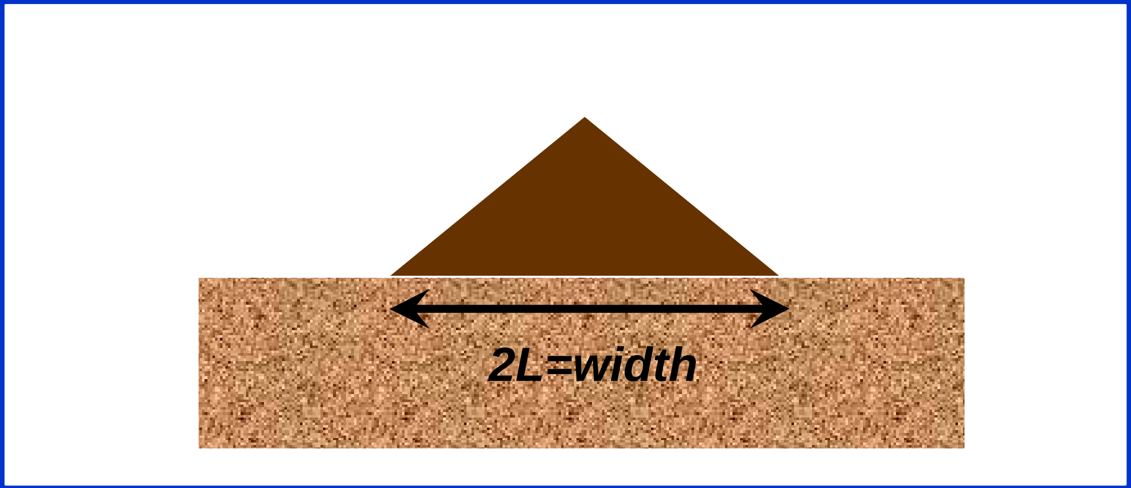
Theoretical Values

H/L	Slope	PGA Amp
0.2	11°	1.0
0.4	22°	1.5
0.6	31°	1.5

Geli et al. (1988)

Topographic Amplification

- Frequencies of maximum amplification: where wavelength equals mountain width



Wavelength of motion = Vs / f
Mountain width = 2L
Amplification frequency, f* ~ Vs / 2L

Larger Vs or smaller L → *f** increases

Topographic Effects

- Field measurements of topographic effects generally larger than theoretical predictions
  - PGA: Theoretical ~ 1.2 to 1.5; field ~ 1.5 to 3.5
  - At *f**: Theoretical ~ 2.0 to 4.0; field ~ 4.0 to 10
- Reasons for inconsistency
  - Complexity of natural ridges vs. theoretical models
  - Interaction of adjacent ridges
  - Underlying velocity structure
  - 3D geometry

No standard procedure to predict topographic amplification

Summary

- Soil Amplification
  - Amplification depends on soil properties and input intensity
  - Amplification is period-dependent
  - Apply soil amplification factors to rock acceleration response spectrum
- Topographic Amplification
  - Ridges can amplify motions
  - Complex problem with no standard procedure for estimation