Implications for structural design motions Presentation to the Canterbury Earthquakes Royal Commission

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Photo: P Stalder

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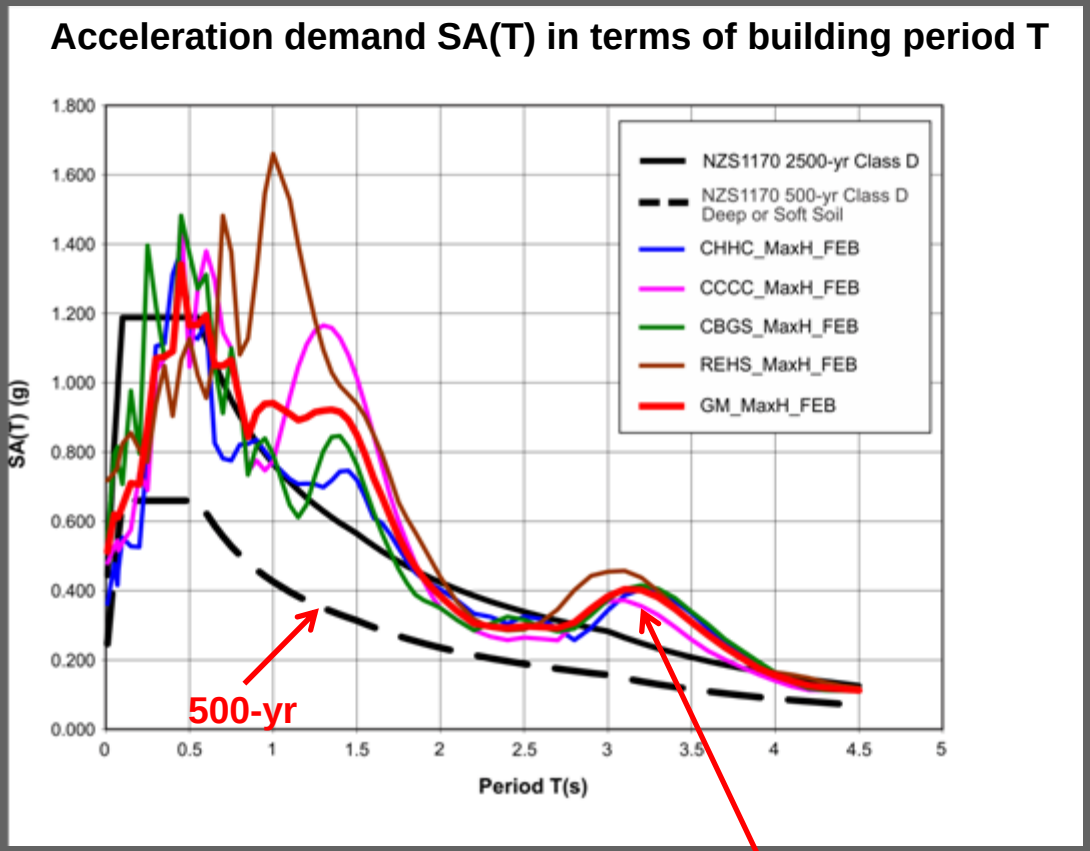
February spectra and NZS1170 design levels - four Geonet sites closest to CBD



500yr =Design-level for normal-use structures

Z=0.22

2500yr = Design-level for post-disaster essential facilities

RZ=1.8*0.22=0.40

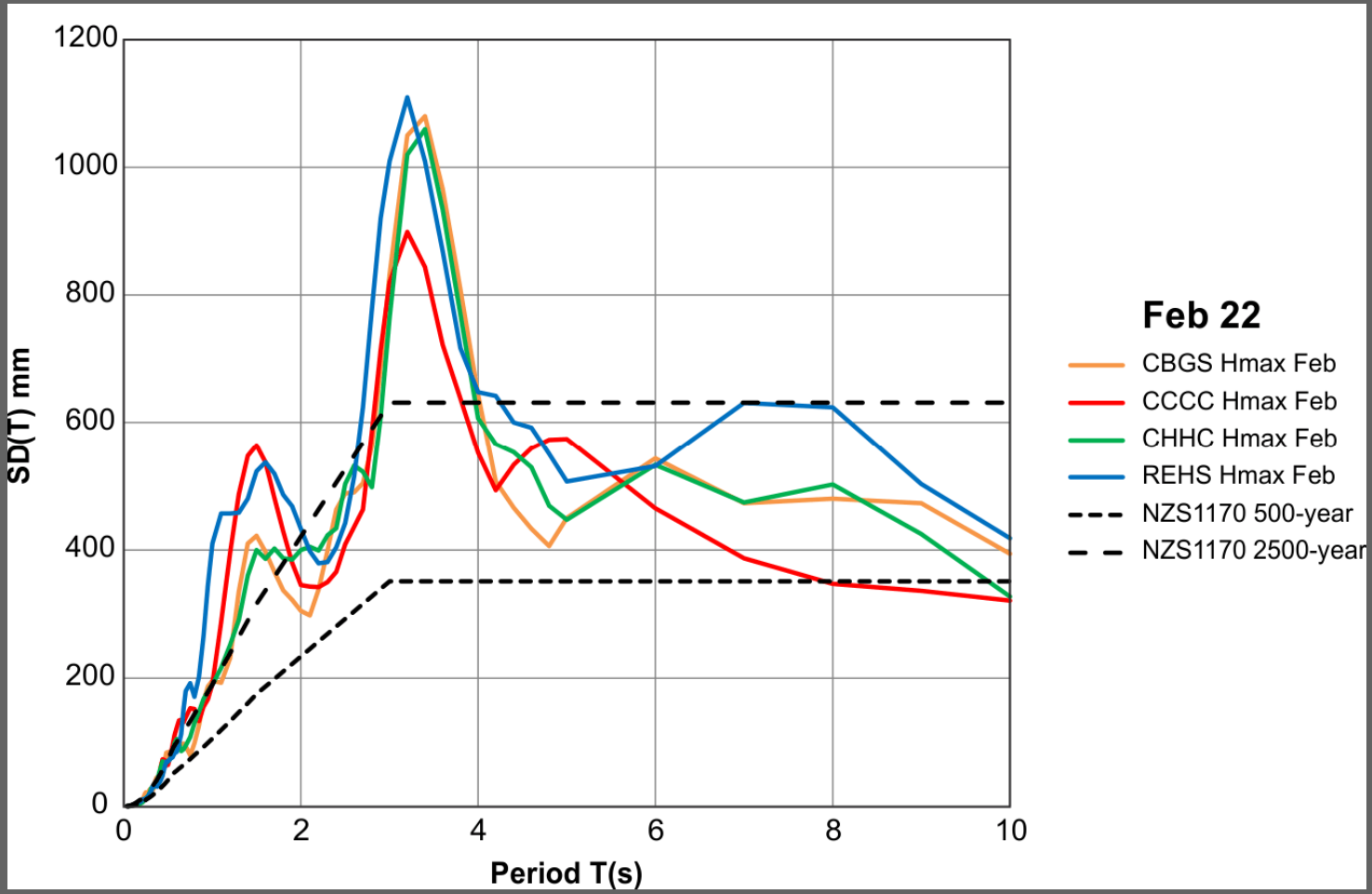
Red curve = geometric mean for the four sites

Peak around 3s close to site period

-several hundred metres of sediments over volcanic rocks

-controls maximum displacement demands for long-period structures (next slide)

Displacement spectrum



Maximum spectral displacement corresponds to peak around 2.5-4s

Reasons for requiring new design-levels for Christchurch region

- Greatly increased seismicity rates compared to low pre-September 2010 rates
  - sequence likely to continue at reducing rates for years rather than months
- Stronger ground motions in CBD than given by models
- Possible causes
  - stress-drops
  - directivity
  - site effects (long-period peak)

New interim seismic hazard model for Christchurch

- **Accounts for ongoing earthquake sequence**
  - **includes decreasing rates with time**
- **Shallow depth**
  - **5 km rather than 10 km minimum in model**
- **Increases ground-motions**
  - **uses increased stress-drop, possibly surrogate for other effects such as directivity for which suitable models not readily available**
- **Adjusts for dominance of magnitude 5-6 events**
  - **advice from Engineering Advisory Group that magnitudes less than 5.5 of little significance for engineered structures**
- **Limited to 1.5s period maximum until long-period modelling of site effects available**

Maximum magnitudes used for distributed seismicity in hazard calculations

- Seismicity model consists of fault sources (from geology) and a grid of distributed seismicity (from historical earthquake catalogue)
- Maximum magnitude of 7.0 in the Christchurch area for grid sources in 2000/2002 National Seismic Hazard Model (NSHM) used to develop NZS1170
- Larger magnitudes were associated with specific known faults e.g. Porters-Grey M7.5, Alpine M8.1
- Maximum magnitude for distributed seismicity increased to 7.2 in 2010 update of NSHM
- Post-February time-varying model for Canterbury has magnitudes up to 7.9 for distributed seismicity

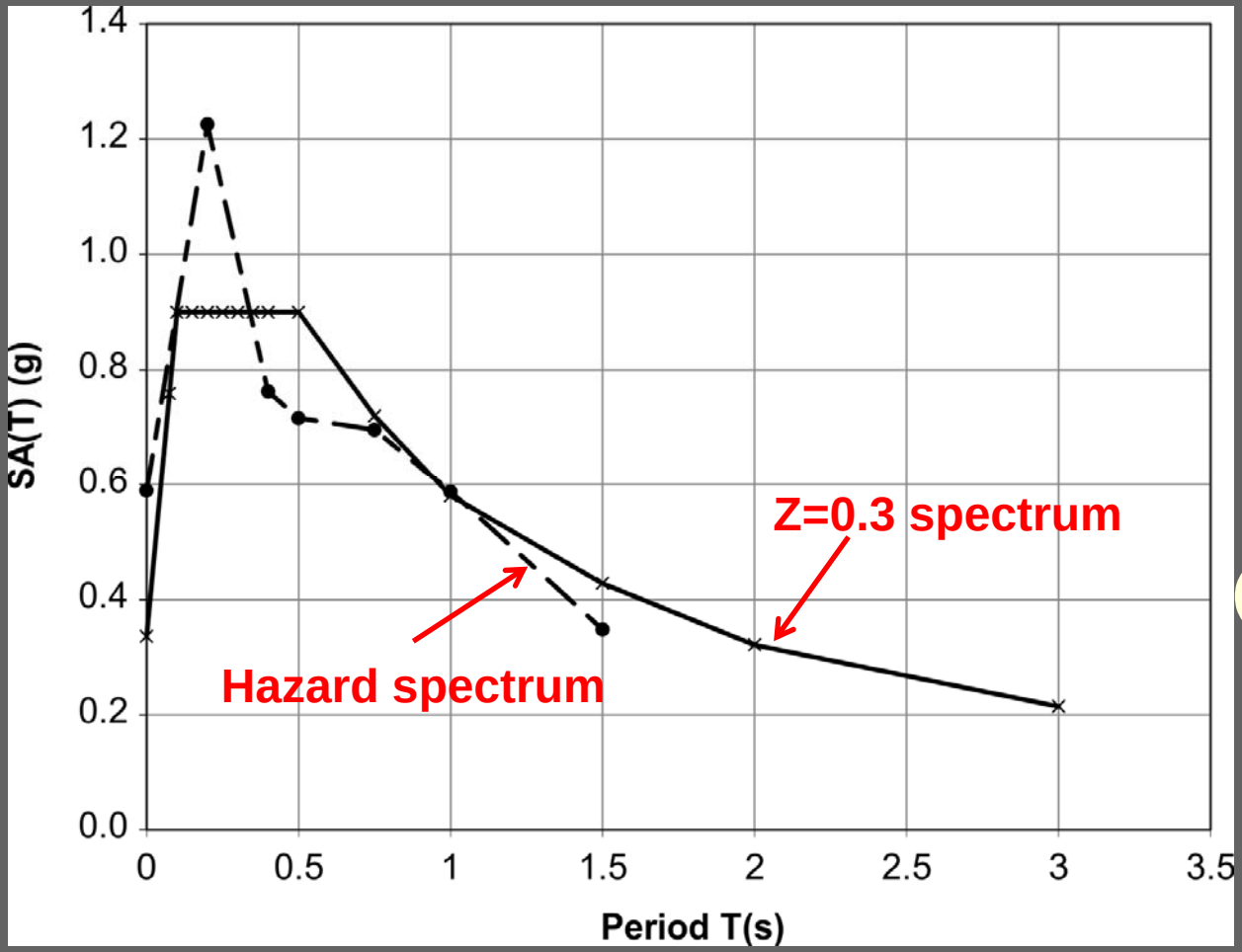
Minimum allowable Z-factor = 0.13 from magnitude 6.5 earthquake at 20 km distance

- Z-factor usually corresponds to a spectral acceleration with an annual exceedance probability of 1/500
- Minimum allowable value Z=0.13 based on scenario earthquake motions
- Corresponds to 2/3 the 84th-percentile (one standard deviation above the median) motions for a magnitude 6.5 earthquake at 20 km distance
- Derived from survivability level in earthquakes that may not be apparent from geology in lowest seismicity regions
- 2/3 factor to convert from survivability to design-level Ultimate Limit State motions
- Comes into play only in lowest seismicity regions
  - north of Bombay Hills, and in south-eastern Otago
  - Christchurch Z=0.22 well above Z=0.13

Preliminary results Z=0.3

- Engineering Advisory Group requested appropriate Z-factor (sets level of design spectrum) to use with NZS1170 Deep Soil spectral shape (site conditions appropriate for most of Christchurch CBD)
- Usual normalisation is in terms of Shallow Soil spectral values
- Initial results gave Z=0.3 using average seismicity rate over next 50 years
  - 50 years is default design life for most structures
  - Z=0.22 in NZS1170
  - approximately 0.4 (or greater) for CBD motions in February

Initial hazard spectrum and Z=0.3 Deep Soil spectrum



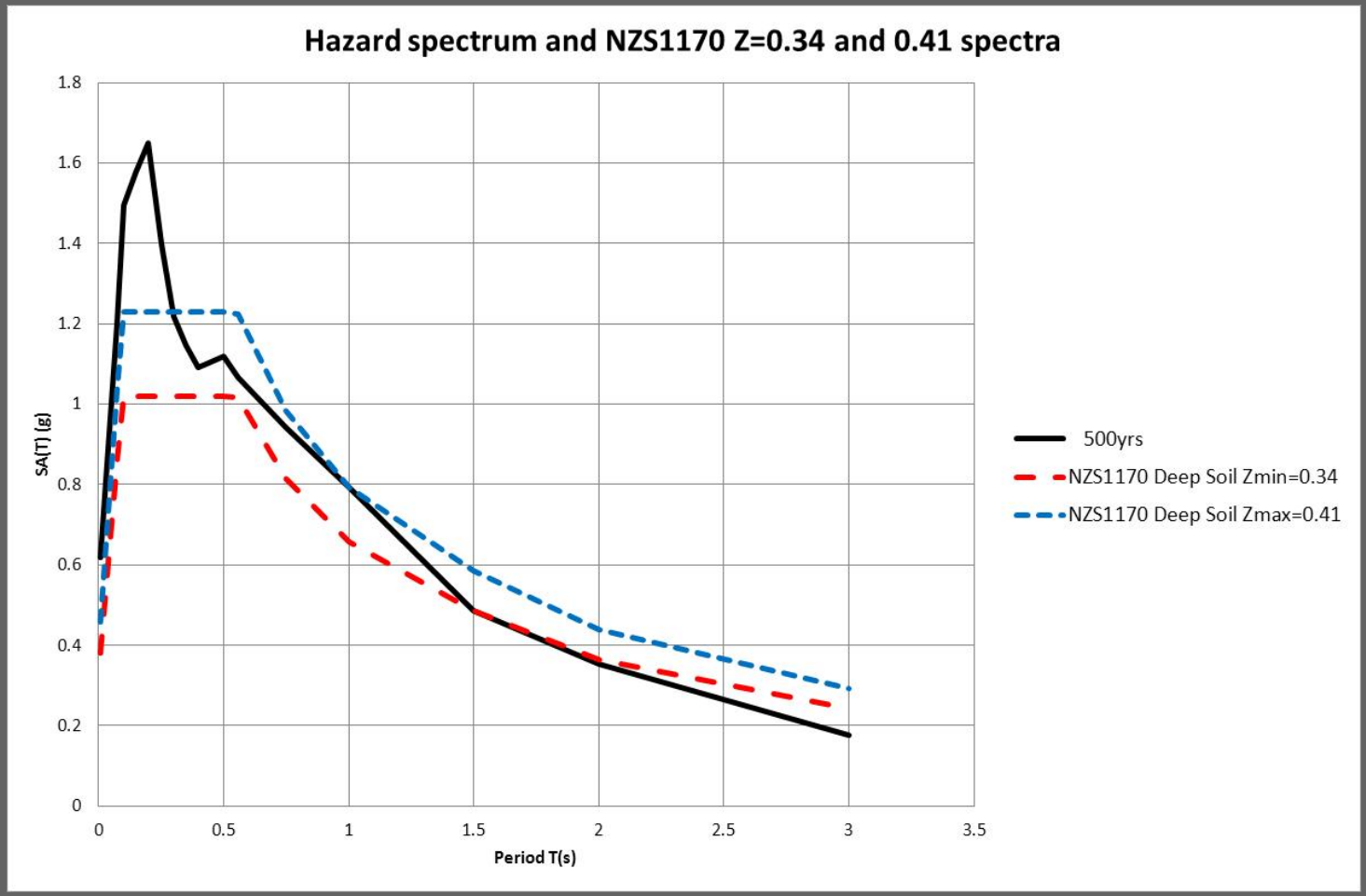
Intended for engineered structures 0.5s-1.5s period 1/500 average annual exceedance probability (AEP) over next 50 years

Excludes long-period site effect around 2.5-4s

Latest model

- Latest model raises Z=0.30 to range Z=0.34-0.41
  - resetting of seismic activity following magnitude 6.0 aftershock on 13 June 2011
  - adjustment of some parameters from US to NZ defaults in new software (NZ uses larger rather than geometric mean of 2 horizontal components)
- Wellington Z=0.4
- February CBD motions approximately Z=0.4 or greater

1/500 AEP hazard spectrum over next 50 years and NZS1170 deep soil Z=0.34 and 0.41 spectra



Zmin=0.34

from matching at 1.5s

Zmax=0.41

from matching at 1s

NZS1170 spectral shape differs from hazard spectrum

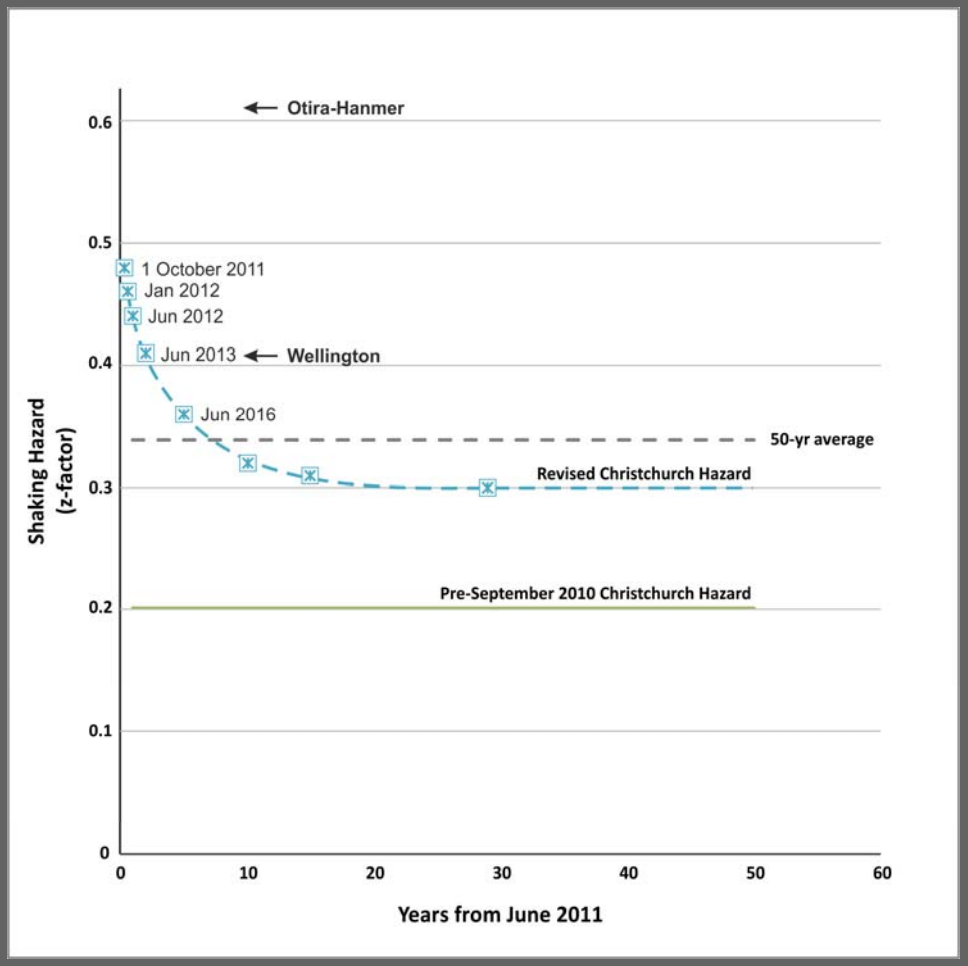
Long-period site-effect not included

Z=0.34 is lower bound for period range 0.5s-1.5s (Zmin)

Time-variation of Z-factor

- Decreasing seismicity causes Z-factor to decrease with time
- Current value greater than Z=0.34 average over next 50-years
- Later falls below Z=0.34 average

Variation with Z-factor over time



Z=0.34 average for next 50 yrs

Z=0.48 for 12 months

from 1 October 2011

Drops to 0.34 in year 8 (2019)

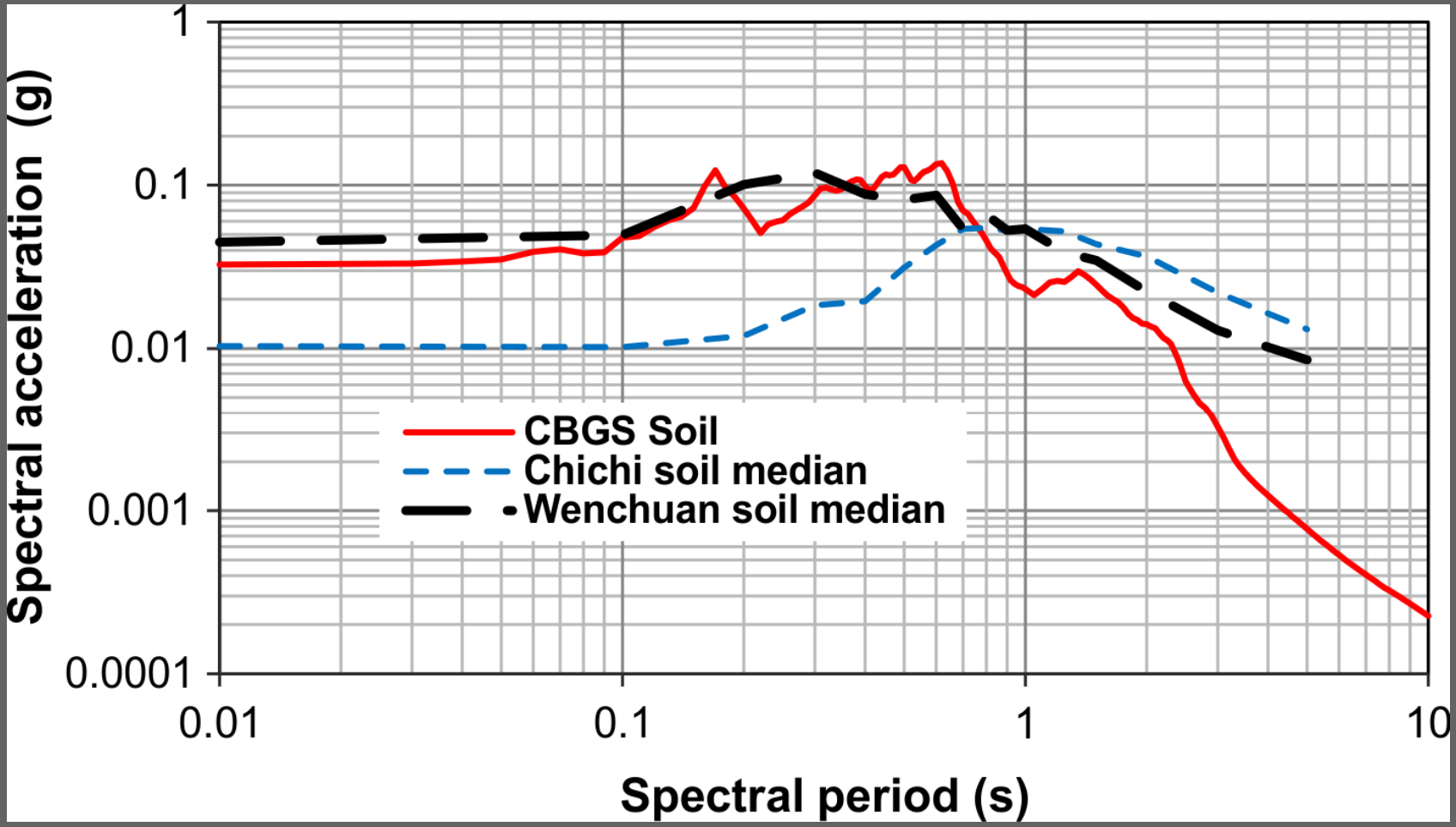
Z=0.3 beyond year 20

(close after year 15)

Peak horizontal ground accelerations

- Peak horizontal ground accelerations (pgas) for design usually scaled from Z-factor
- Low-magnitude dominance of ongoing earthquake sequence causes hazard spectra to be relatively strong in high frequencies
- Pga (corresponds to zero spectral period) is a high-frequency measure of ground motion
- Stronger pgas than given by standard spectral shapes scaled by Z
- Recommend directly-estimated pgas rather than scaling from Z-factor

Estimated Christchurch spectra for Alpine Fault event



Much lower than even Z=0.22 design spectrum which peaks at 0.66g

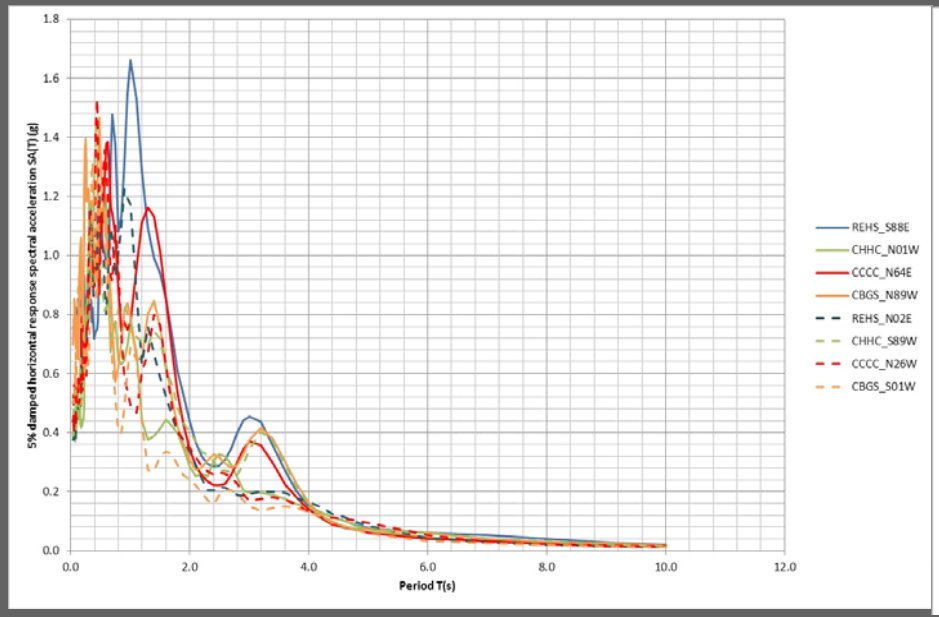
Chichi Mw7.6 in Taiwan in 1999, Wenchuan Mw7.9 in China in 2008

Vertical Motions

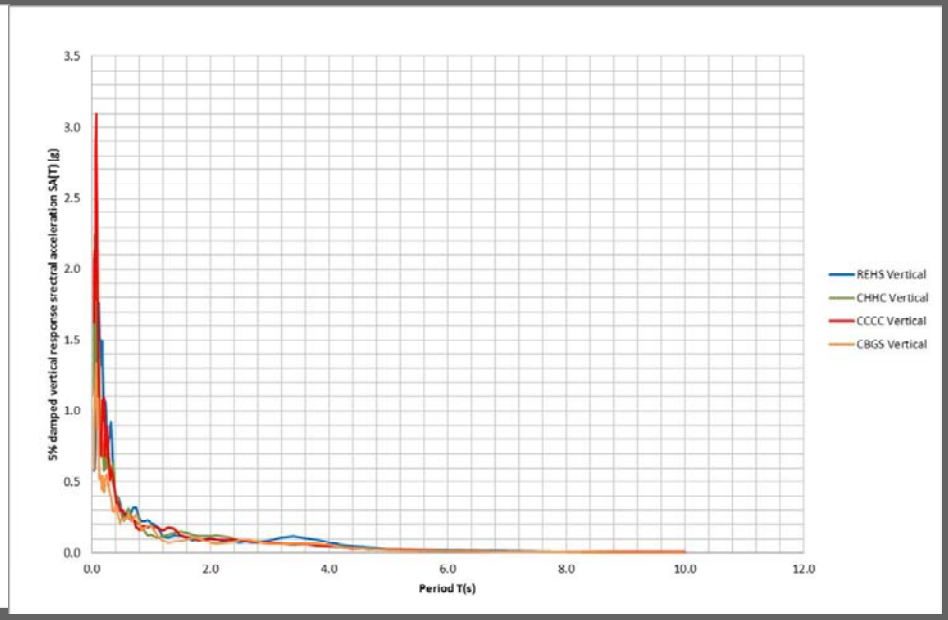
- NZS1170 recommends vertical spectrum = 0.7 * horizontal (very simplistic)
- Vertical spectra in Christchurch often stronger than horizontal in the very short-period range
  - common for near-source spectra
  - high-frequency in character
- NZS1170 Commentary has appropriate guidance on vertical spectra
- GNS Science routinely uses procedure modified from Eurocode to generate vertical spectra
- Recommend such a procedure should be incorporated in NZS1170

Horizontal and Vertical CBD spectra

Horizontal Spectra
(axis 0-1.8g)



Vertical Spectra
(axis 0-3.5g)



Horizontal spectra cover much wider period band

(peaks of some vertical spectra much higher, up to ~2 x horizontal)

Summary

- Zmin=0.34 for period range 0.5s-1.5s in latest model
  - Based on matching 1/500 AEP deep soil spectrum at 1.5s
  - Increased from earlier recommendation of Z=0.3
- Zmin varies with time
  - 0.48 in first year, 0.30 from 20 years on
- Pre-September values
  - Z=0.22 for Christchurch, Z=0.40 for Wellington
- 22 February motions approximately Z=0.4 or greater
- Still modelling peak spectral displacements around 3s, which corresponds to site period

THANK YOU

Parameter selection compared to NZS1170

Christchurch

- Depth 5 km (+)
- Minimum magnitude 5.5 (-)
- Factors for stress-drop ratio of 1.5 (+)
- Magnitude-weighting across all periods (-)
- Z = Zmin (-)
- = SA_{deep}(1.5s)/1.43
- = 0.34
- (0.57 from 0.5*$SA_{shallow}$(0.5s)
- Spectrum lower bound 0.5s-1.5s
- + increase, - decrease in SA

NZS1170

- Shallowest layer 10 km
- Mmin 5.0
- No stress-drop factors
- MWFs to 0.5s period
- Z=0.5*$SA_{shallow}$ (0.5s)
- = 0.22
- Spectral shape near upper bound for anywhere in NZ (apart from truncation at short period)