IMPLICATIONS OF STRONG MOTION DATA FROM THE 2001 NISQUALLY, WASHINGTON EARTHQUAKE

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Summary

Approximately 100 strong-motion digital accelerographs recorded ground motions throughout the Pacific Northwest during the M 6.8 Nisqually earthquake, which occurred near Olympia on the subducted Juan de Fuca plate in the same general vicinity of the M7.1 1949 and M6.5 1965 events. Although many ground-motion records were obtained, only two buildings (DNR in Olympia and the Crowne Plaza Hotel in Seattle) recorded the shaking.

The peak ground acceleration (PGA) data from the Nisqually earthquake exhibited a higher rate of attenuation with distance than predicted by representative attenuation equations, an observation attributed mainly to the historical processing of older, strong motion paper and film records above a certain PGA threshold. Nevertheless, PGA values from the few records from the 1949 and 1965 earthquakes are within the band of PGA values from the Nisqually earthquake. In fact, records from common or nearby sites (within 100m) during these three earthquakes are similar when allowances are made for differences in magnitude and size of the recording stations.

The above observations, which pertain to stiff soil motions, suggest the Nisqually earthquake was a typical Puget Sound intraplate subduction event. However, this conclusion may not be valid in the softer soil deposits of the Duwamish River Valley in the industrial area of South Seattle where widespread liquefaction was observed during all three events. Strong motions were recorded at several of these soft soil sites that liquefied during the Nisqually earthquake with PGA's ranging from 0.25 to 0.30 g, the highest values generally recorded in the region from this event. The anomaly is the 1949 Seattle accelerogram, also recorded in this area (Army District site) on soft soil but with acceleration levels around a factor of 4 less than the soft soil Nisqually motions. This site, within 500m of the Duwamish River, showed no apparent signs of liquefaction during the 1949, 1965, and 2001 earthquakes, whereas, the historical evidence indicates that many of the same strong motion sites that liquefied during the Nisqually earthquake also liquefied during the 1949 and 1965 events. Although these observations suggest that the Army District site may have anomalously low site response, it is difficult to imagine that the actual ground motion at this site during the Nisqually earthquake was

significantly less (by factors of 5 to 10 in spectral acceleration within some period bands) than the motions at the other strong motion sites that did liquefy during this event. A resolution of this issue is important because the question posed by structural engineers engaged in post-Nisqually seismic retrofit of buildings in South Seattle is whether consistently strong motions have been and will continue to be observed on soft soil sites in this area during future intraplate events, which are a dominate contributor to the seismic hazard in Puget Sound. A continually operating station at the Army District site would have helped address the question.

Another interesting observation from the Nisqually earthquake was the site response in South Seattle. The soft soil and nearly soft rock records from this area indicated relative site amplification factors of 2 to 3 in response spectra across a wide oscillator period band from 0 to 5 sec. Estimates of soft soil motions from the SHAKE code were in fair to good agreement with observed motions provided both liquefaction and non-liquefaction cases were modeled. The latter case represents the soil profile prior to the onset of liquefaction, which appears to have occurred several seconds after the first S-wave arrival at one of the strong motion stations.

Engineering Implications

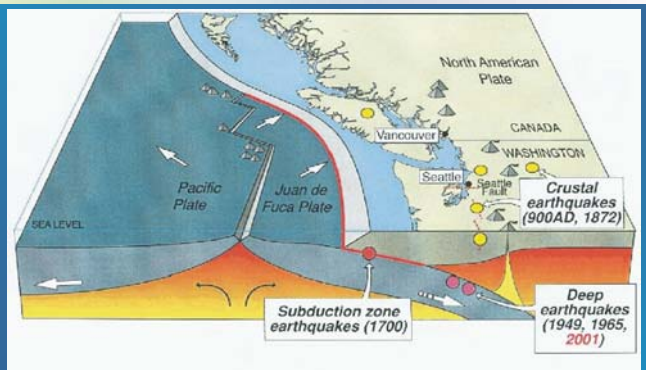
Nisqually Earthquake
Ground-Motion Data

URS

Presentation

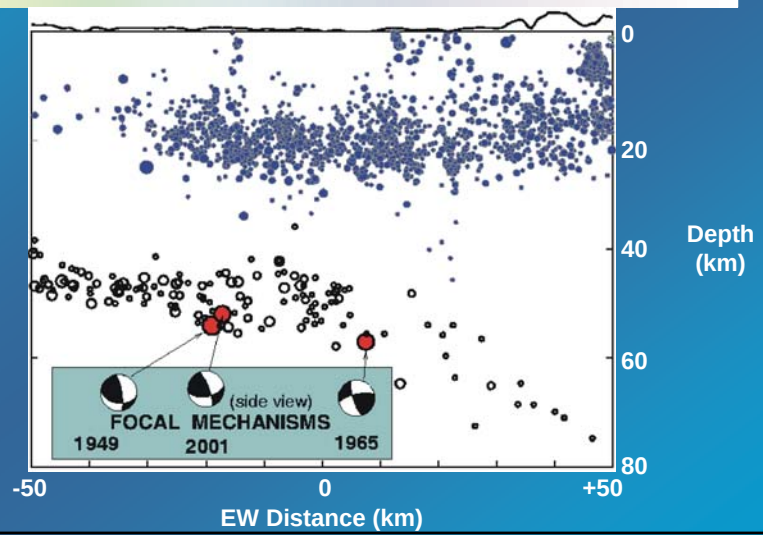
- Background
- Comparison with 1949 and 1965
- South Seattle data

Cascadia Earthquake Sources



Source	Affected area	Max. Size	Recurrence
Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

Deep Earthquakes Beneath Puget Sound

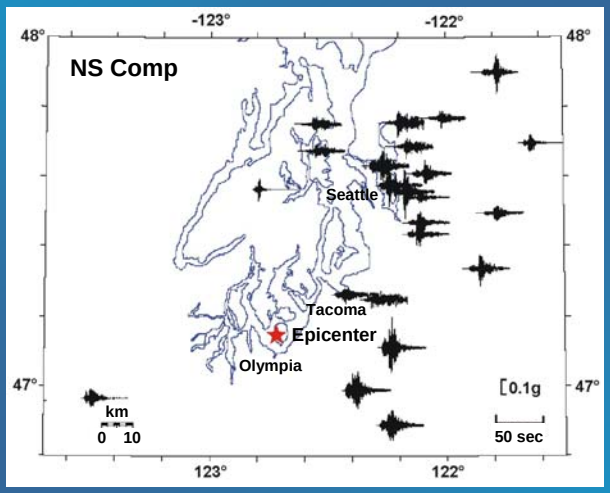


Two Instrumented Buildings

Olympia
DNR Building
- **6 Stories**
- **11 Channels**

Seattle
Crowne Plaza Hotel
- **34 Stories**
- **12 Channels**

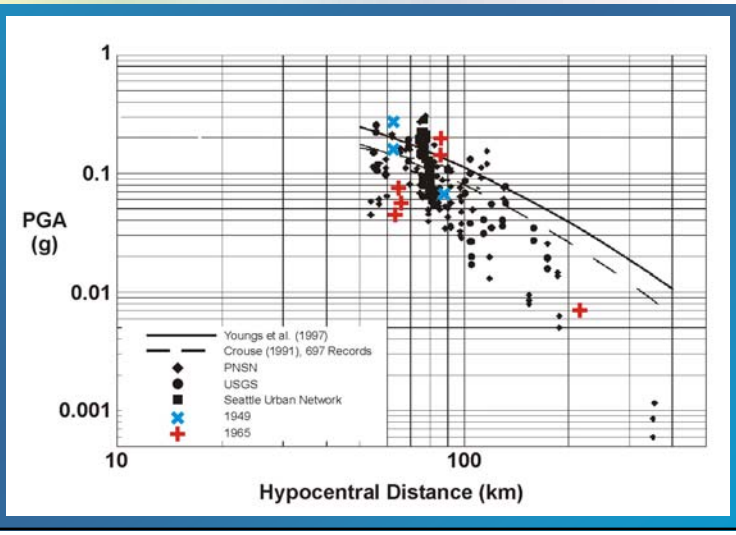
Regional Accelerograms



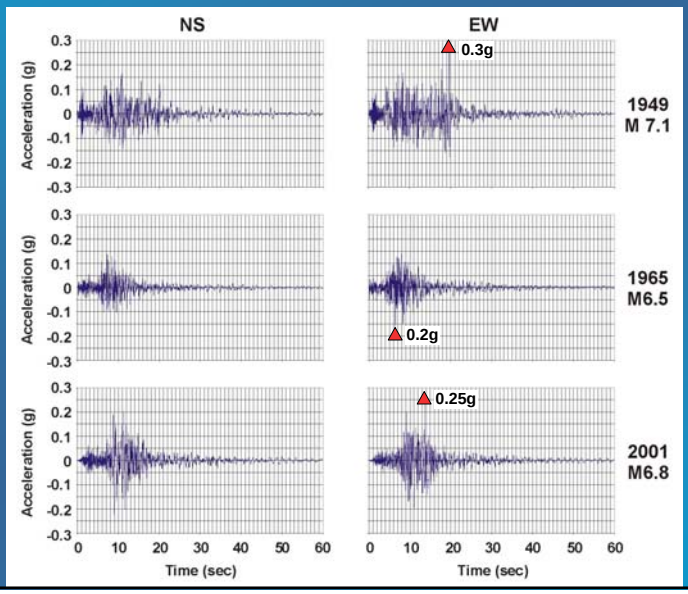
- ~100 records
- Three arrays

How do 2001 data compare to 1949 and 1965 data?

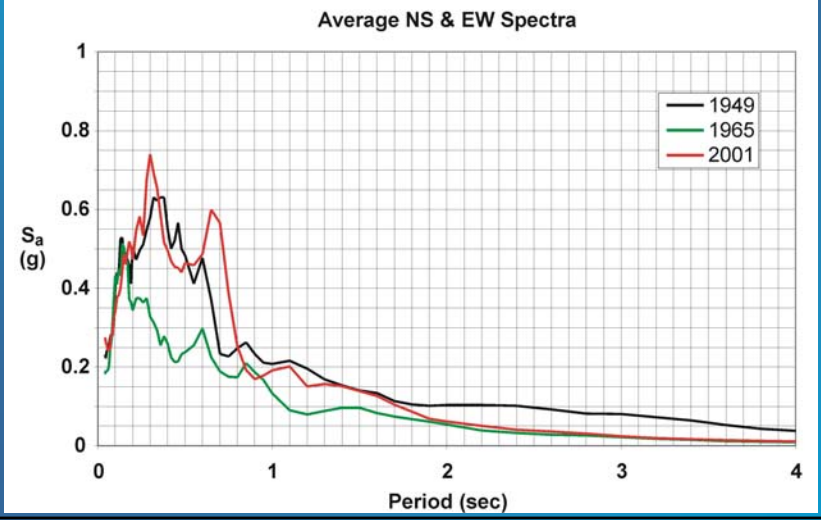
PGA vs Hypocentral Distance Soil Sites



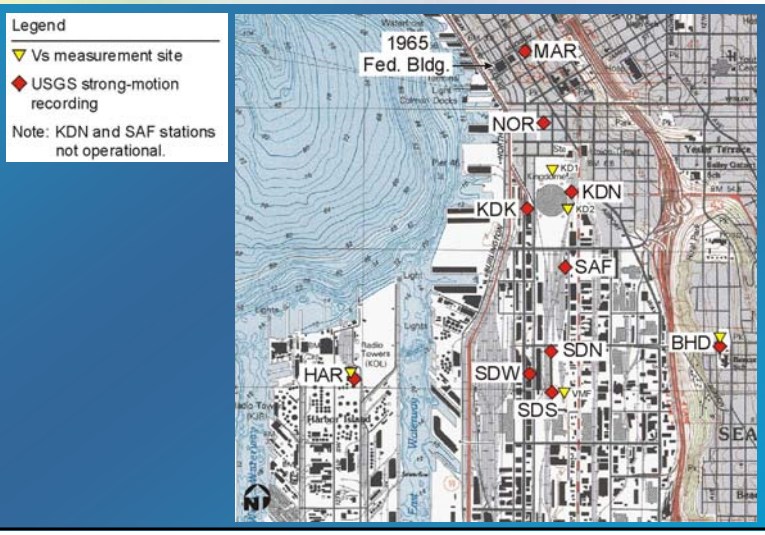
Olympia Highway Test Lab



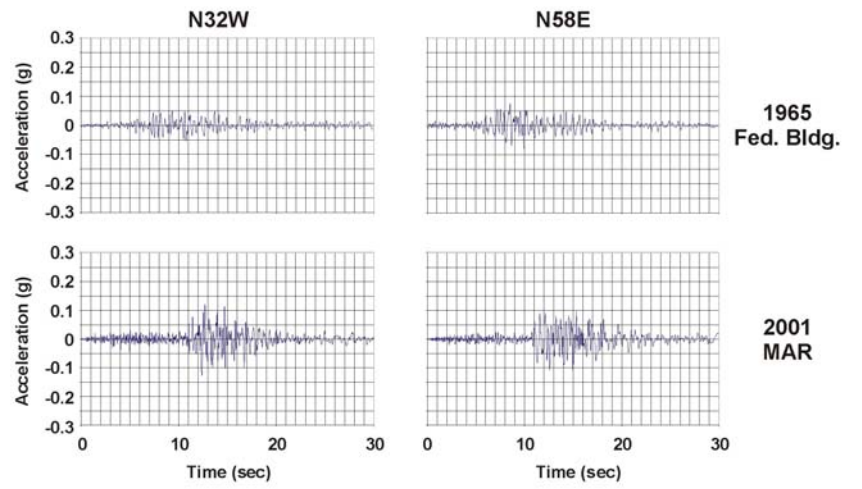
Olympia Highway Test Lab



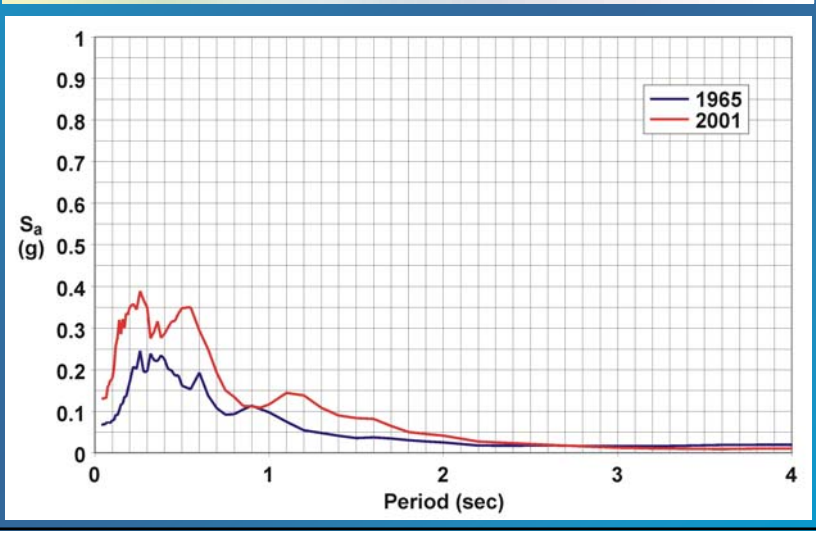
Recording Stations



1965 Fed. Bldg. vs 2001 MAR Seattle Records



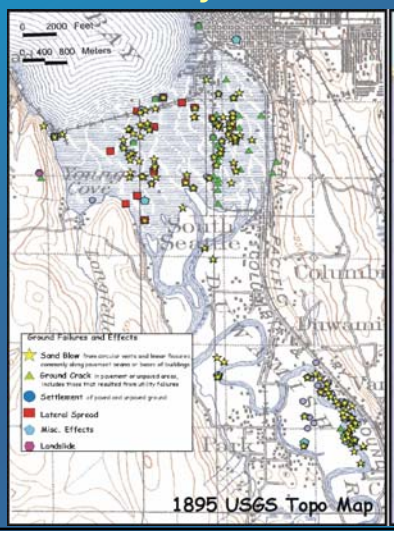
1965 Federal Building vs 200 MAR Seattle Records

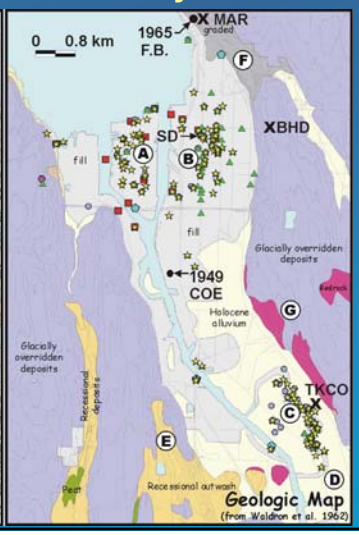


Surface Geology

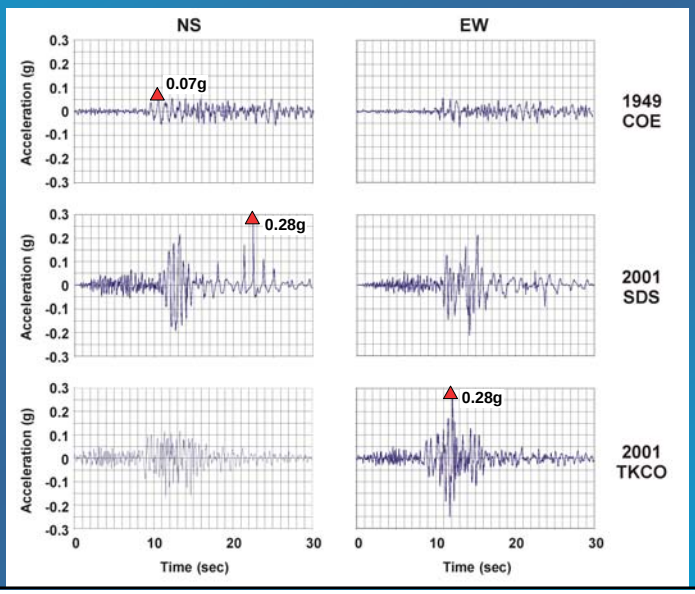
Before hydr. fill

After hydr. fill





1949 vs 2001 Seattle Records



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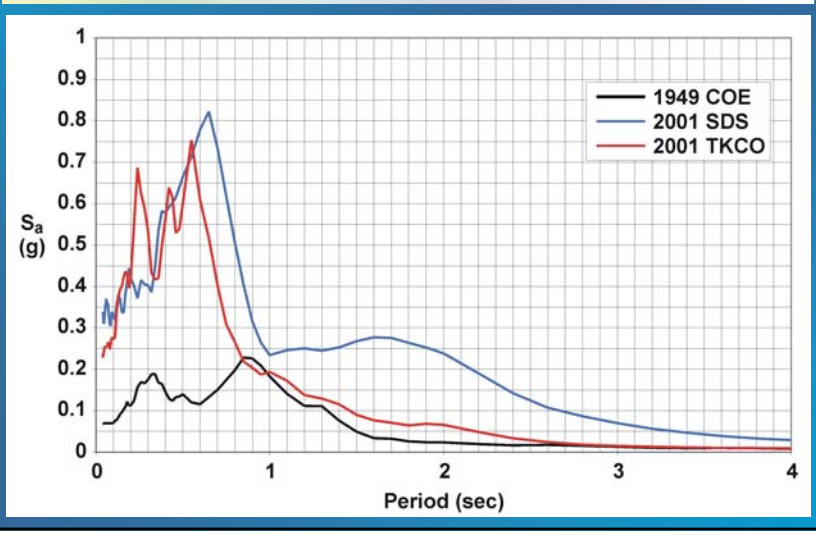
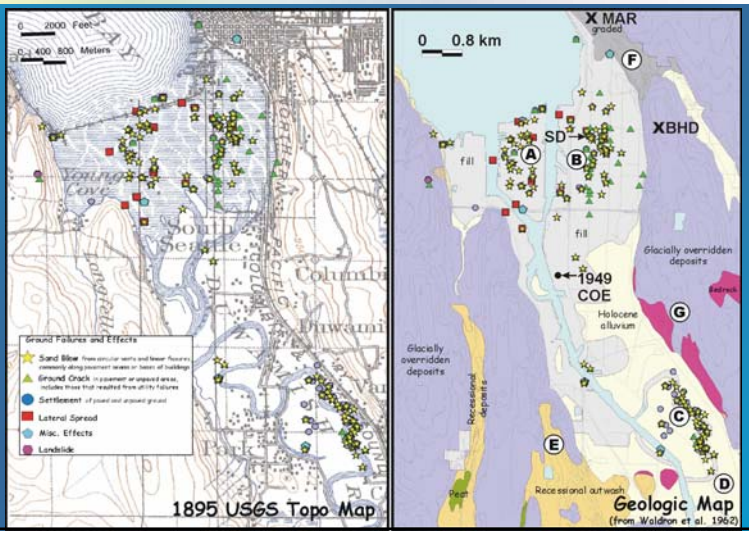


SODO District Records



Recording Stations

Legend

- Vs measurement site
- USGS strong-motion recording

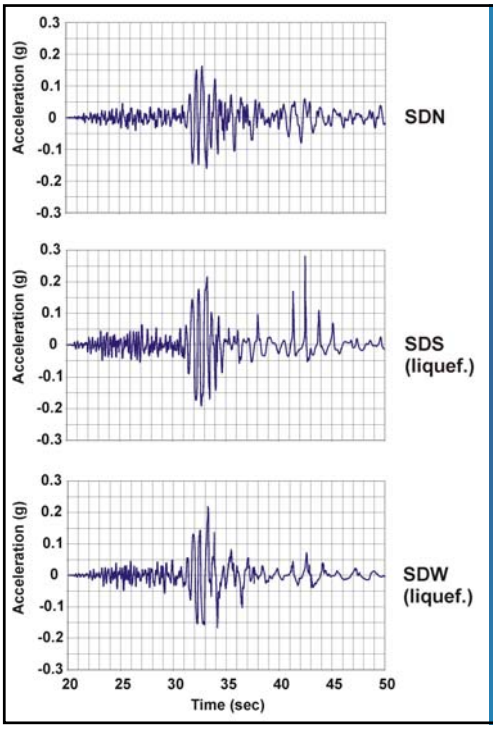
Note: KDN and SAF stations not operational.

SDN and SDS Stations

SDW Station

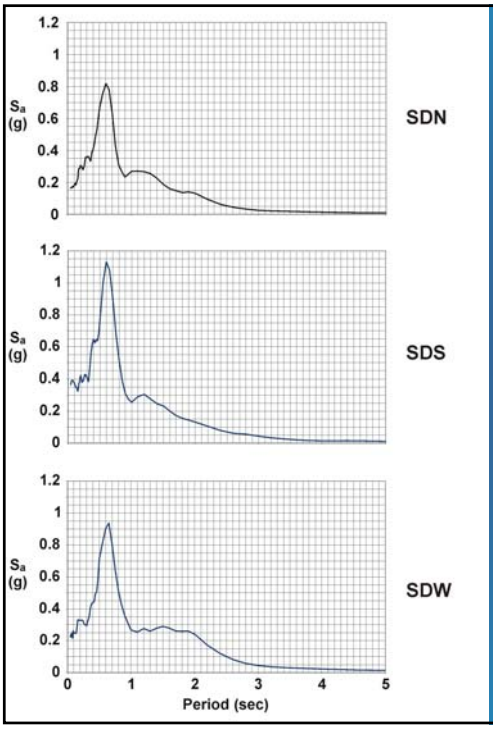
Front

Back



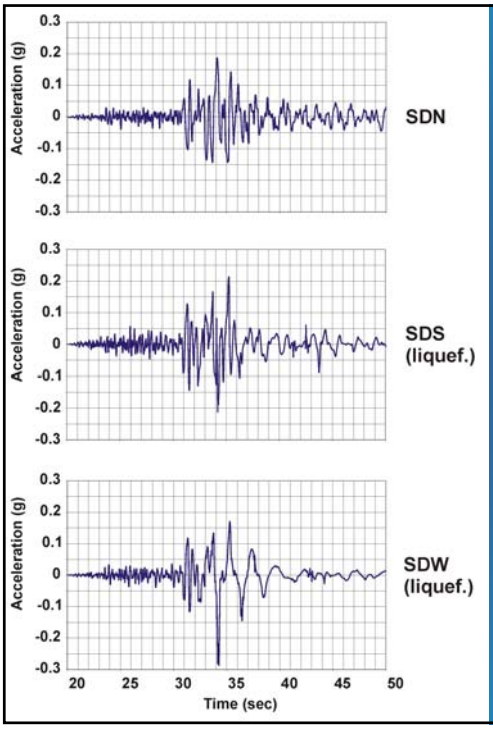
SODO District Soft Soil, NS Records

- Strong 1/2-sec period motion 31-34 sec
- Suggestion of liquifaction



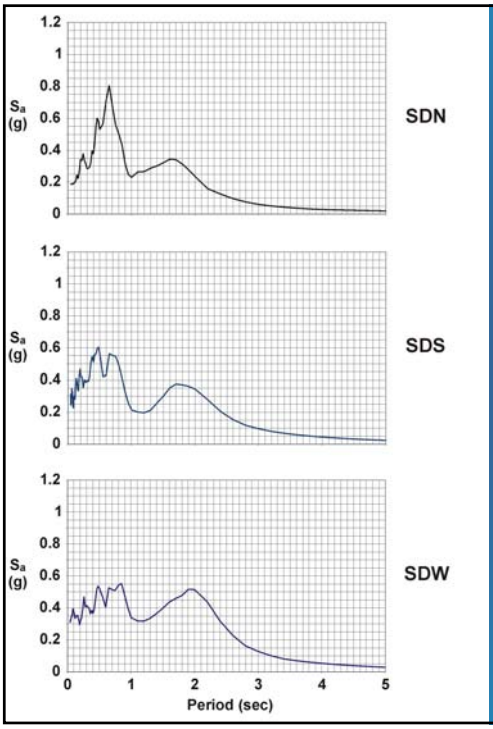
NS Response Spectra, $\xi = 5\%$

- Peak ~ 1 g @ 0.6 sec



SODO District: Soft Soil, EW Records

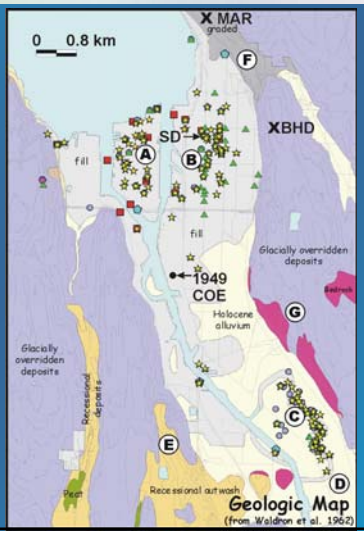
- Strong evidence of liquefaction @ ~ 34 sec @ SDW
- Apparent 2-sec motion



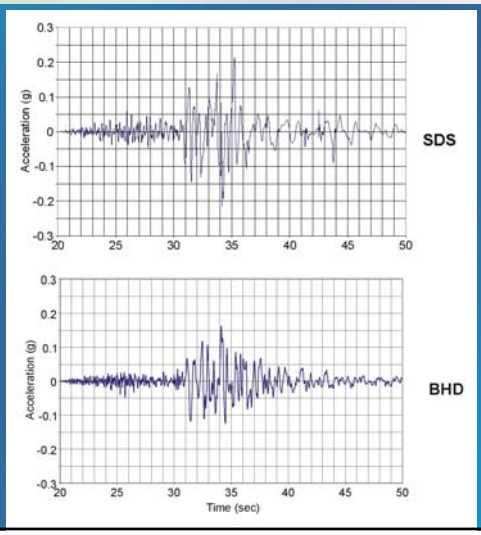
EW Response Spectra, $\xi = 5\%$

- S_a = 0.4-0.5g @ 2 sec!
- Period shift
  1.6 sec (SDN)
  2.0 sec (SDW)

Site Response



Soft vs. Stiff Soil EW Records



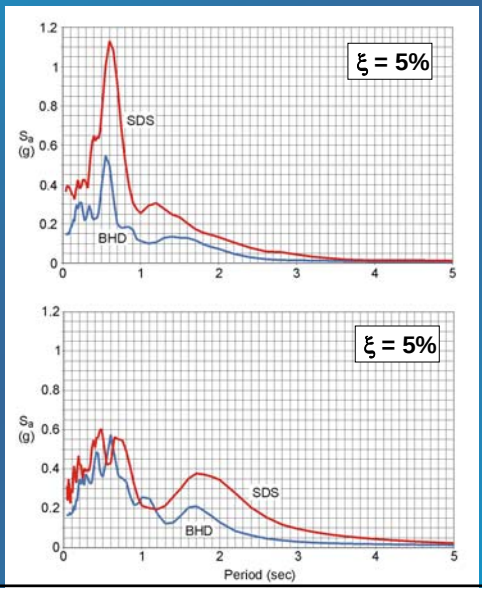
S_F Soil

$\overline{V}_S^{30m}$ = 148 m/s

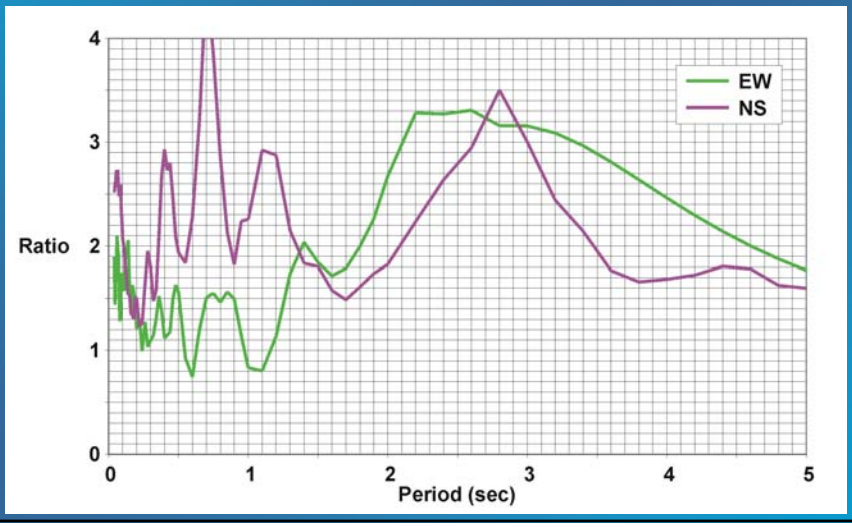
S_C Soil

$\overline{V}_S^{30m}$ = 680 m/s

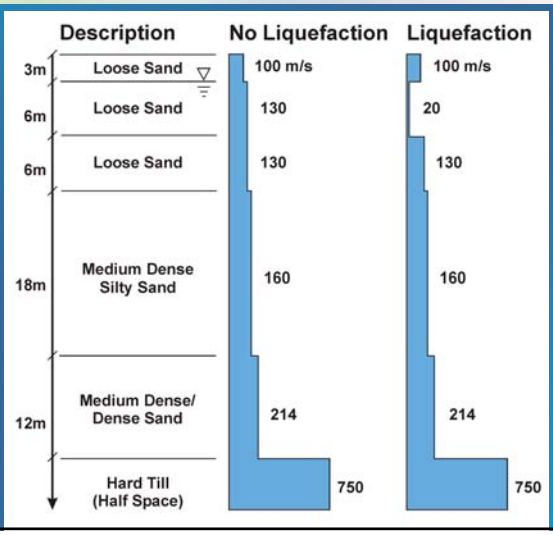
BHD and SDS Response Spectra



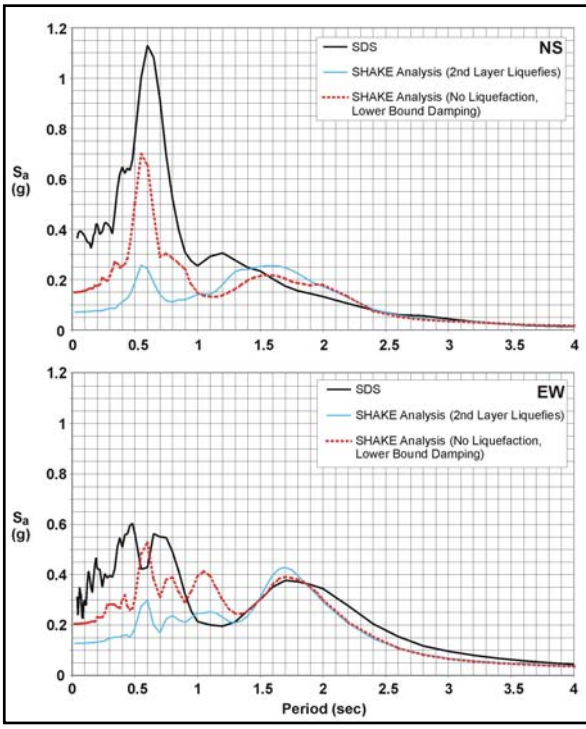
Response Spectral Ratio: SDS/BHD



Soil and V_s Profiles - SDS



Shake Prediction vs SDS Recording



2001 Nisqually Earthquake Conclusions

- Average ground motions
- Interesting site response
  - Liquefaction
  - Nonlinear response

2001 Nisqually Earthquake Recommendations

- Reoccupy 1949 and 1965 stations
- Reoccupy and enhance SODO sites
  - Add downhole array at SDS
- Measure ambient building periods