Implementation of near-fault forward directivity effects in seismic design codes

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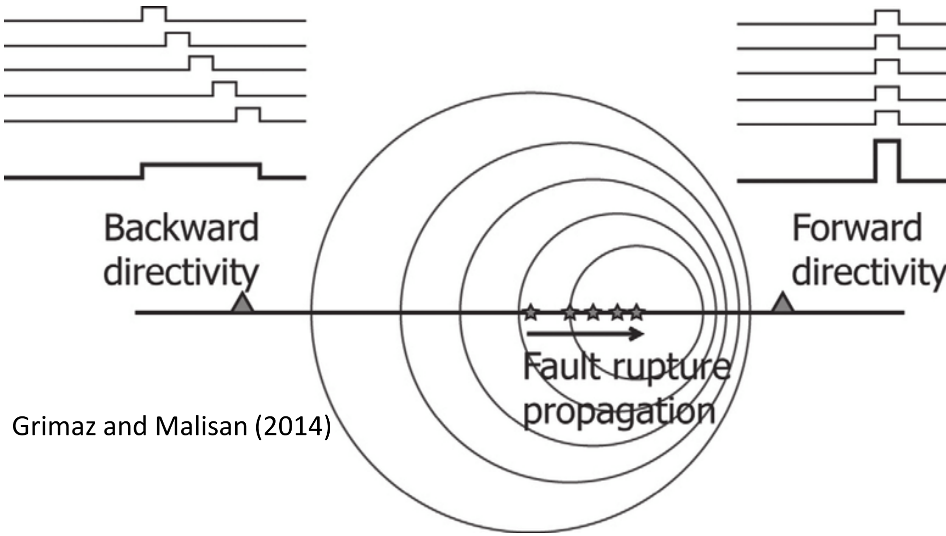
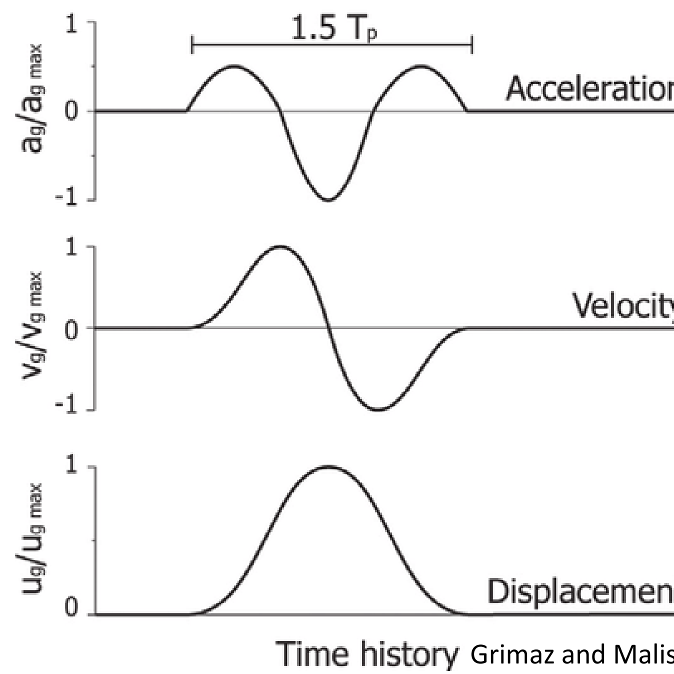
Forward directivity



Grimaz and Malisan (2014)

The rupture front arising towards the site (forward directivity) leads to a distinct long-period and large amplitude velocity pulse that results in unexpected demands on structural systems



Grimaz and Malisan (2014)

A double-sided forward directivity velocity pulse increasing the amplitude of ground motions towards longer periods

Facts

- Studies on recorded near-fault ground motions and their effects on structures have started almost 50 years ago (e.g., Housner and Trifunac, 1967)
- In the last two decades, many seismological models have been developed to estimate ground-motion (spectral) amplitude demands due to near-fault effects (e.g., Sommervile et al. 1997)
- The near-fault effects can now be incorporated into PSHA (e.g., Shahi and Baker, 2011)
- However, complete consideration of near-fault effects (in particular forward directivity) by design codes is still limited (e.g., UBC, 1997)

Objective

Consider the recently developed directivity models and integrate some of them to PSHA

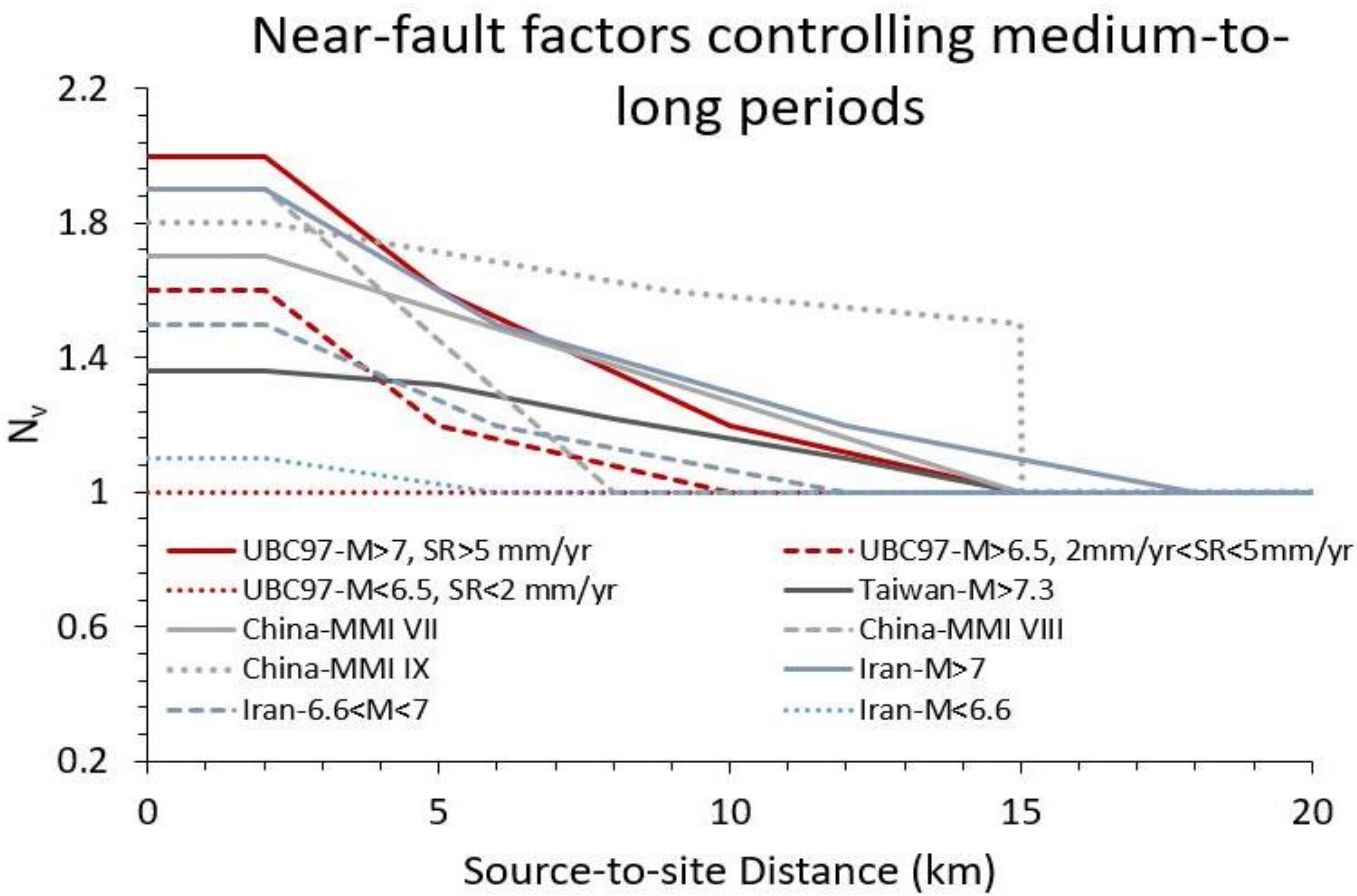
Run case studies using an in-house PSHA code to see how magnitude, fault-site geometry, slip rate and return period effect the spectral amplitudes when directivity is prominent

Simplify these observations as much as possible to extract some rules to incorporate near-fault forward directivity effects in design codes

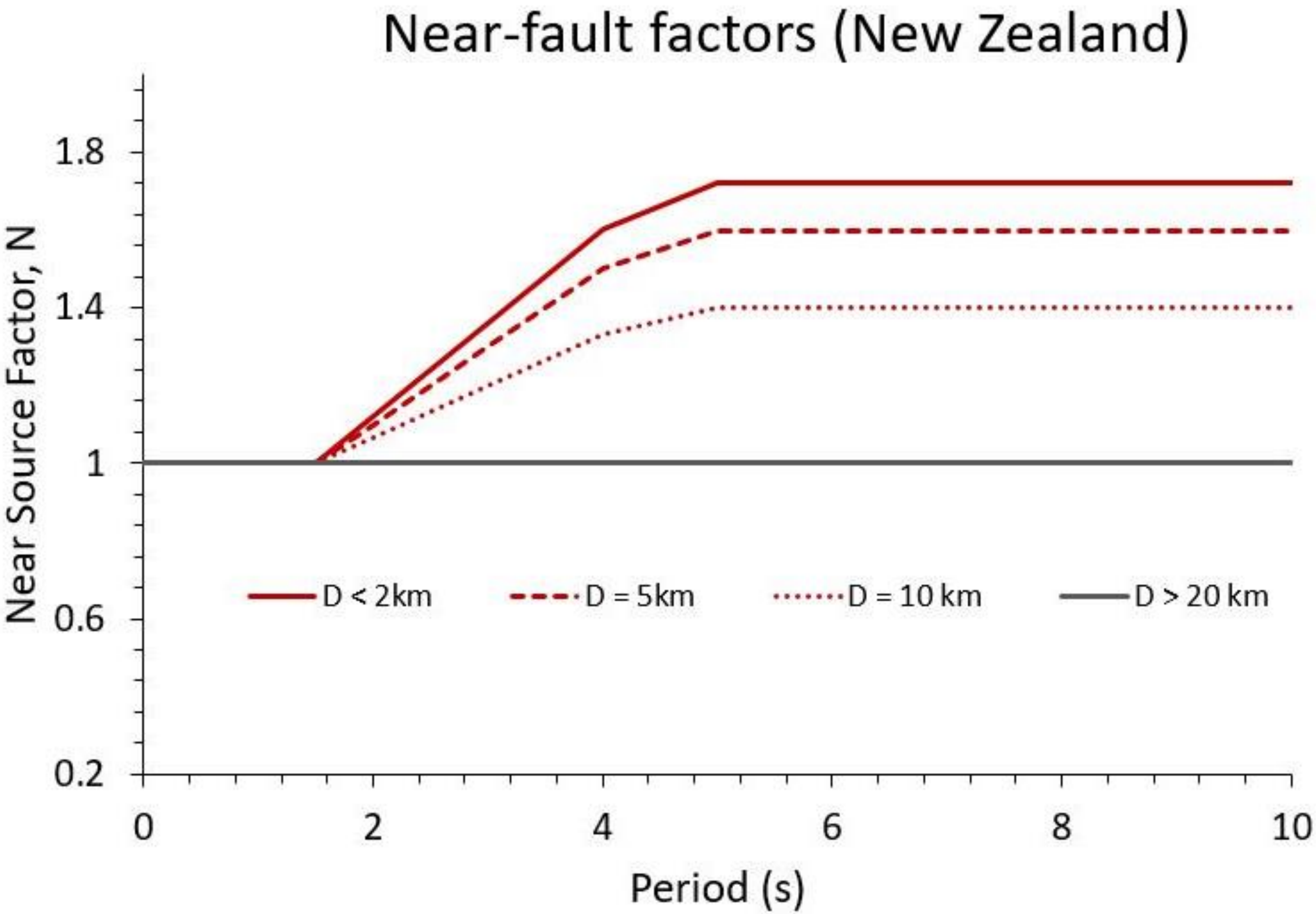
Outline

- Current code approaches
- Selected directivity models
- Important features of directivity models
- Rules for code implementation
- Observations
- Conclusions

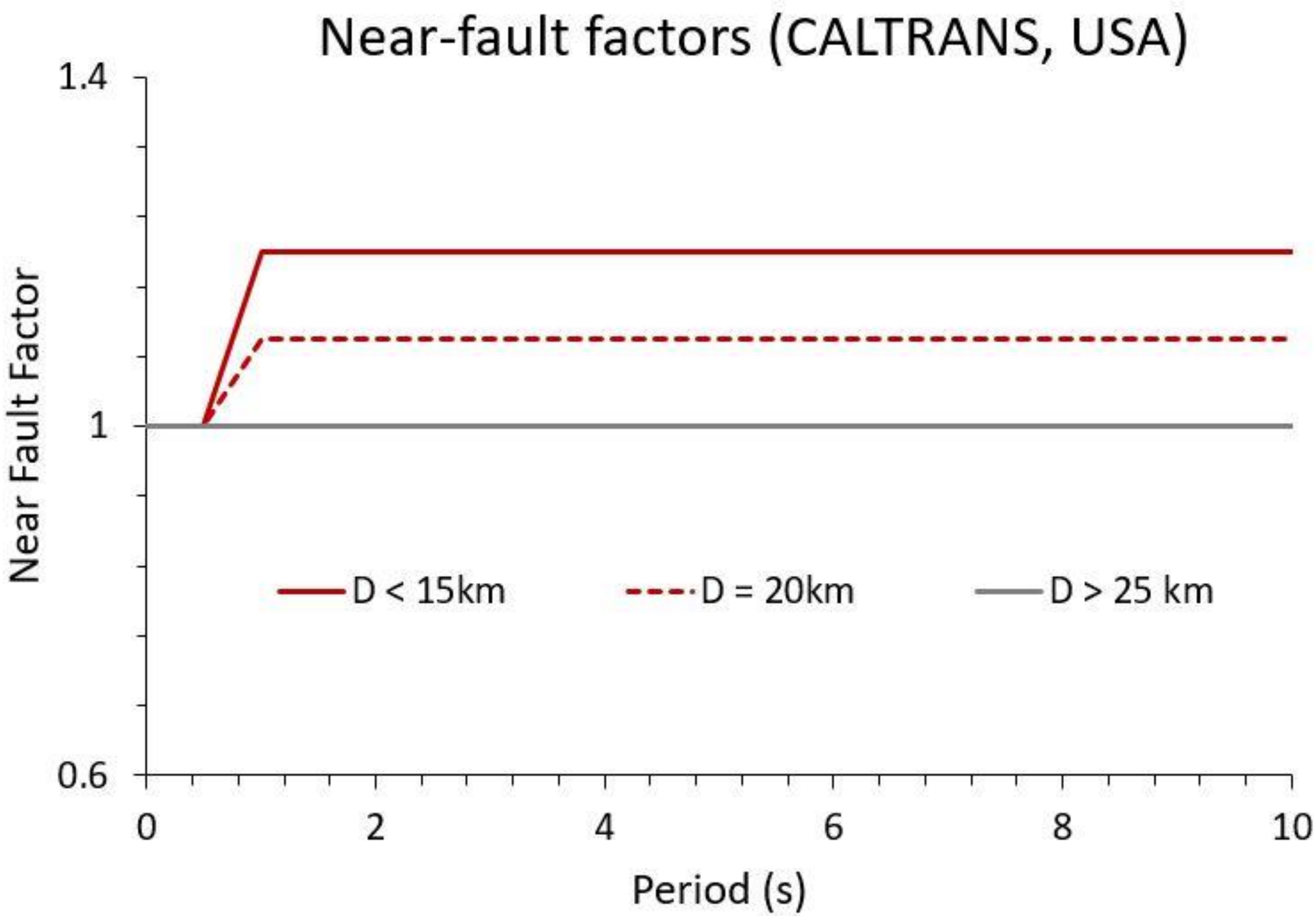
Current Code Approaches (1/3)



Current Code Approaches (2/3)



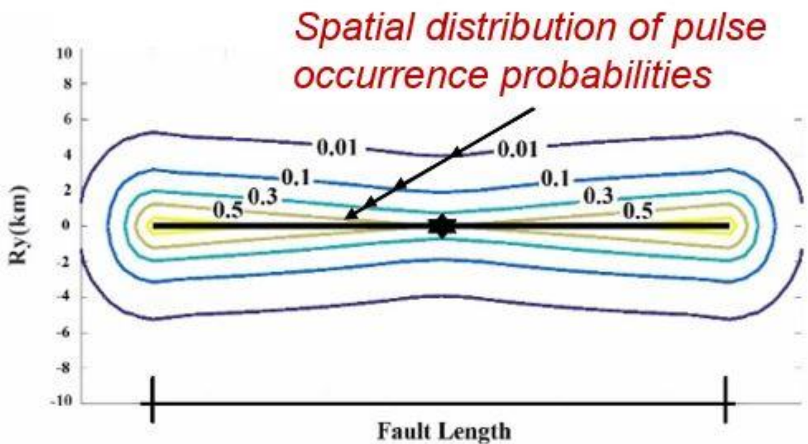
Current Code Approaches (3/3)

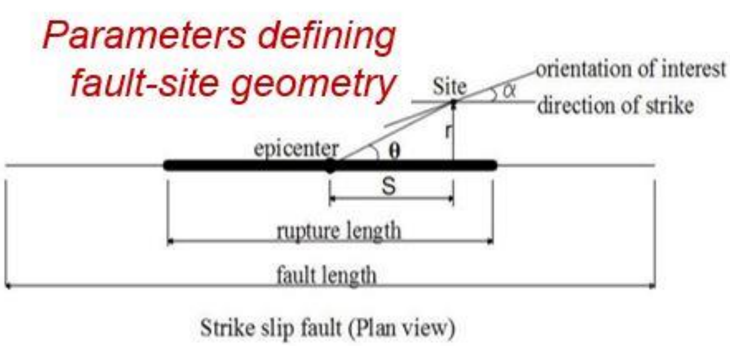


Directivity models considered (Shahi and Baker, 2011; SHB11)

- A probabilistic seismic hazard model
- Uses a modified ground-motion predictive model (GMPM) to compute Pr($S_a > x$) given an earthquake scenario magnitude *m*, distance to ruptured fault segment *r* and fault-site geometry *z*.

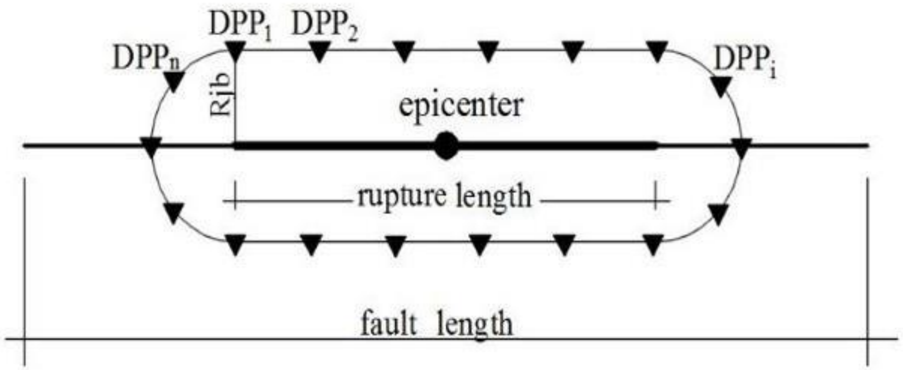
SHB11 defines the probability of observing a pulse and its occurrence for a range of orientations (relative to fault strike, α) from fault-site geometry (larger pulse occurrence probability at fault edges)





Directivity models considered (Chiou and Spudich, 2013; CHS13)

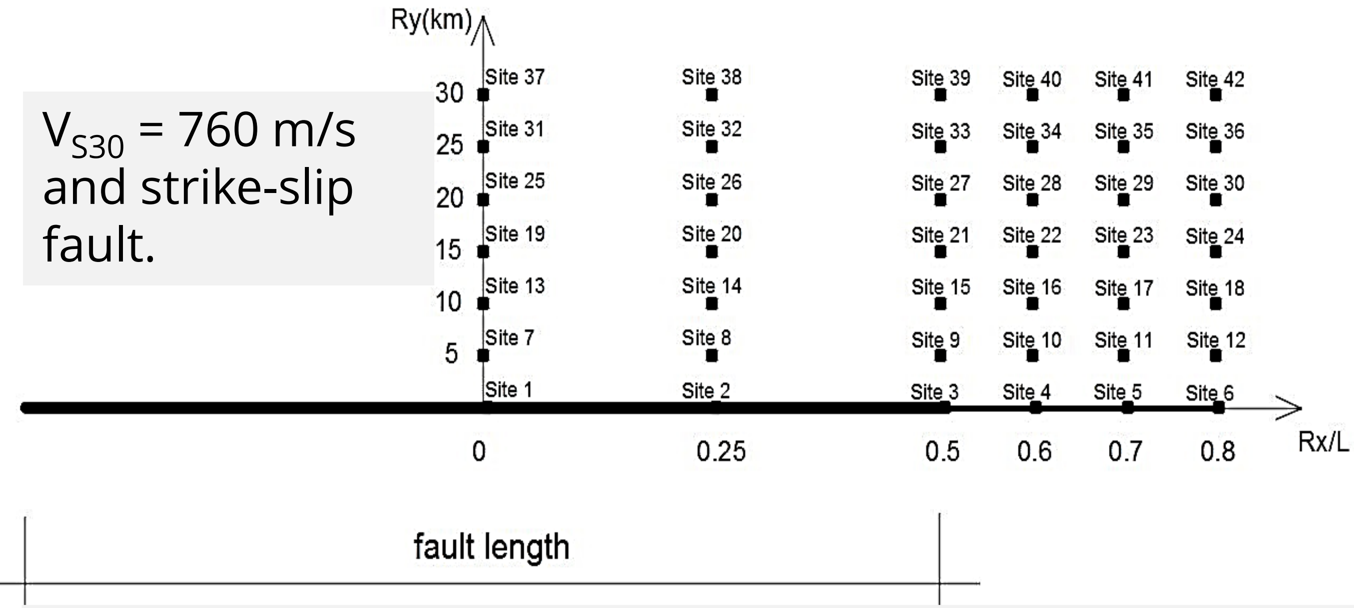
- The GMPM by Chiou and Youngs (CY14) uses DPP as the predictor of forward directivity effect.
- Given an earthquake scenario, CY14 centers DPP on its mean ($\overline{DPP}$) over a suite of sites located at the same distance. The influence of forward directivity at a specific site *i* is determined by subtracting the ($\overline{DPP}$) from DPP_i (ΔDPP).



Large ΔDPP indicates stronger forward directivity effects. When ΔDPP is zero, the site of interest is not dominated by the pulselike waveforms due to directivity.

PSHA calculations

V_{S30} = 760 m/s and strike-slip fault.



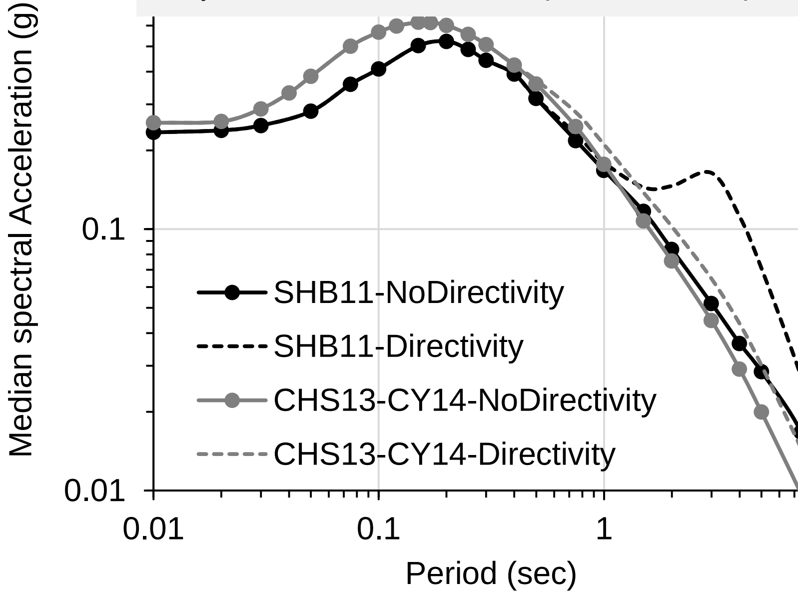
SHB11: Geomean (GMRotI50) to fault-normal horizontal component (when directivity is dominant)
CHS13: RotD50 to directivity dominated RotD50

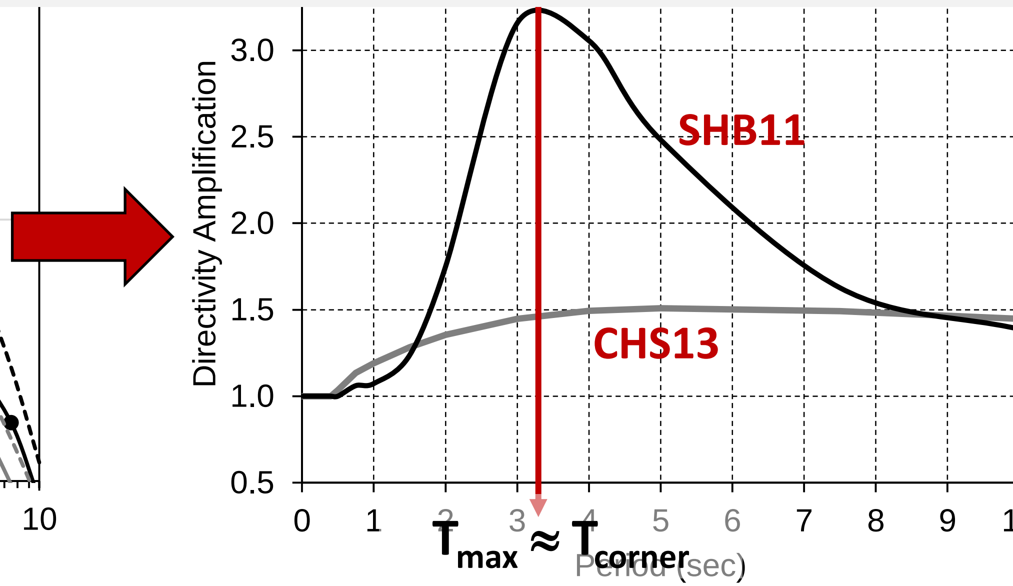
$$Directivity\ Amp.: \frac{Fault\ Normal\ (directivity)}{Geomean\ (no\ directvity)}\ or\ \frac{RotD50\ (directivity)}{RotD50\ (no\ directivity)}$$

- Suite of PSHA analysis using the site layout given on the left for
  - Slip rates (SR) equal to 0.5 cm/yr, 1.0 cm/yr and 2.0 cm/yr
  - Return periods (RP) equal to 475 yr and 2475 yr
  - Characteristic fault magnitudes (M_{ch}) equal to 6.25, 6.7, 7.0, 7.2 and 7.5

Important Model Features (1/2)

Deterministic case study: A strike-slip earthquake of M_w 7.1. The site is at the far end of the fault, 5 km to the ruptured segment. The hypocenter is at the center of the ruptured fault area (w = 10km).



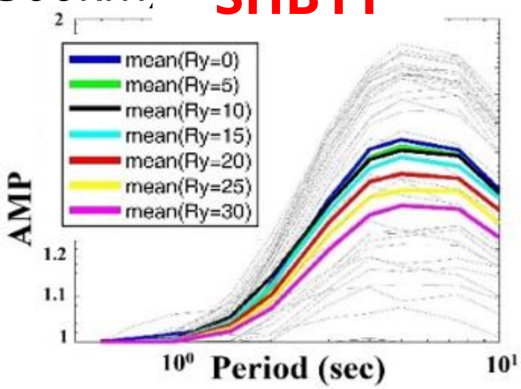


- SHB11 marks the pulse influence more and its directivity amplifications are higher because the directivity dominant spectral amplitudes are estimated for fault-normal component. CHS13 estimates directivity dominant spectral amplitudes for RotD50.
- The directivity amplitudes become maximum approximately at the same period (T_{corner} for CHS13 and T_{max} for SHB11).

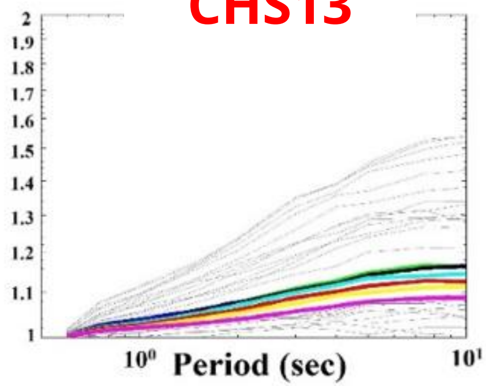
Important Model Features (2/2)

2475-year return period directivity amplifications for a strike-slip fault of s = 2.0 cm/year) that is capable of producing characteristic earthquakes of M_{ch} 7.3 (i.e., L = 300km)

SHB11

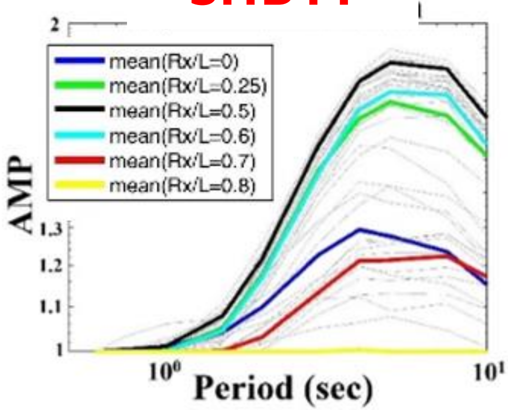


CHS13

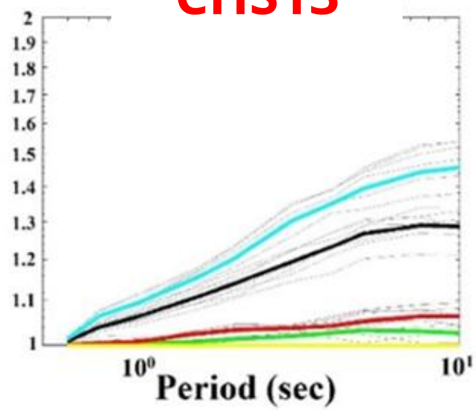


Directivity amplifications at different distances perpendicular to fault strike (R_y = 0, 5, 10 15, 20, 25, 30 km). Thick colored lines are mean directivity amplifications for each R_y

SHB11

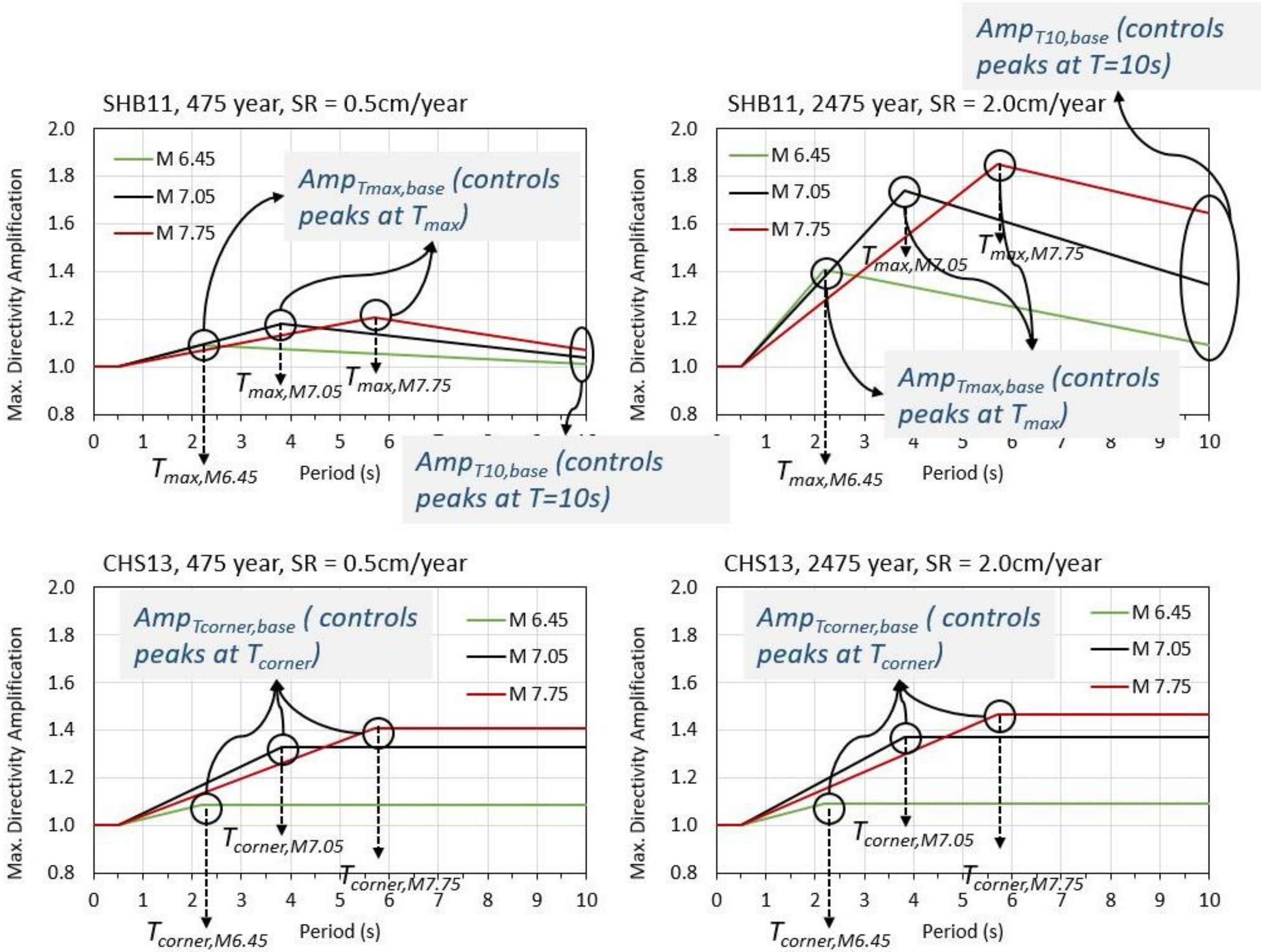


CHS13



Directivity amplifications at different locations along the fault strike (R_x/L= 0, 0.25, 0.5 0.6, 0.7, 0.8). Thick colored lines are mean directivity amplifications for each R_x/L.

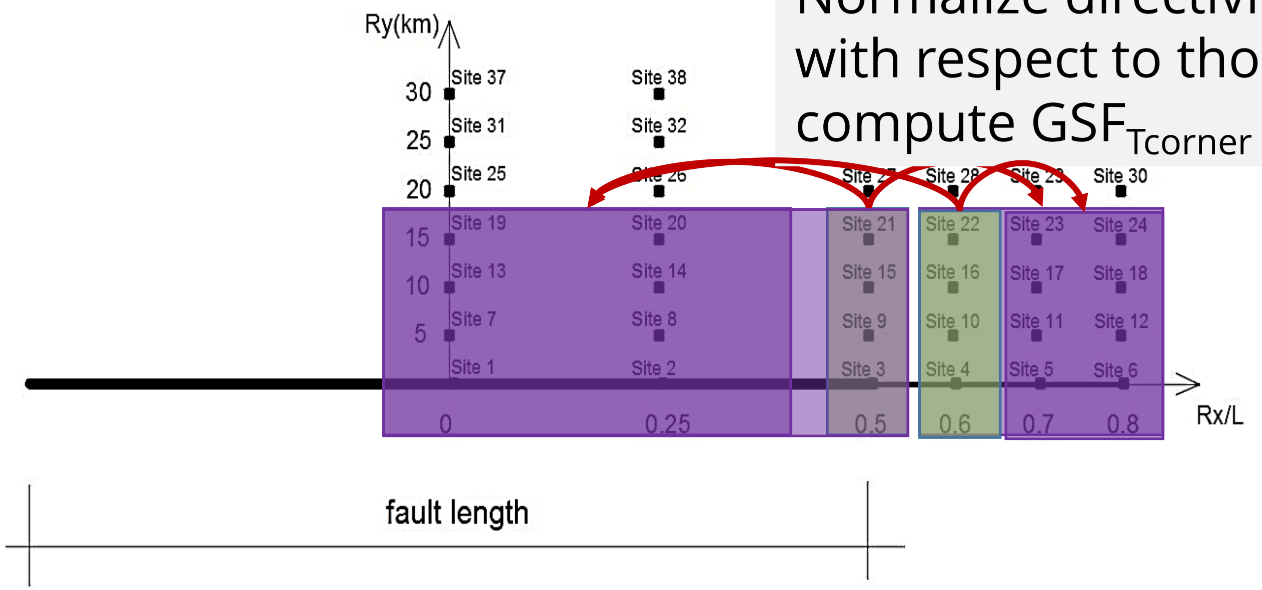
Directivity Rules for Codes (1/3)



Directivity Rules for Codes (2/3)

- Directivity amplications at other sites (again for rupture distances up to 15 km) are computed from by modifying base functions ($Amp_{Tmax,base}$ and $Amp_{T10base}$ for SHB11 and $Amp_{Tcorner,base}$ for CHS13). The modification factors are called as geometry scale factors: GSF_{Tmax} and GSF_{T10} for SHB11 and $GSF_{Tcorner}$ for CHS13.

Normalize directivity amplifications with respect to those at R_x/L = 0.6 to compute $GSF_{Tcorner}$ for CHS13

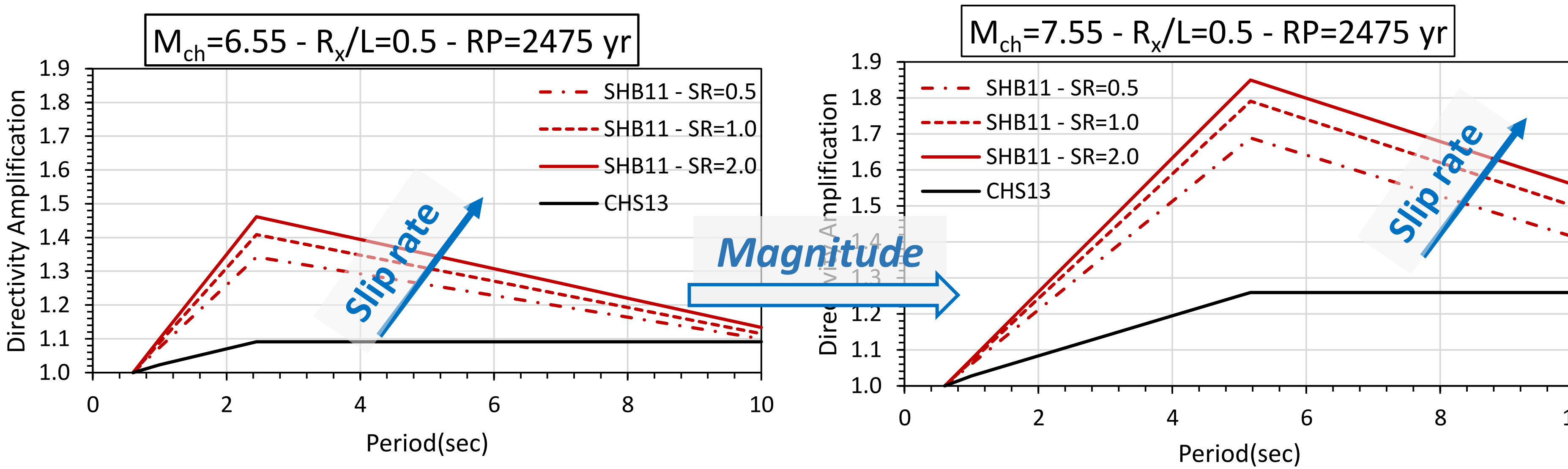


Directivity Rules for Codes (3/3)

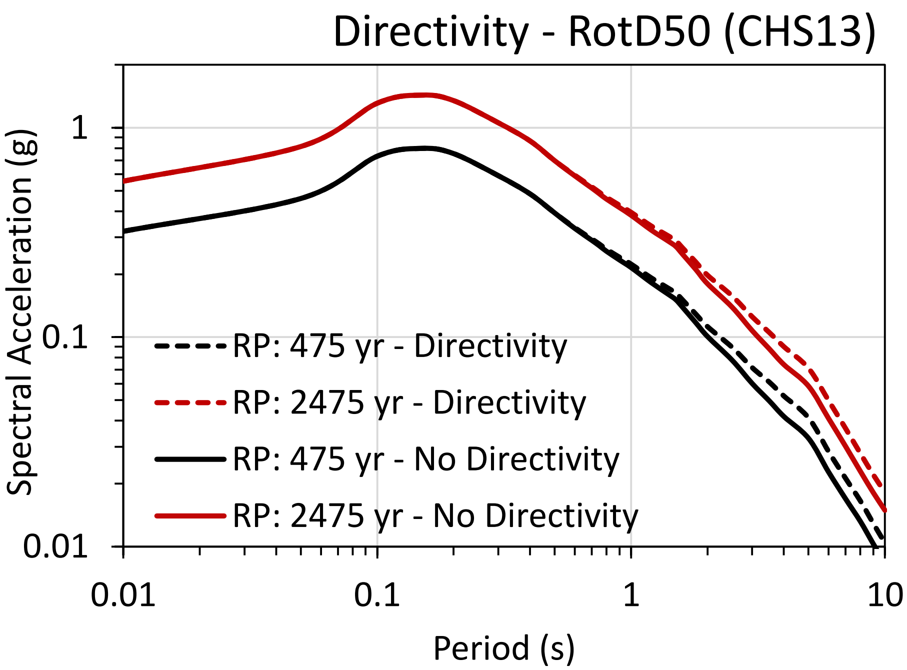
- Directivity amplifications are assumed to be invariant for distances up to R_y = 15km. They taper down to unity with a linear trend between 15km < R_y ≤ 30km.

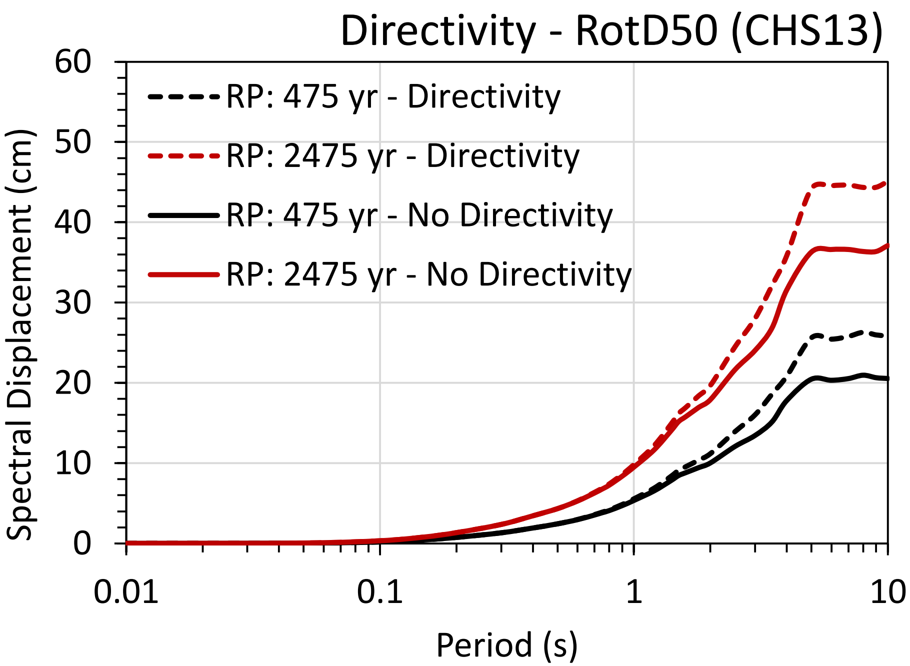
$$AMP^{SHB11\ or\ CHS13}(T) = AMP^{SHB11\ or\ CHS13}_{0km\ \leq\ R_{rup} \leq 15km}(T) + \left[\left(1 - AMP^{SHB11\ or\ CHS13}_{0km\ \leq\ R_{rup} \leq 15km}(T)\right) \cdot \left(\frac{R_{rup}-15}{15}\right)\right]$$

Results: Importance of return period, slip rate, location along the fault



Results: Case study





Conclusions (1/2)

- Current codes do not have a clear answer to incorporate directivity effects to design spectrum. (mostly UBC approach). However, directivity effects are important in terms of ground motion demand.
- We considered two narrow-band directivity models (SHB11 and CHS13) to run several PSHA cases by to develop some expressions to account for directivity in establishing design spectrum.
- The expressions are sensitive to return period (475-year and 2475-year), slip rate, fault-site geometry and characteristic magnitude of the fault segment.
- CHS13 based model currently estimates directivity for RotD50 horizontal component whereas SHB11 based model estimates directivity for fault-normal component.

Conclusions (2/2)

- There are significant differences between SHB11 and CHS13 in terms of estimated directivity amplitudes. Because their theoretical background are different.
- Independence of slip rate makes CHS13 model more practical for code implementation.
- Further studies are necessary to fully cover directivity effects that includes maximum direction and see how fault-normal and maximum direction components are related to each other in the fault vicinity. Such studies will make the SHB11 results even more viable.

Thank you