

# Simulated Deformations of Seattle High-Rise Buildings from a Hypothetical Giant Cascadian Earthquake

Tom Heaton

Jing Yang (Ph.D. thesis)

Caltech Earthquake Engineering Research Laboratory

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Thesis available at [heaton.caltech.edu](http://heaton.caltech.edu)



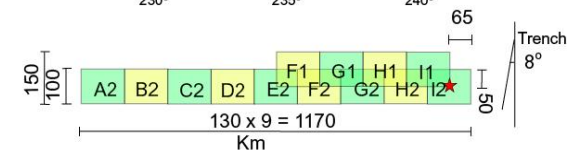
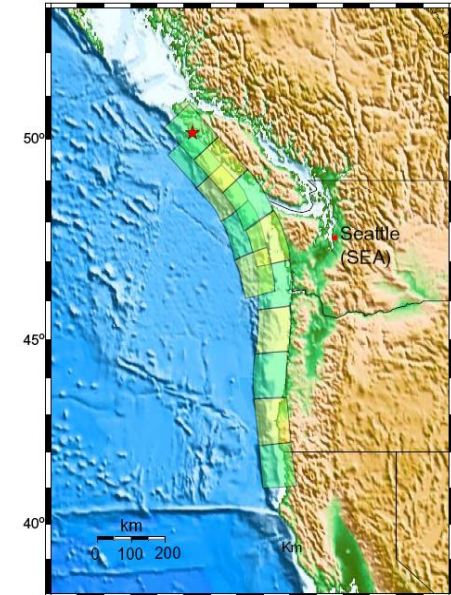
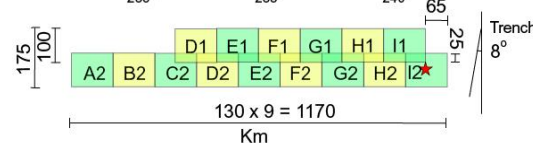
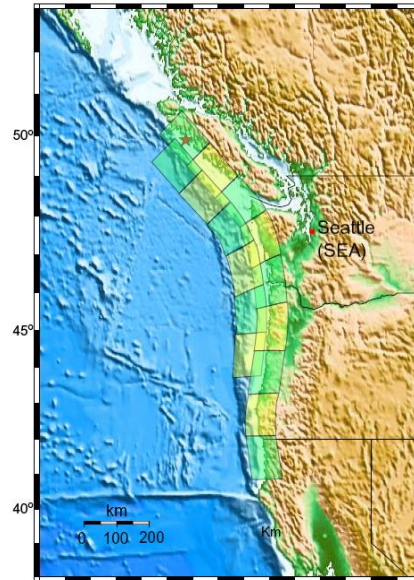
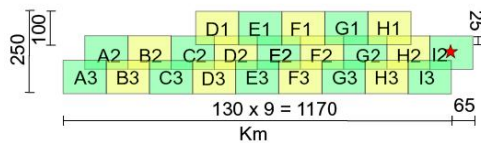
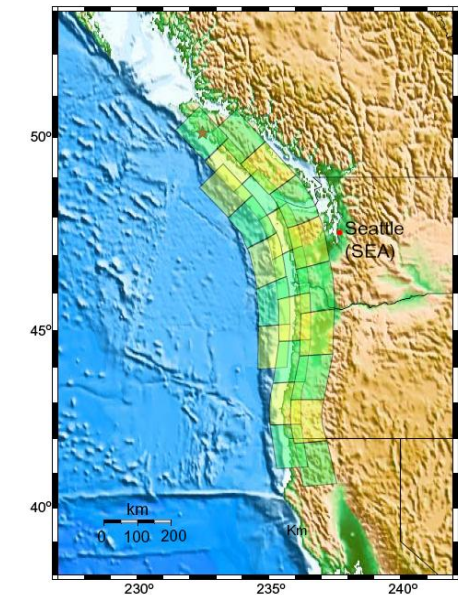
- M 9+ with an average repeat  $\approx 400$  years
- Deep basin that amplifies long periods
- No strong motion records, no high-rises near a M 9
- Think Anchorage Alaska in 1964, but with high-rises
- PSHA only hides the key issues

# Empirical Green's Functions as a method to extrapolate to very large magnitudes

Wide model

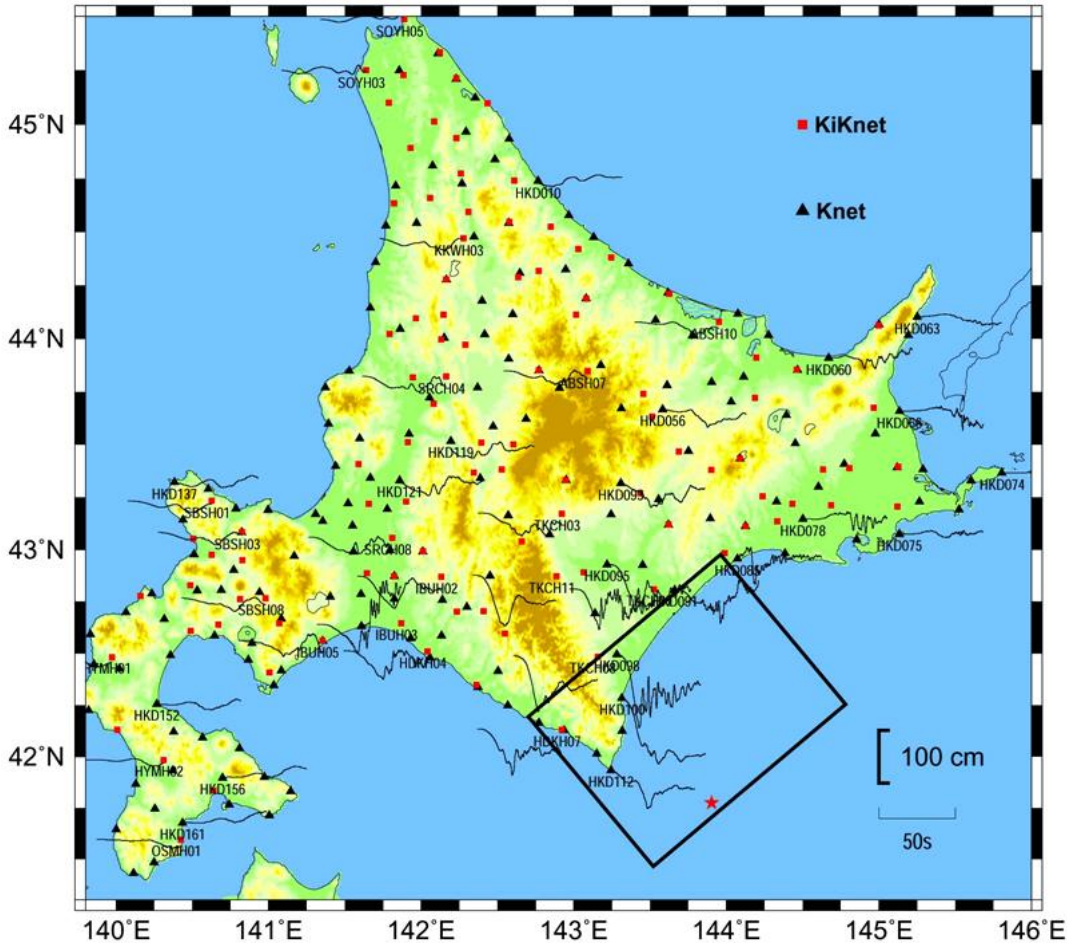
Medium model

Narrow model

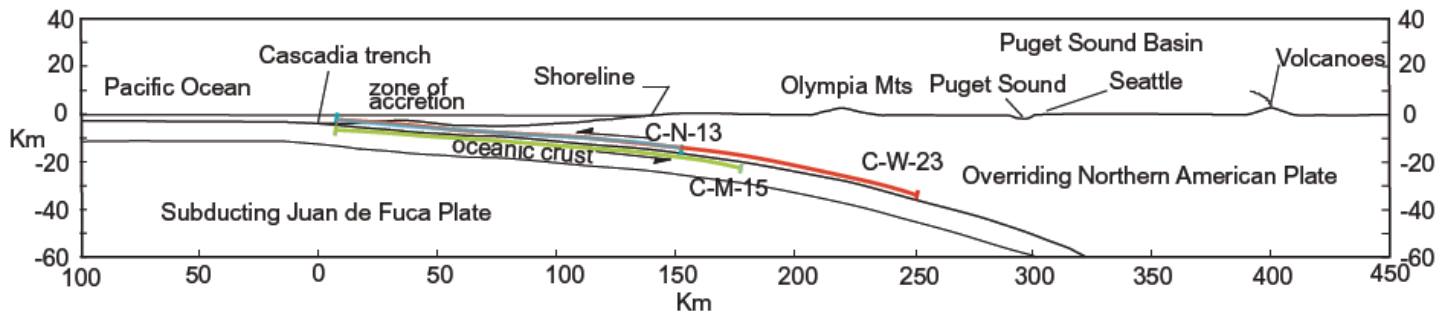
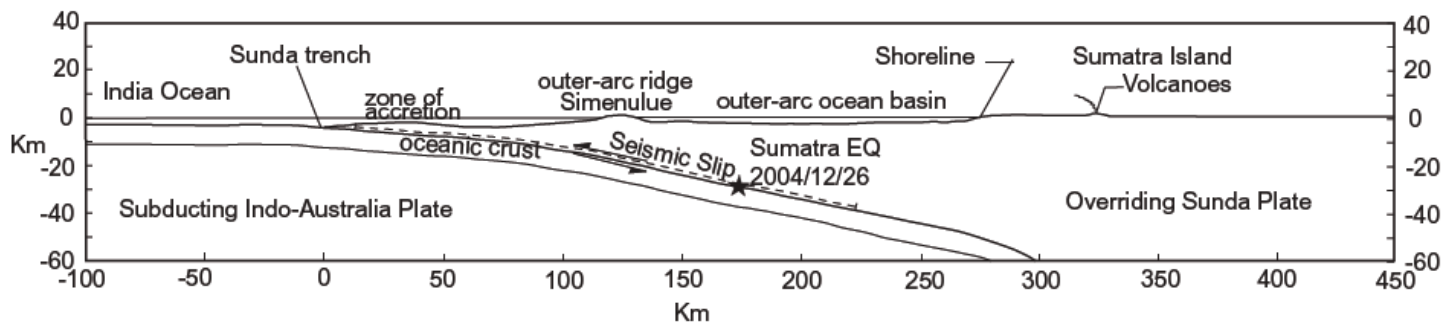
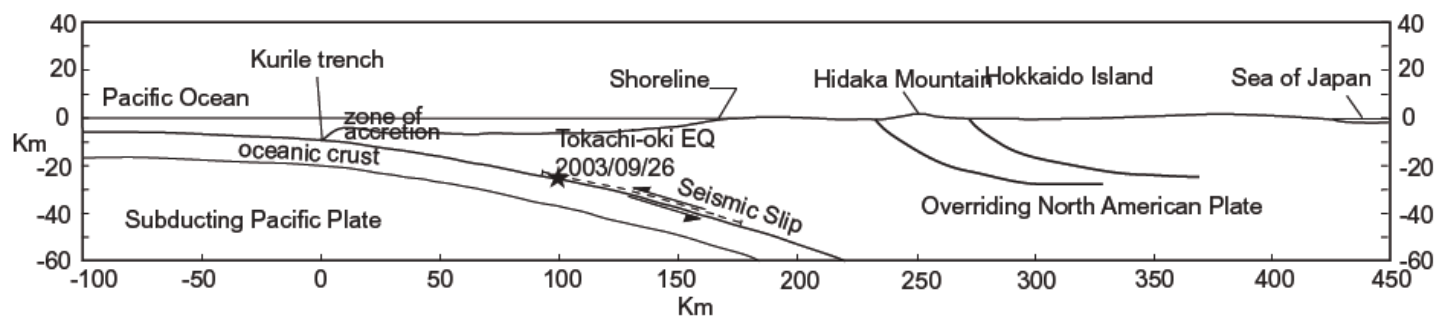


- Repeat of the giant ( $M > 9$ ) Cascadia earthquake of 1700
- Simulate rock ground motions with 2003 Tokachi-Oki  $M 8.3$  rock records as empirical Green's functions
- Include effect of the Seattle basin by a transfer function derived from teleseismic S-waves transect (Pratt and Brocher, 2006)

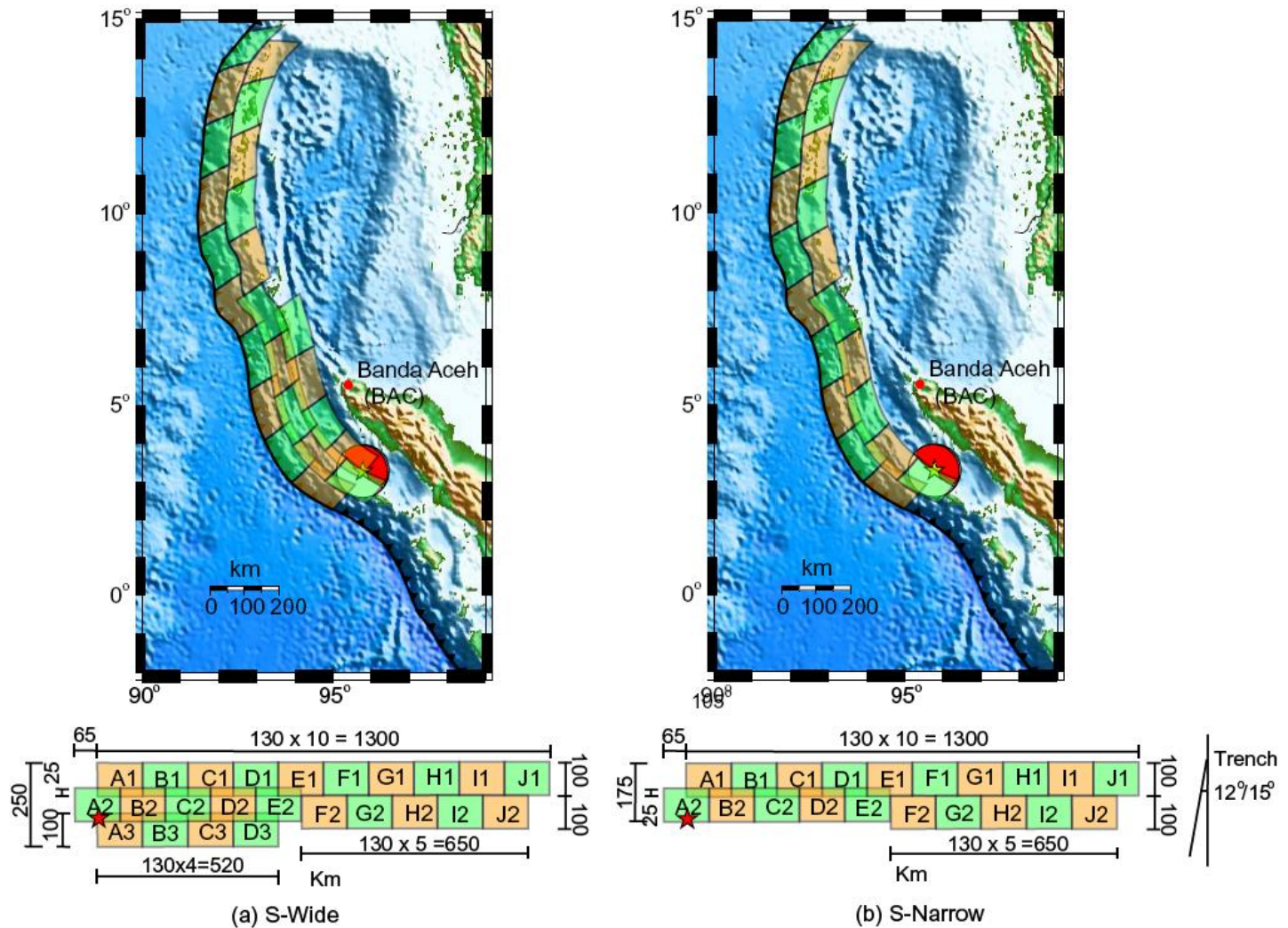
# Ground Motion Recordings of the M 8.3 Tokachi-oki earthquake



- Many strong motion records
- Site conditions are known
- Largest well recorded subduction earthquake

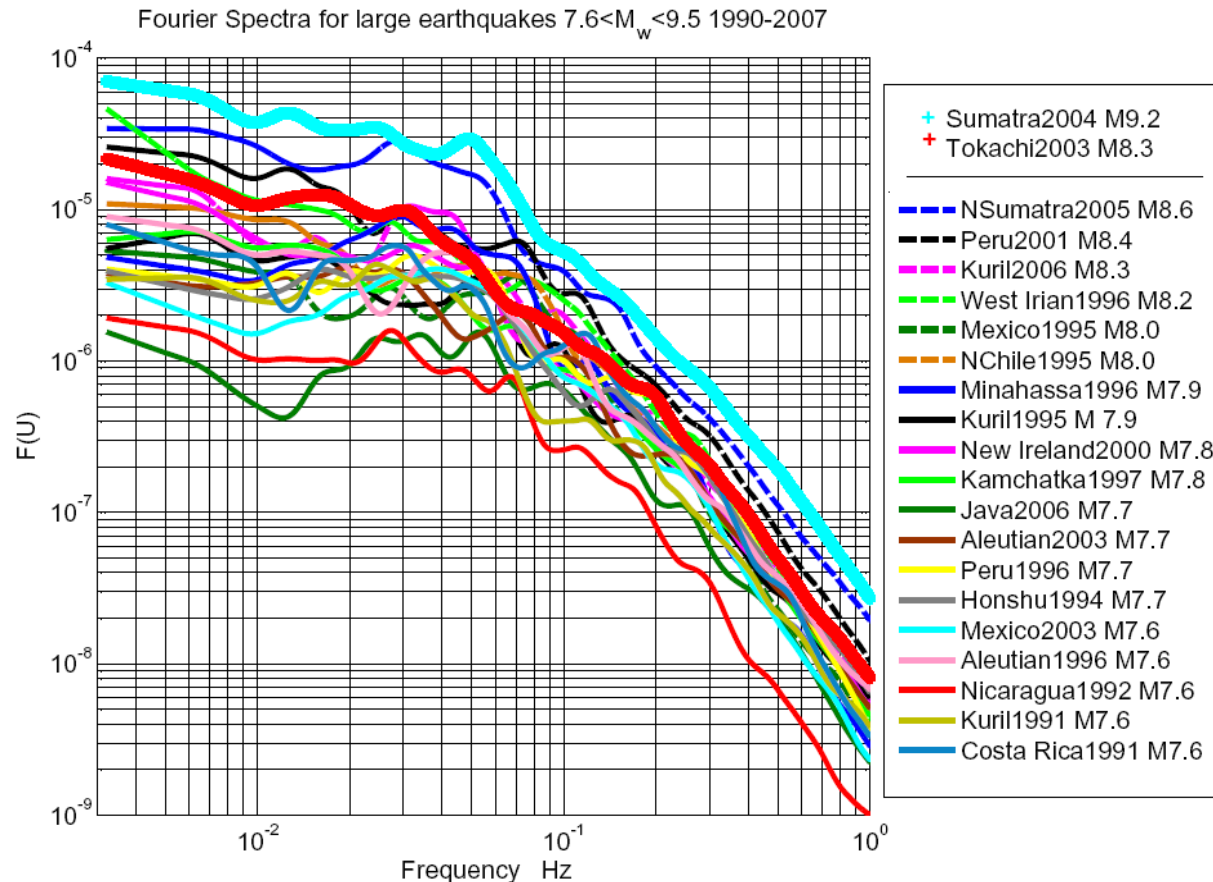


- Giant Cascadian earthquakes assumed to be similar to Sumatra (2004, M9.2)
- Tokachi-Oki (2003 M8.2) provides Green's functions for simulating teleseismic records of Sumatra (2004 M 9.2) and strong motion records for Sumatra and Cascadia



- Simulation of teleseismic records of Sumatra
- Two models differ in the down-dip width of the rupture

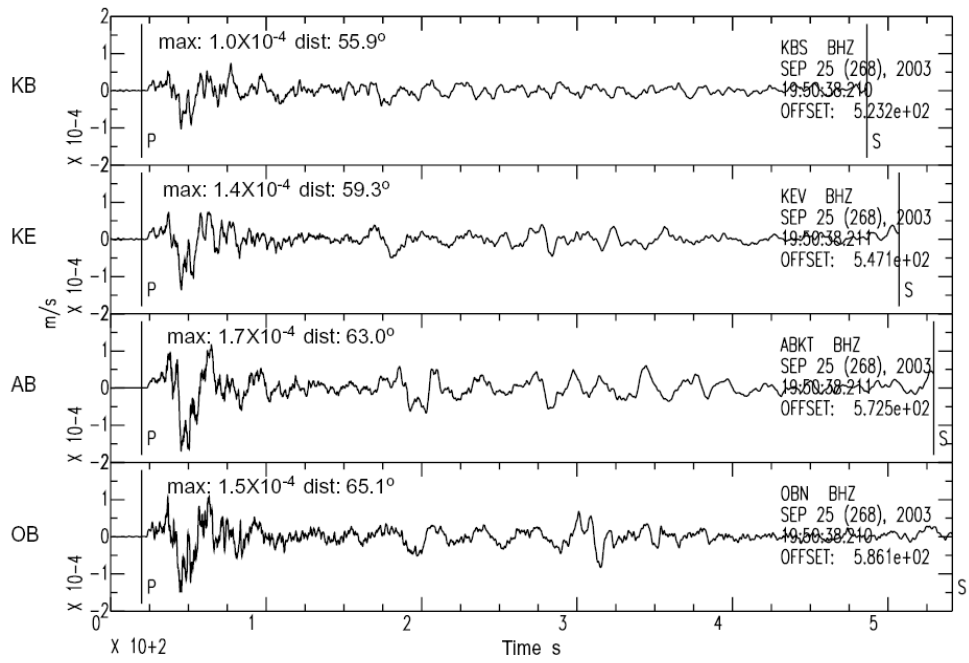
# Average P-wave Spectra for the Largest subduction Earthquakes in the past 20 years



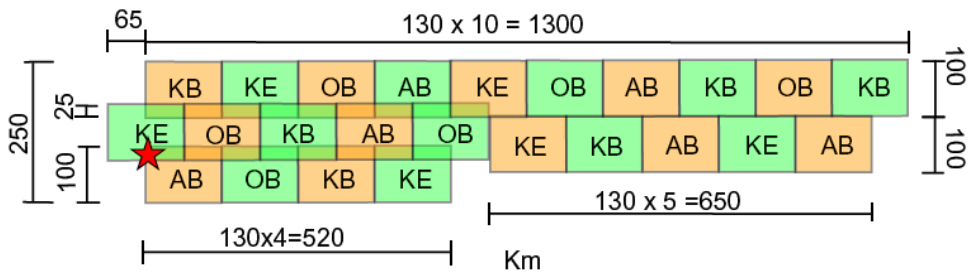
- Sumatra and Tokachi-Oki have similar spectral envelopes so Tokachi-Oki might be an acceptable source of empirical Green's functions

# Teleseismic Tokachi-Oki P-waves

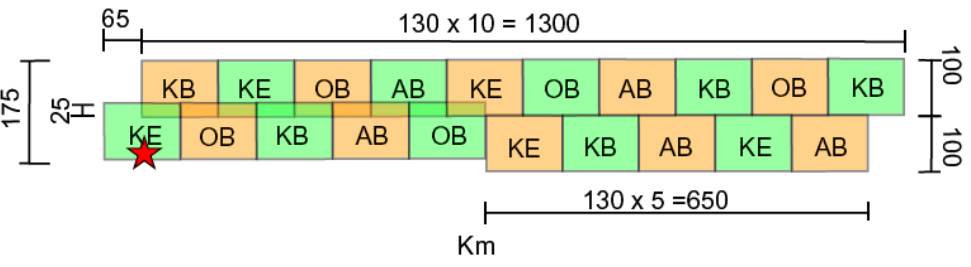
- Use records that are median in amplitude

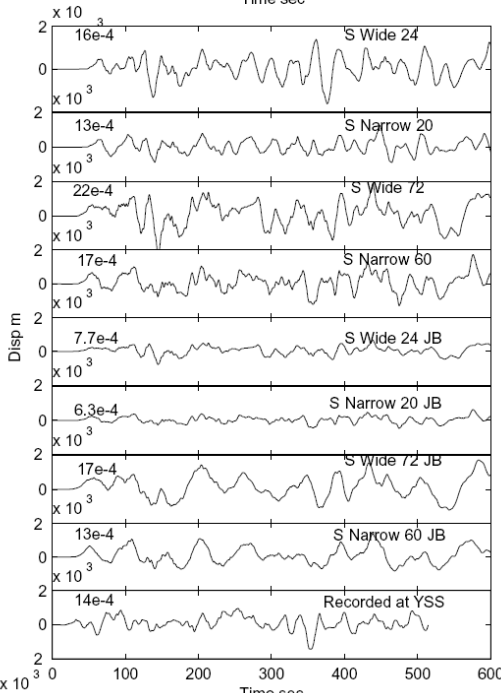
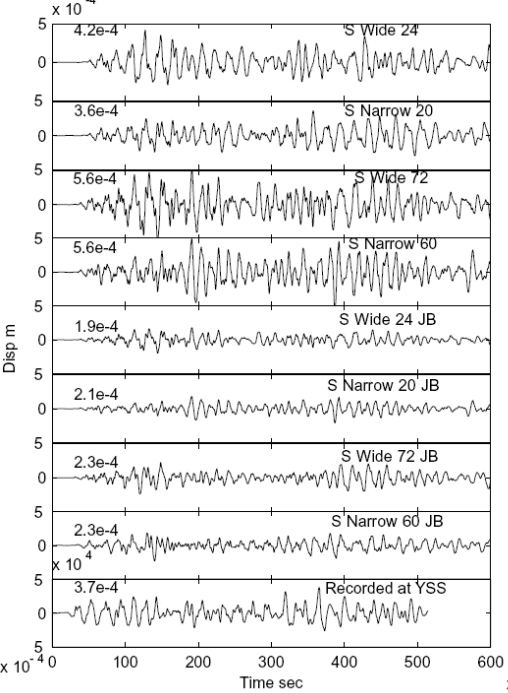
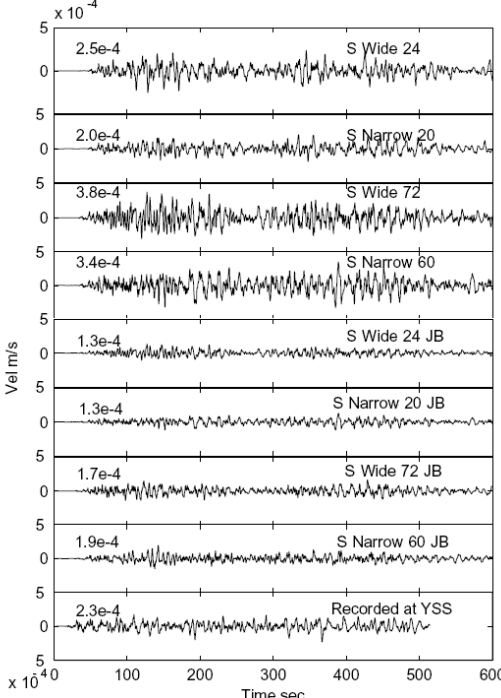
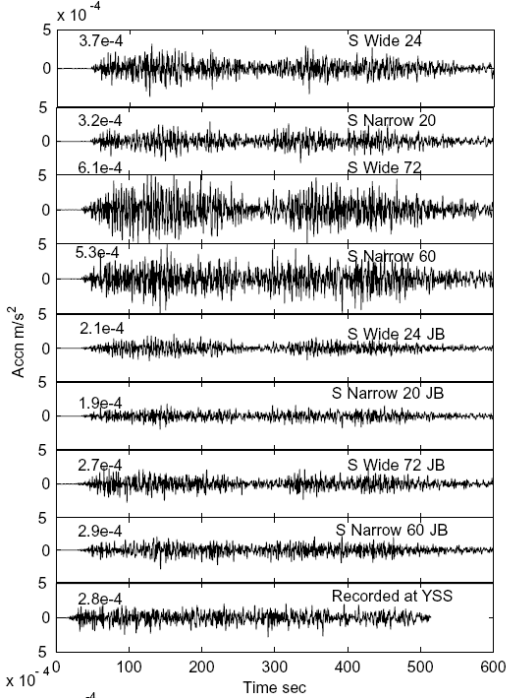


S-Wide



S-Narrow

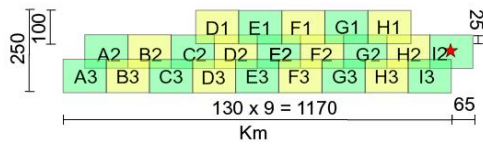
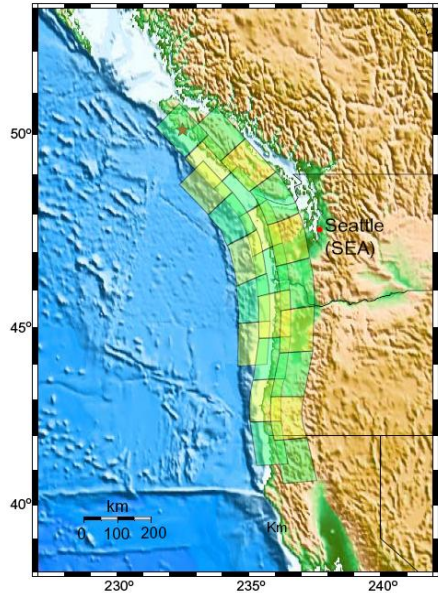




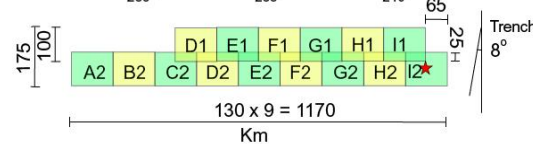
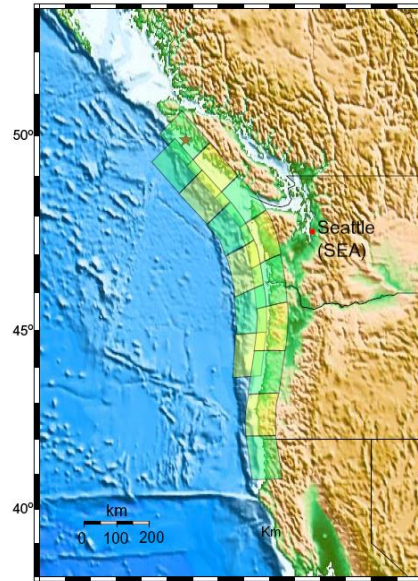
- Simulated teleseismic P-waves compared with typical Sumatran record
- Focus on models that best match in the 1 to 10 sec period band
- YSS is a median P-waveform for Sumatra
- All records are on the same scale
- Tiling Sumatra with 20 Tokachi-Oki earthquakes seems to work acceptably

# Cascadia Rupture Models

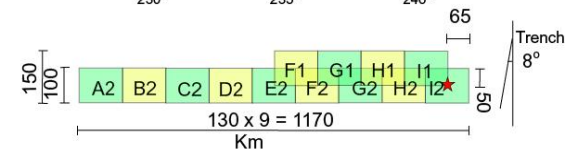
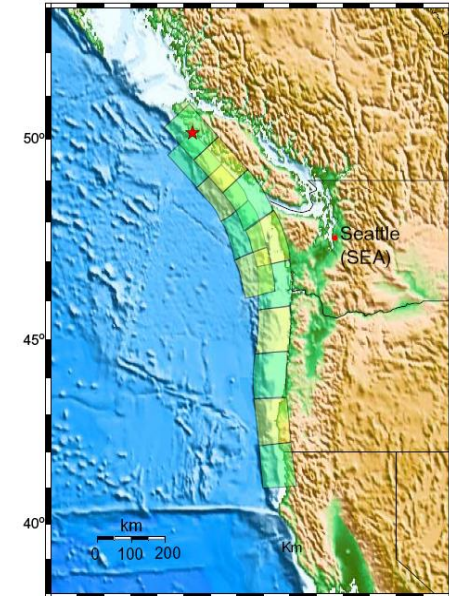
Wide model



Medium model

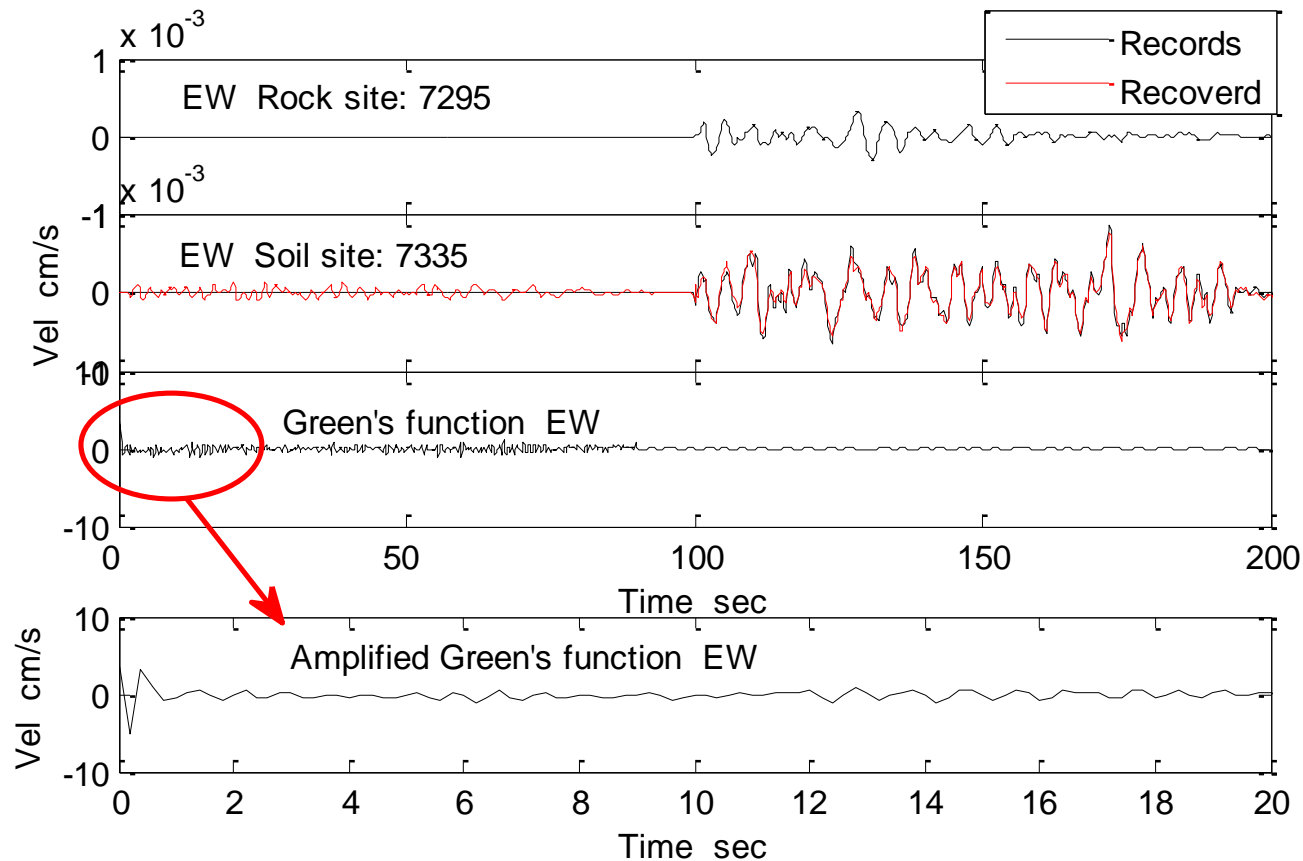


Narrow model



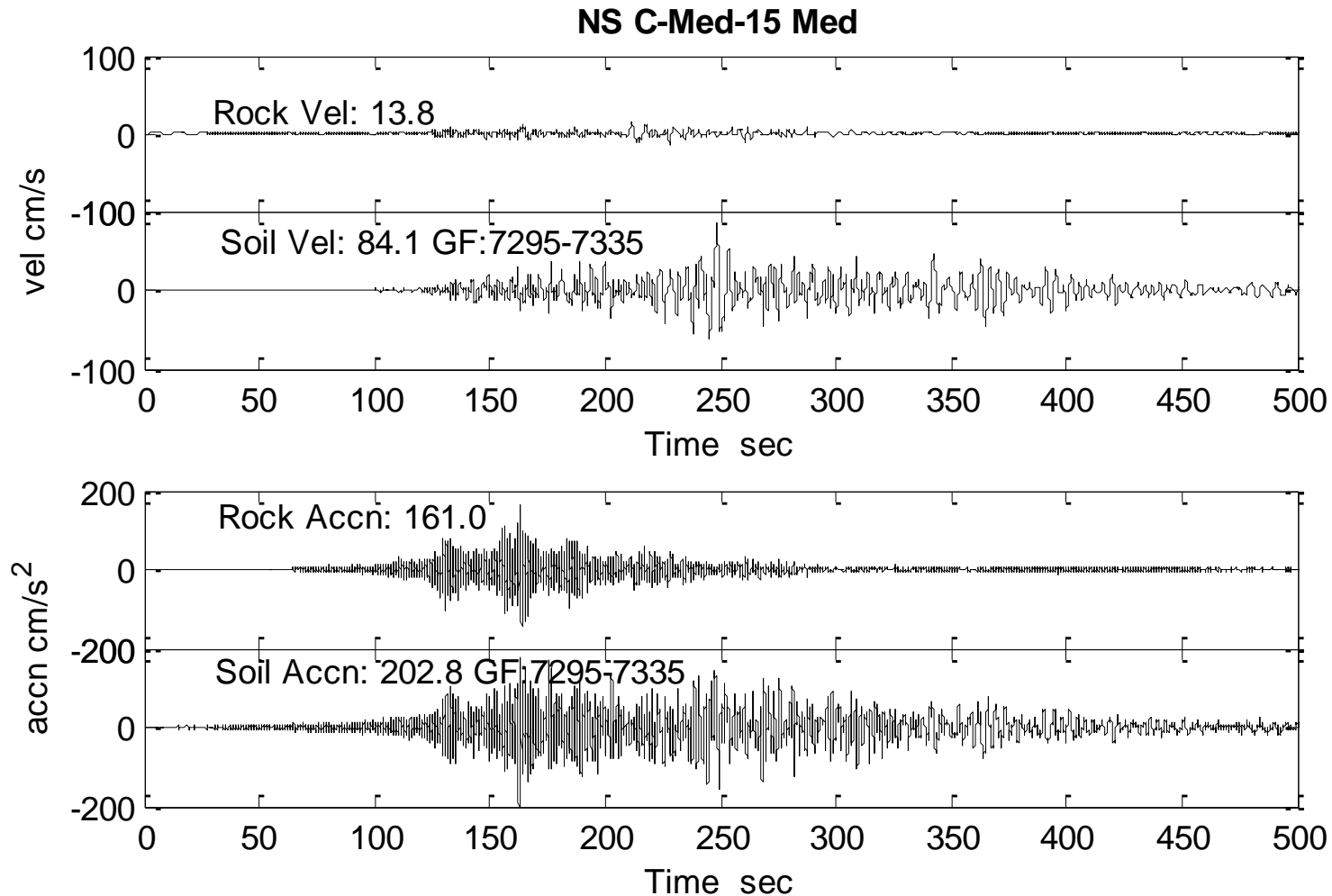
- Coastal co-seismic subsidence in 1700 suggest narrow model
- Wide model extends down dip to approximate location of the boundary with slow slip events

# Seattle Basin transfer function for teleseismic S-waves



Based on a study by Pratt and Brocher (2006)

# Simulated rock and basin ground motions for medium rupture



# John Hall's design of a 20-story steel MRF building

- Building U20

1994 UBC zone 4

Stiff soil, 3.5 sec. period

- Building J20

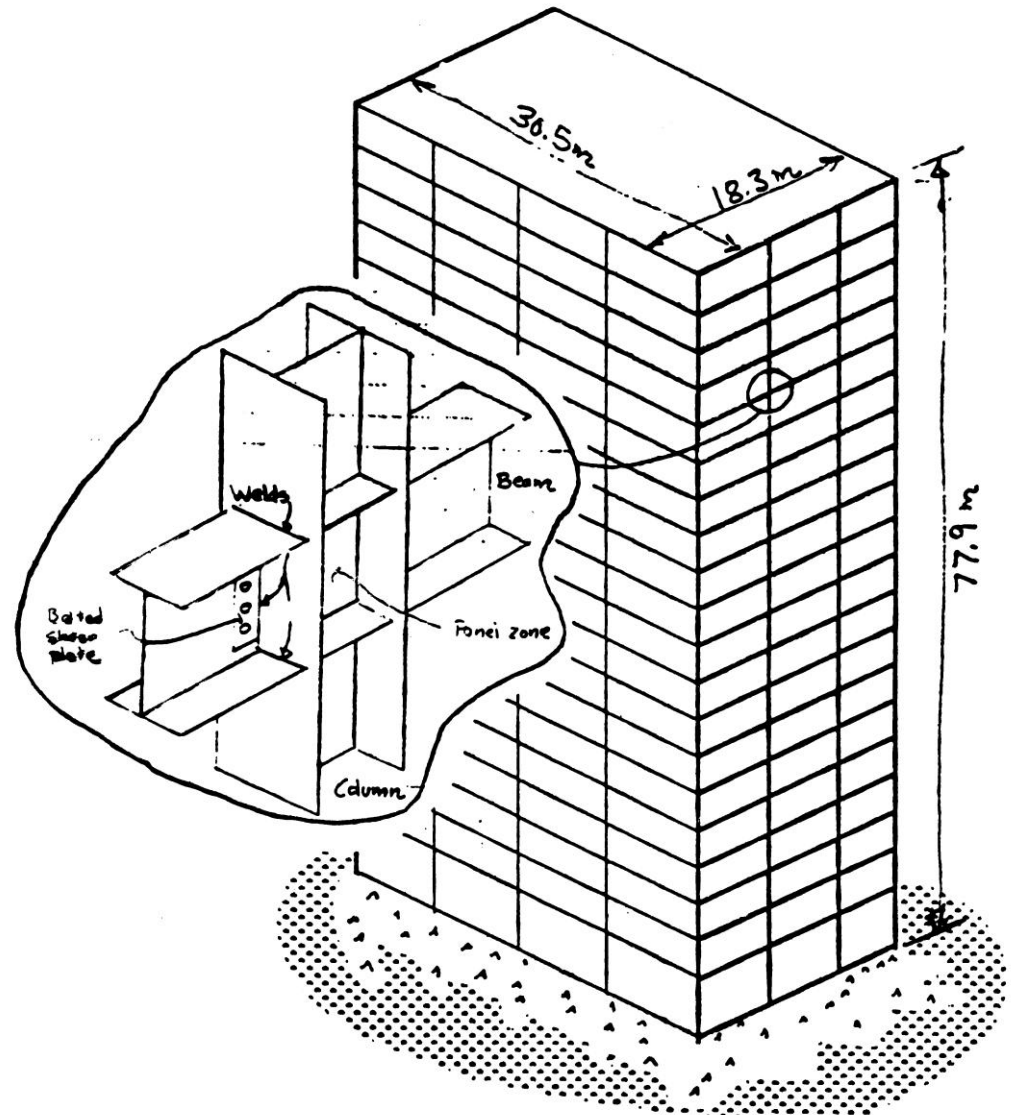
1992 Japan code

3.05 sec period

- Both designs consider

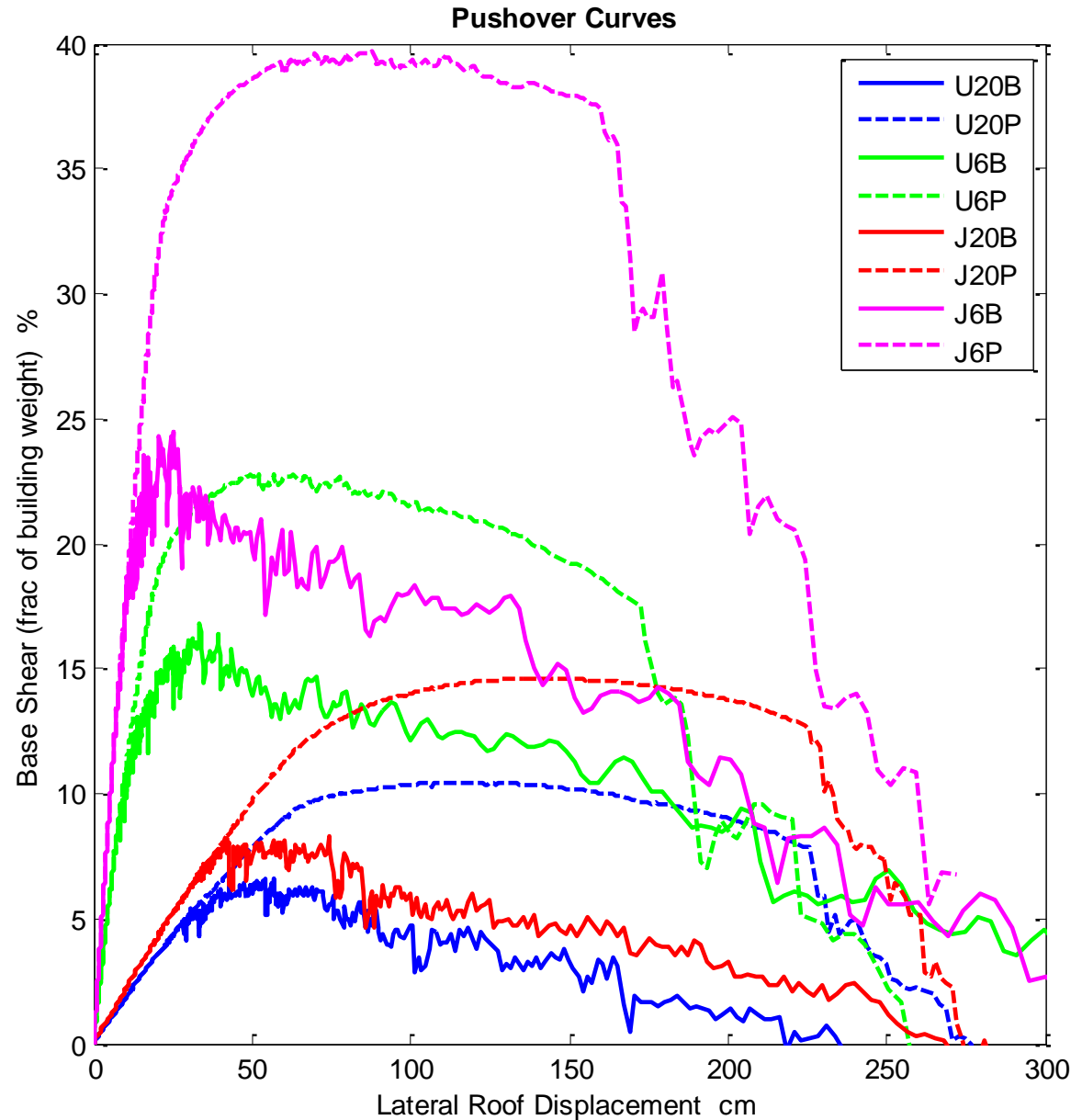
Perfect welds

Brittle welds

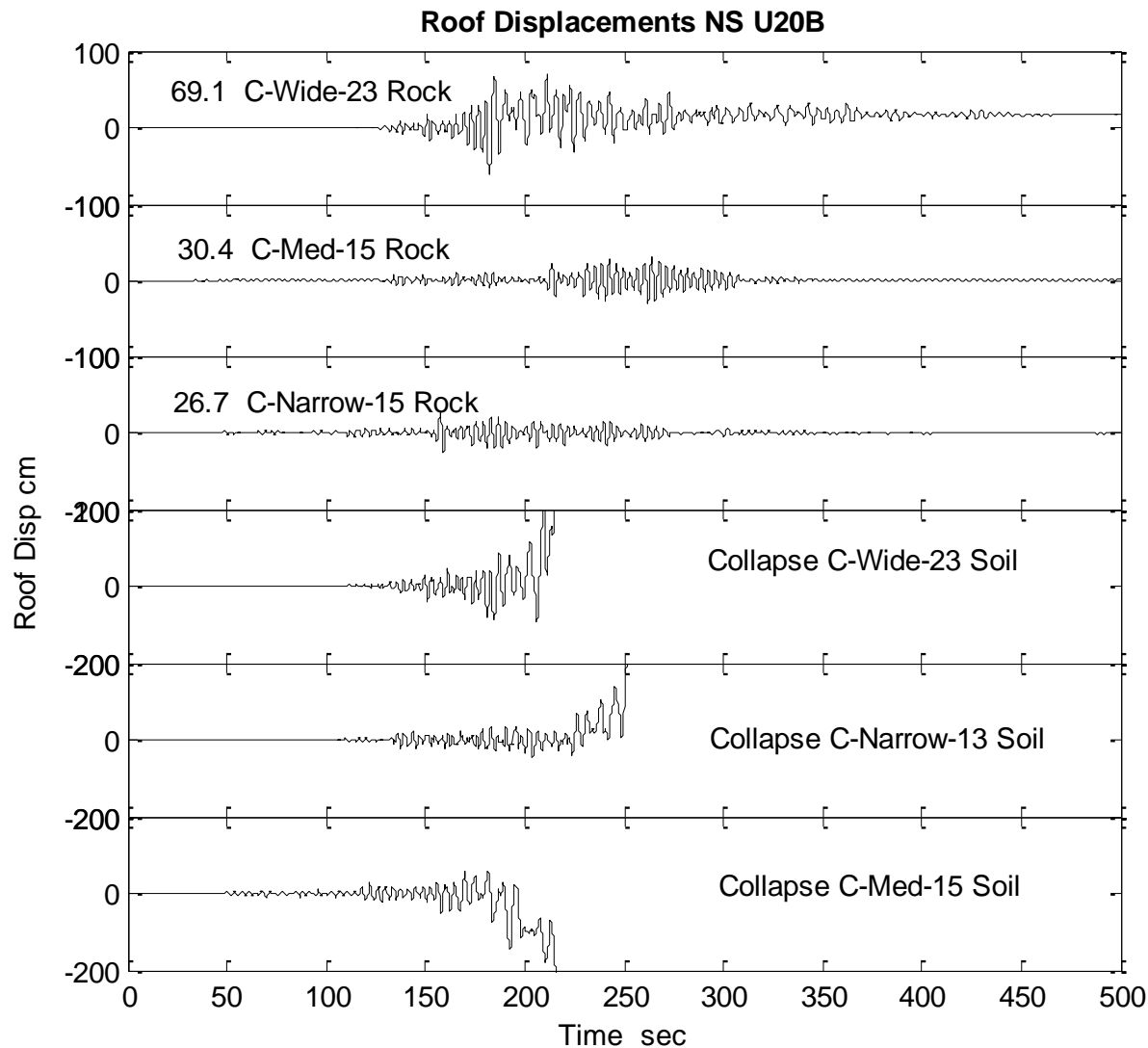


# Pushover Analysis

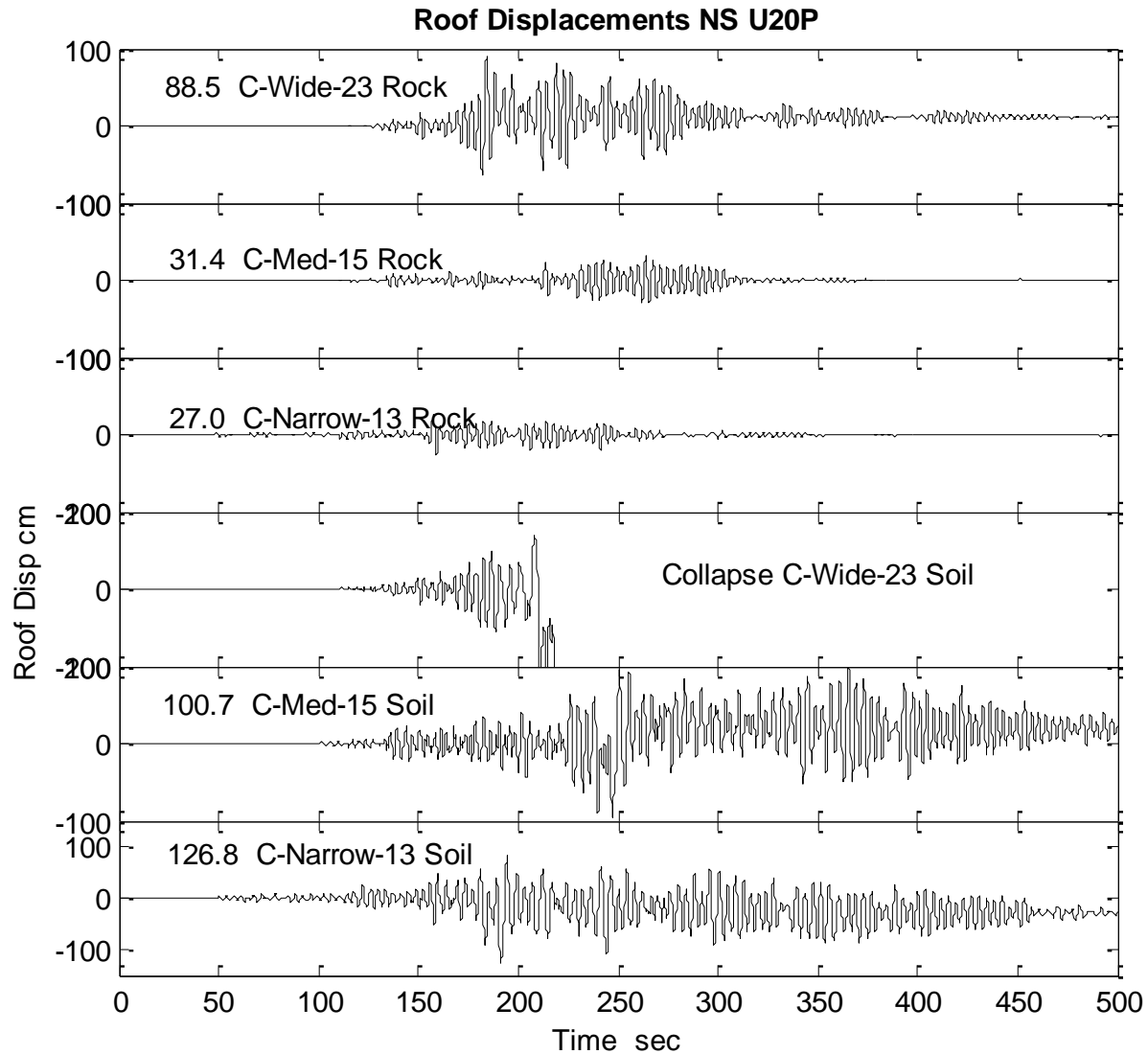
- Special attention to P-delta instability
- Story mechanism collapse
- Frame 2-D fiber-element code of Hall (1997)



# Roof Displacement U-20 Brittle welds



# Roof Displacement U-20 Perfect welds



**Table 6.3: PGA and PGV of simulated strong ground motions in station SEA and performance of 20- and 6- story buildings shaken by these motions.**

Model Name		Rock						Soil					
		C-Wide-23		C-Med-15		C-Narrow-13		C-Wide-23		C-Med-15		C-Narrow-13	
Direction		EW	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW	NS
PGA cm/s <sup>2</sup>	max	428	416	153	134	88	102	666	742	358	357	311	263
	med	267	230	153	161	50	77	419	578	172	203	131	226
	min	208	181	47	51	35	38	276	300	103	152	49	66
PGV cm/s	max	60	78	39	39	39	38	227	227	103	222	127	131
	med	55	43	21	14	20	18	121	290	52	84	48	82
	min	32	24	20	16	5	6	92	103	41	54	18	25
U20B IDR (%)	max	3.0	2.3	2.1	2.6	2.0	2.0	CO	CO	CO	CO	CO	CO
	med	1.6	2.3	0.6	0.4	0.6	0.4	CO	CO	1.5	CO	2.3	CO
	min	0.6	0.7	0.7	0.4	0.1	0.1	2.1	CO	2.1	CO	0.5	1.3
U20P IDR (%)	max	1.0	1.2	0.6	1.0	0.8	1.4	CO	CO	3.0	CO	CO	CO
	med	1.4	1.8	0.4	0.3	0.4	0.3	CO	CO	1.2	2.4	1.2	2.9
	min	0.4	0.5	0.4	0.3	0.1	0.1	1.5	1.7	1.0	2.2	0.4	0.6
J20B IDR (%)	max	2.8	2.1	1.1	2.2	0.9	2.5	CO	CO	CO	CO	CO	CO
	med	2.3	2.6	0.4	0.3	0.5	0.3	CO	CO	1.9	CO	2.1	4.4
	min	0.9	0.5	0.4	0.2	0.1	0.1	1.6	CO	2.4	4.3	0.7	0.3
J20P IDR (%)	max	1.0	1.1	0.5	0.5	0.5	0.7	CO	CO	CO	6.2	5.0	CO
	med	1.0	1.2	0.4	0.3	0.4	0.3	4.2	CO	1.1	1.2	1.0	0.9
	min	0.5	0.4	0.4	0.2	0.1	0.1	1.9	1.2	1.1	1.0	0.5	0.3
U6B IDR (%)	max	1.8	2.0	1.3	1.1	0.9	0.7	CO	CO	CO	CO	CO	CO
	med	1.6	1.2	0.3	0.2	0.2	0.4	CO	CO	2.1	3.5	1.7	3.5
	min	1.5	1.0	0.2	0.3	0.1	0.1	3.9	4.7	1.3	3.4	0.3	0.6
U6P IDR (%)	max	1.6	2.1	1.0	0.8	0.8	0.5	CO	CO	CO	CO	4.7	CO
	med	1.0	1.0	0.3	0.2	0.2	0.4	CO	CO	1.3	1.9	1.1	1.8
	min	1.1	0.9	0.2	0.3	0.1	0.1	4.6	4.7	1.2	1.8	0.3	0.5
J6B IDR (%)	max	1.1	1.5	0.7	0.5	0.4	0.3	CO	CO	CO	CO	5.4	CO
	med	0.8	0.6	0.2	0.2	0.1	0.2	CO	CO	0.8	1.9	0.6	1.9
	min	0.6	0.3	0.1	0.2	0.1	0.1	3.9	3.5	0.7	2.0	0.3	0.4
J6P IDR (%)	max	0.9	1.4	0.6	0.5	0.4	0.3	CO	CO	3.1	3.8	2.3	2.4
	med	0.6	0.5	0.2	0.2	0.1	0.2	2.4	CO	0.8	0.8	0.7	1.2
	min	0.5	0.3	0.1	0.2	0.1	0.1	2.4	2.4	0.7	1.1	0.3	0.4

# Conclusions

- Presence of brittle welds significantly degrades performance (2-8 times more likely to collapse)
- Amplification by the Seattle basin could be a very serious issue
- Reliable prediction of down dip limit of rupture is a critical issue
- Simulating building behavior for a hundred cycles of yielding/damaging motion is a critical issue
- Cannot conclude that Seattle high-rises will perform acceptably in a giant earthquake
- Don't hide this issue in PSHA!