Adjustments of the 2015 updates of the Swiss Hazard Model to different Rock conditions (Vs-Kappa adjustment)

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1 Executive Summary

This report provides the information and data to adjust seismic hazard estimates (i.e. uniform hazard spectra, ground shaking maps and hazard curves) to different rock conditions (Vs30-kappa adjustment). The proposed adjustment ratios (factors) are key elements to facilitate back compatibility between the 2015 updates of the Swiss Hazard Model (Wiemer et al, 2015) and other seismic hazard studies valid for Switzerland (Giardini et al., 2004).

2 Background Information

A key element of the 2015 update of the Swiss Hazard Model (hereafter SuiHAZ15, Wiemer et al 2016) is the definition of a uniform generic reference-rock definition for hazard estimates.

The Swiss generic reference rock model of Poggi et al. (2011) is defined by shear-wave velocity as a function of depth, and derived through the characterization of 27 sites of the permanent seismic networks in Switzerland. Figure 1a shows the measured velocity profiles at these sites (Fäh et al., 2009). Poggi et al. (2011) associated quarter-wavelength average velocity at these sites with empirical frequency-dependent amplification functions using spectral modelling (Edwards et al., 2008). The resulting Swiss reference rock corresponds to Vs30 = 1100 m/s and to a site attenuation (*kappa*) for this reference of 0.016s (Edwards and Fäh, 2013).

To facilitate comparisons with other seismic hazard models in Switzerland, i.e. SwisHaz 2004 (Giardini et al., 2004), Pegasos Refinement Project 2013 (Renault et al., 2014) or the Swiss seismic design code (SIA261, 2014) we provide adjustment factors (ratios) between the reference rock (V_{s30} ~ 1100m/s, kappa=0.016s) and different V_{s30} – *kappa* pairs.

Hereafter, the adopted procedure to obtain these adjustment ratios is summarized:

1) Compute the *kappa* values corresponding to various values of V_{s30} using the equation proposed by Edwards, Fäh et al (2011):

$$\log_{10}(\kappa\ (s)) = -0.000278(V_{s30}) - 1.49 \qquad (1)$$

2) Compute the delta kappa ($\Delta\kappa\ (s)$), as a difference between the *kappa* of different V_{s30} values and reference kappa (corresponding to Vs30~1100m/s):

$$\Delta\kappa\ (s) = \kappa(Vs30) - \kappa_{refrence\mathrm{Vs30}} \qquad (2)$$

Kappa values are listed in Table 1. An illustrative relationship between kappa and $\Delta\kappa\ (s)$ as function of V_{s30} is presented in Fig. 2. Negative $\Delta\kappa\ (s)$ are obtained for Vs30 > 1100m/s that corresponds to an increase of energy at high frequency. Positive $\Delta\kappa\ (s)$ are obtained for vs30 < 1100m/s that corresponds to a reduction of the energy at high frequency.

3) Compute Fourier amplification ratios between the host (reference rock/*kappa*) and the target (various Vs30, $\Delta\kappa$ *(s)*). The method proposed by Poggi et al. (2011) and Poggi et al. (2013) is used to compute the Fourier amplification functions, based on the calculation of the quarter-wavelength amplification and the correction for $\Delta\kappa$ *(s)*. Examples of the Fourier amplification functions are shown in Figure 3.

4) Apply the Fourier amplification ratios to response spectra using a combination of spectral modeling techniques and random vibration theory. Because the transforming Fourier amplification functions into response spectral amplification functions is a non-linear process, a general form of source and path effects are used to simulate the spectral shape on a reference velocity structure as a function of various parameters. The parameters are the corner frequency, stress drop, seismic moment and distance, regional Q-model and geometrical spreading model, reference near-site attenuation term, etc. These parameters are identical with those of Edwards and Fäh (2013a) for the Swiss stochastic model.

5) The SMSIM FORTRAN package (Boore 2005) is used to compute response spectral amplification functions using stochastic modeling. At first, the response spectra are computed with random vibration theory (RVT) for a given scenario, including also the site-specific amplification (target spectrum). Next, the site-specific spectrum is divided by the rock reference spectrum, to compute the adjustment factors. These are ratios between the reference spectra for Vs30~1100m/s, kappa =0.016s and amplified response spectra for various Vs30 and corresponding kappa values. The values of Vs30 range from 500 to 2500m/s. The adjustment ratios are listed in the Appendix A.

The resulting adjustment ratios are recommended when comparing the seismic hazard estimates (hazard maps, curves, uniform hazard spectra) incorporating in their ground motion models the Vs30 and kappa (site-specific attenuation) correlation. Note, that in this manuscript the amplification functions are presented in the frequency domain, to highlight features that are relevant in site response analysis. Alternatively, the adjustment ratios and the equal hazard spectra are generally presented in period, for compatibility with the standard engineering representation. Examples of Fourier amplification functions and adjustment ratios in frequency domain are illustrated in Figure 4.

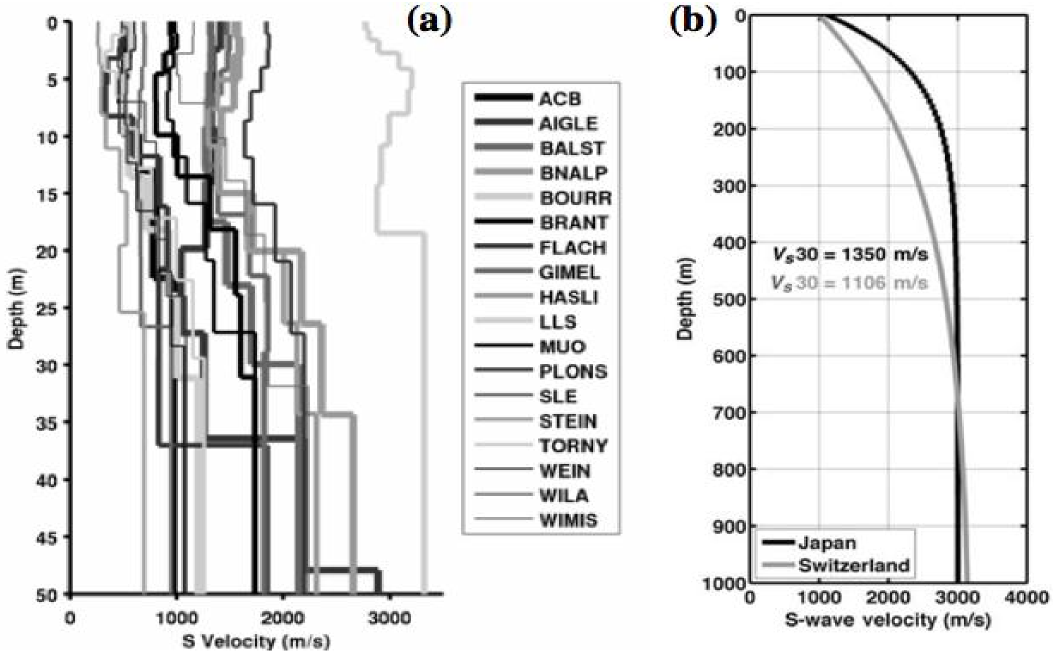


Figure1: (a) Example of the 27 characterized S-wave velocity profiles for the SED station using active and passive analysis (Fäh et al., 2009); (b) Comparison of the inverted reference S-wave velocity profile of the Swiss reference rock profile (Vs30=1106m/s) with the S-wave profiles obtained from Japanese network (Vs30=1350m/s) (from Poggi et al., 2013).

V_{s30}	κ (s)	*Δκ (s) with reference to V_{s30} = 1100 m/s*
500	0.0235	0.0075
600	0.0220	0.0060
700	0.0207	0.0047
800	0.0194	0.0034
900	0.0182	0.0022
1000	0.0171	0.0011
1100	**0.0160**	**0.0000**
1200	0.0150	-0.0010
1300	0.0141	-0.0019
1400	0.0132	-0.0028
1500	0.0124	-0.0036
1600	0.0116	-0.0044
1700	0.0109	-0.0051
1800	0.0102	-0.0058
1900	0.0096	-0.0064
2000	0.0090	-0.0070
2100	0.0084	-0.0076
2200	0.0079	-0.0081
2300	0.0074	-0.0086
2400	0.0070	-0.0090
2500	0.0065	-0.0095

Table 1: $V_{s30} - \kappa$ relation as described by (eq.1) and V_{s30} - Δκ *(s)* relation (eq. 2) the reference coefficients

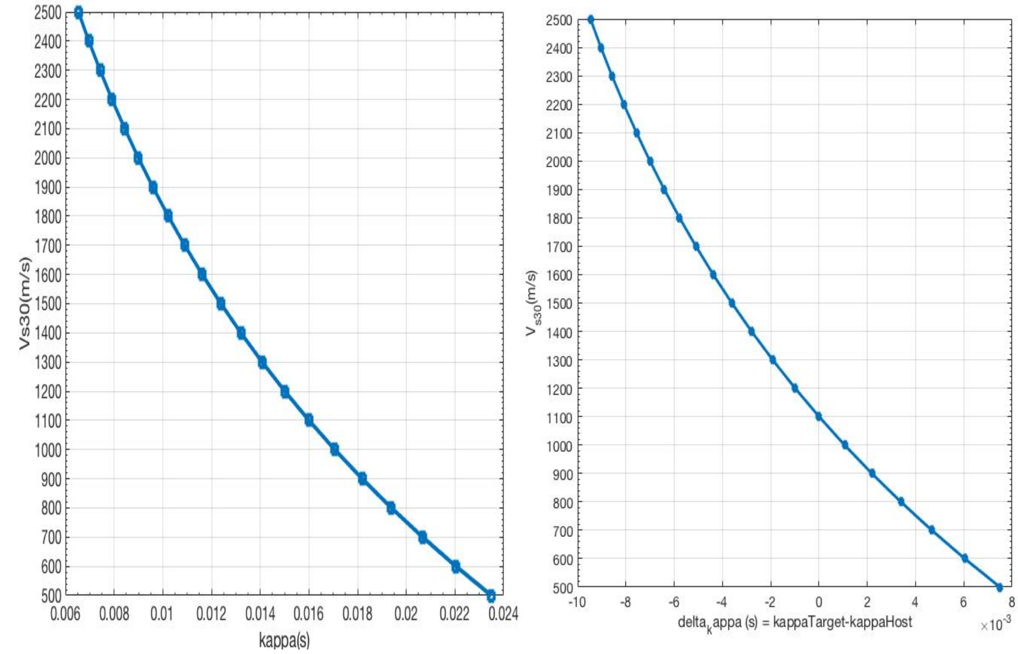


Figure 2: Ilustrative example of the relationship between *kappa* (left) and *delta kappa (right)* as a function of various values of Vs30. Kappa values were obtained with Eq. 1; delta kappa is the difference between the reference kappa (k~0.016 for Vs30~1100m/s) and *kappa* values for various values of Vs30 as listed in table 1.

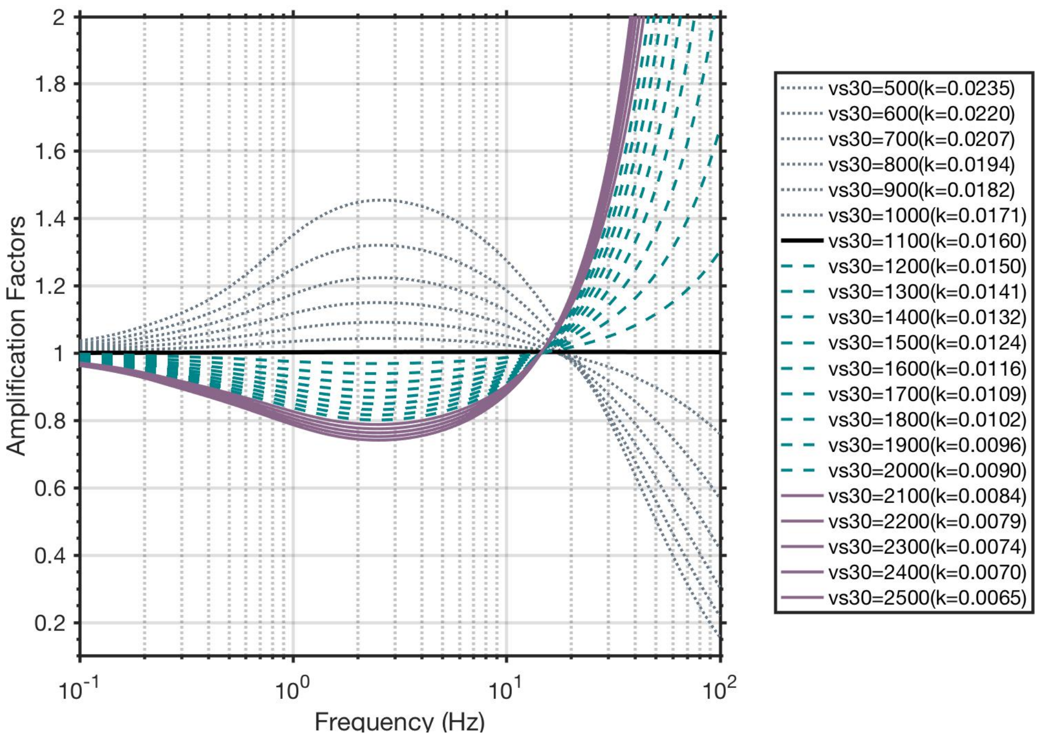


Figure 3: Fourier amplification functions based on the calculation of the quarter-wavelength amplification and the correction for Δκ (s) as obtained in Step 3.

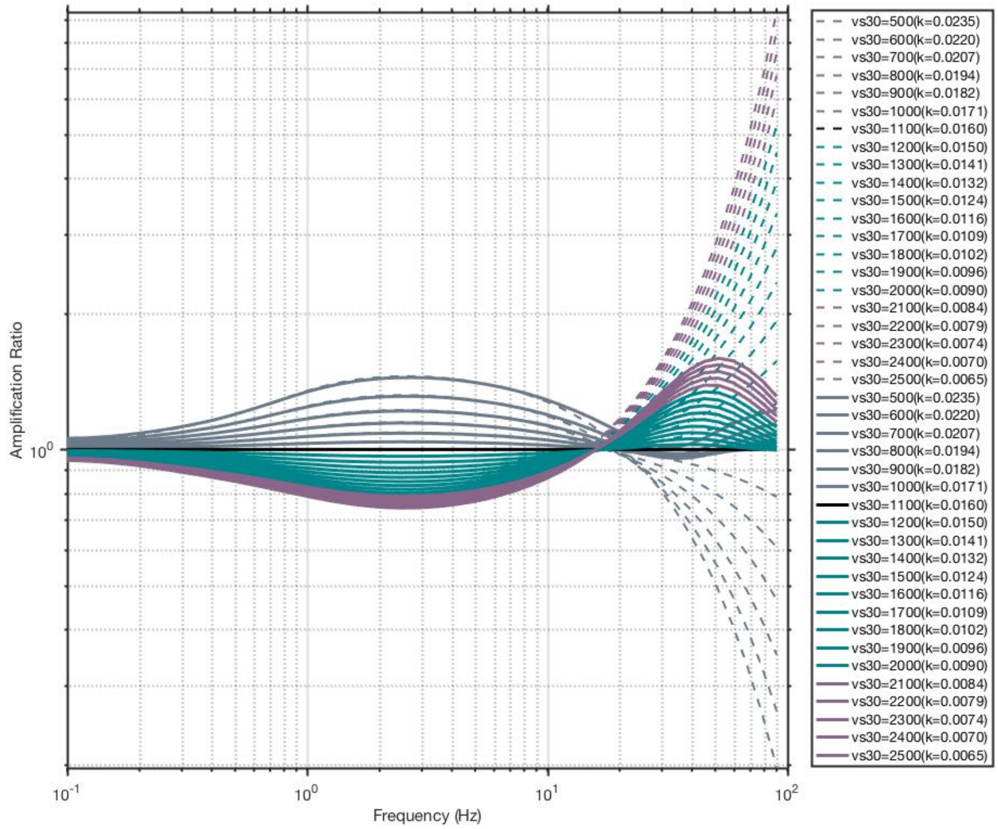


Figure 4: Comparison of Fourier amplifications factors (dashed lines) and response spectra adjustment ratios (continuous lines) in frequency domain.

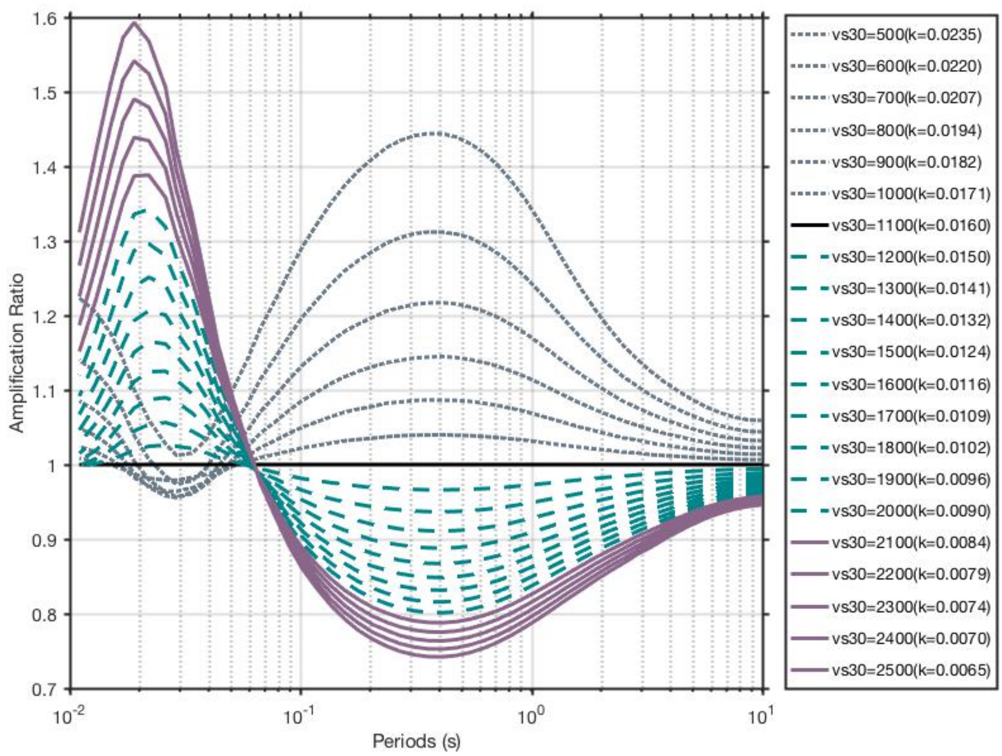


Figure 5: Adjustment ratios for various Vs30-kappa pairs and the reference rock (Vs30~1100m/s and kappa=0.016)

3 V_{s30}-*kappa* adjustment

The adjustment ratios for V_{s30} - *kappa* are recommended for use when converting seismic hazard outputs for reference rock that considers the Vs30-kappa model, i.e. PRP2013 (Renault, 2014). The adjustment ratios are period specific. The values are given in the Appendix. They have to be multiplied with the corresponding value for the V_{s30} = 1100m/s reference profile i.e. we expect de-amplification for adjustment ratios value smaller than 1 and amplification for ratios greater than 1. Figure 6 illustrates uniform hazard spectra – UHS - mean median and 16th and 84th quantiles of the SuiHaz2015 (Wiemer et al. 2015) adjusted for a Vs30 ~ 800m/s. The comparison is given for site Sion. It can be observed that the adjusted UHS are increased for spectral periods > 0.1s when compared with the reference UHS (Vs30~1100/m, kappa~0.016s). However, the spectral acceleration decreases as very short periods, as the ratio is decreasing (see adjusting ratios in Figure 5).

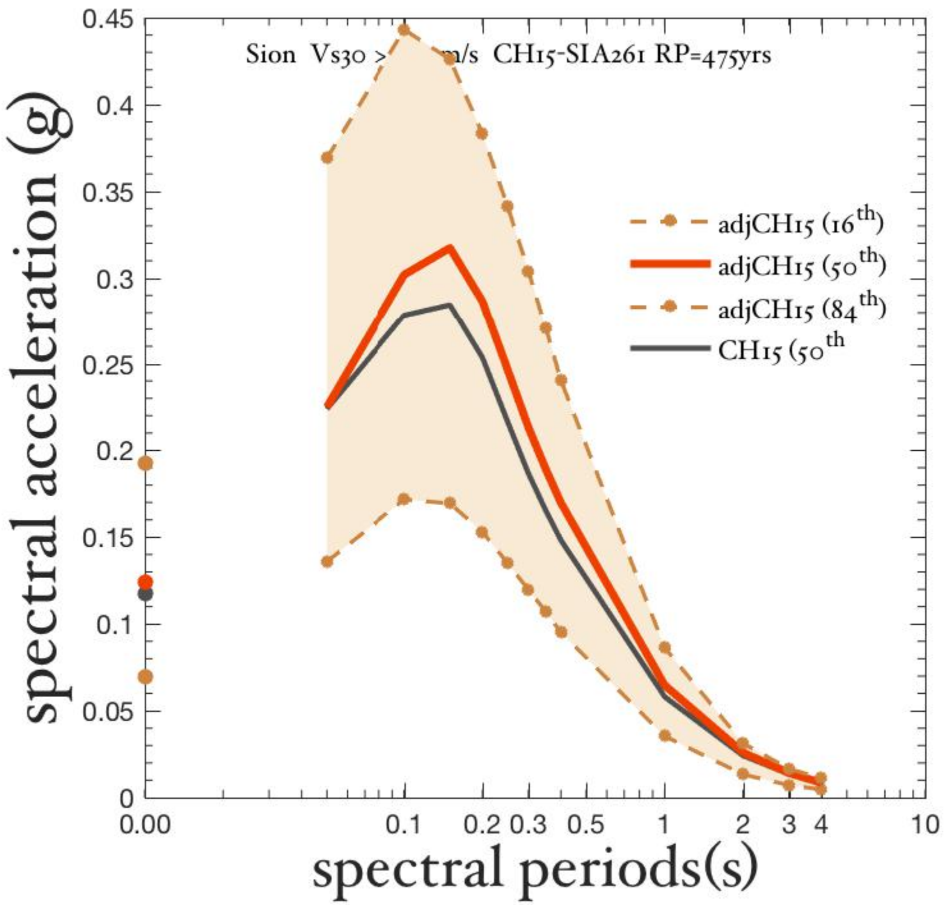
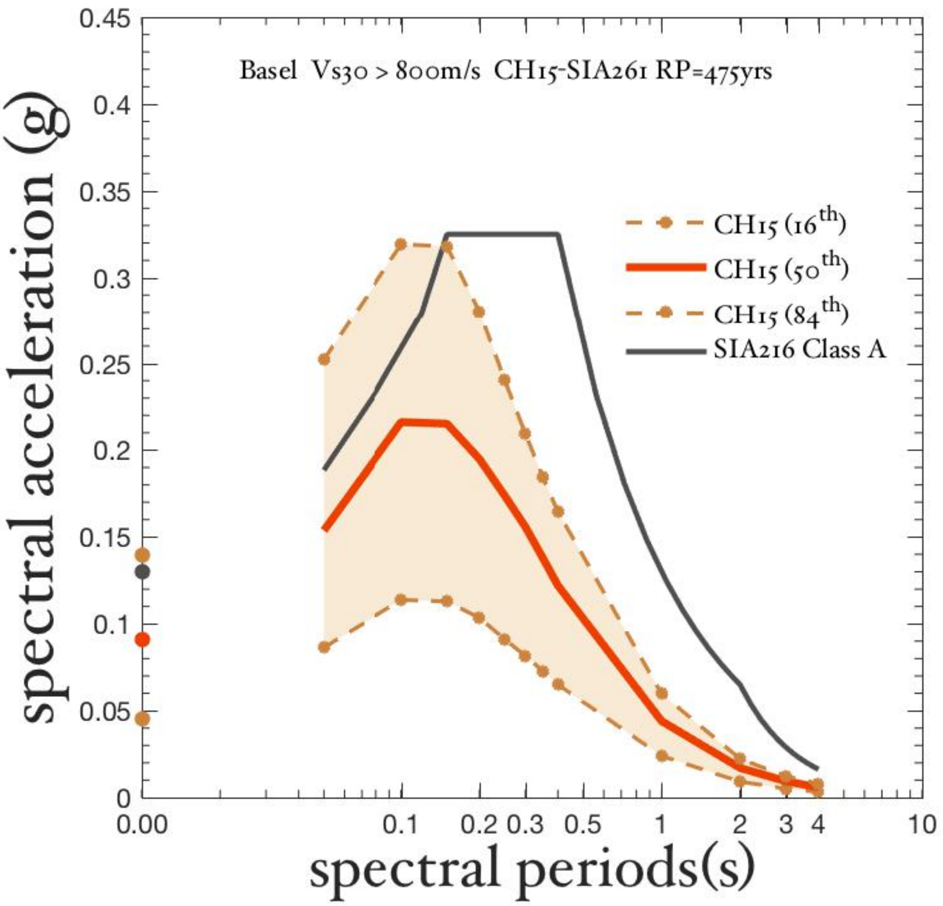
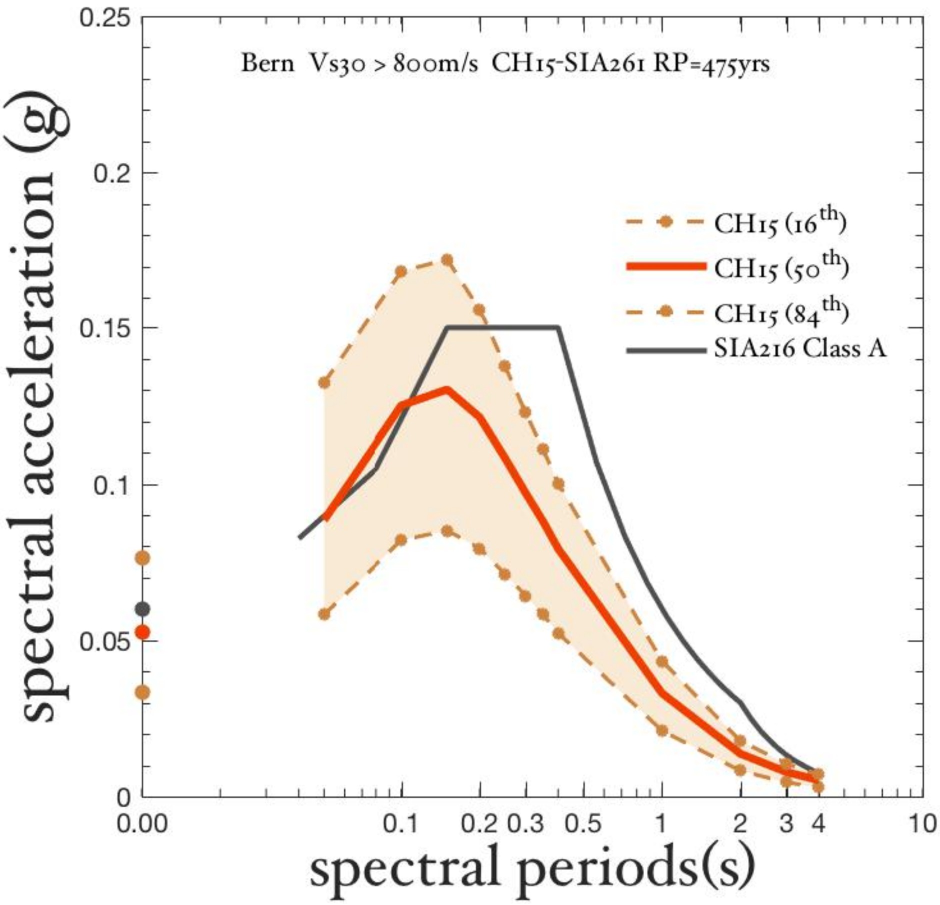


Figure 6: Adjustments of Uniform Hazard Spectra of SuiHaz2015 on reference rock Vs30=1100 m/s (*k* ~ 0.016s) to a Vs30~800m/s (k~0.0194). The adjustment ratios corresponding to the target spectrum (Vs30~800m/s) plotted in Fig. 4 are multiplied with the median UHS (50th, black line) to obtained the adjusted UHS (valid for V_{s30}~800m/s, *k*~0.0194). The comparison is illustrated for Sion, Switzerland.

Next, we provide comparison of uniform hazard spectra of the SuiHaz2015 adjusted for a reference rock - Vs30 > 800m/sec (soil-class A in SIA261 2014) with the corresponding design spectra. The adjusted UHS were obtained by multiplying the adjustment ratios plotted in Fig. 5 with the uniform hazard spectra of the SuiHaz2015 for various cities in Switzerland. The adjustment factors are listed in the Appendix.




Bern Vs30 > 800m/s CH15-SIA261 RP=475yrs
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SIA216 Class A
spectral acceleration (g)
spectral periods(s)
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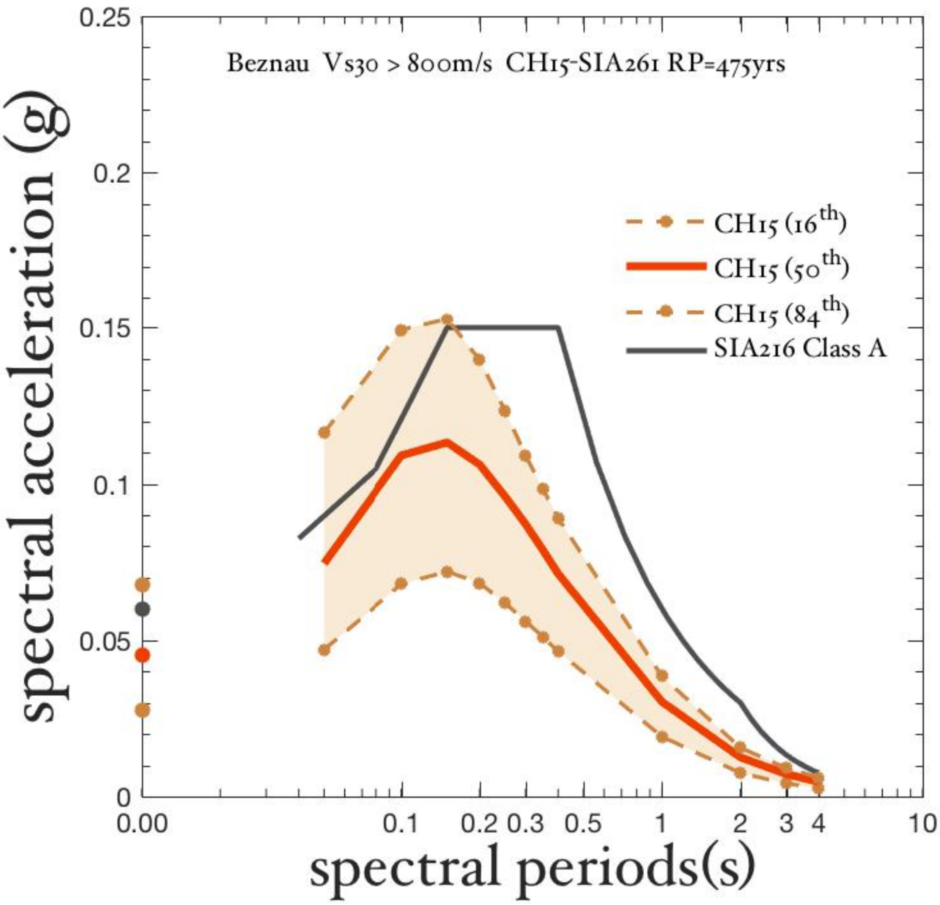
Beznau Vs30 > 800m/s CH15-SIA261 RP=475yrs
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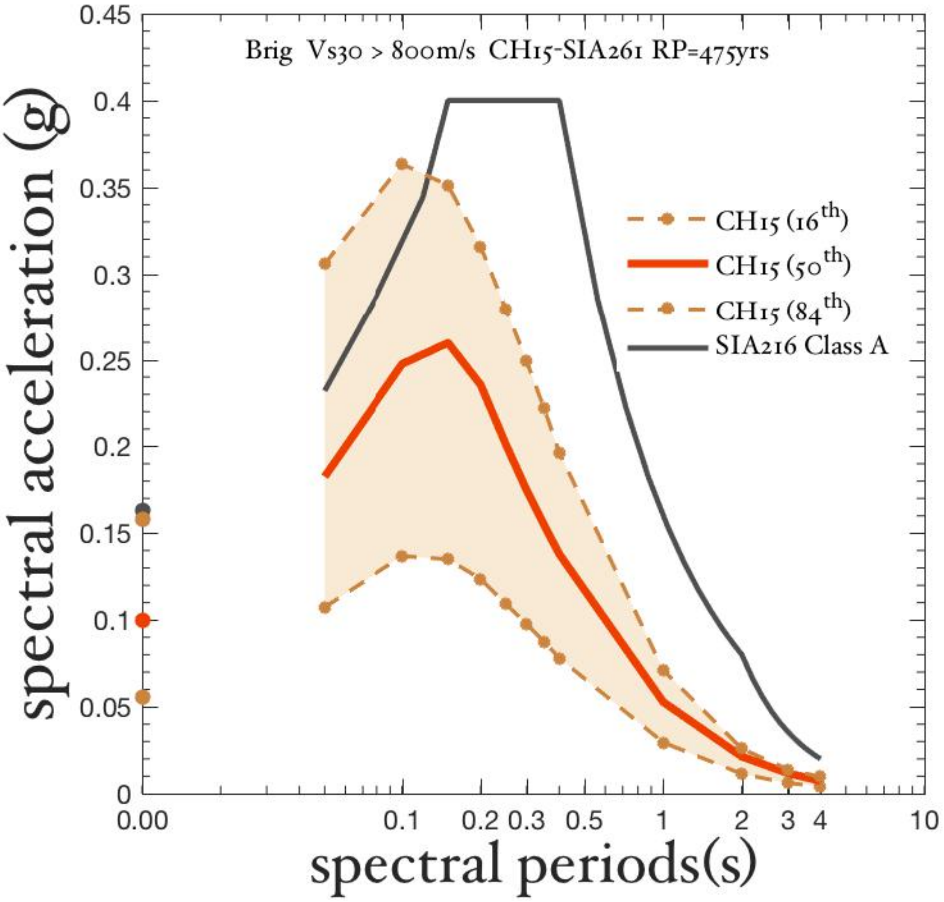
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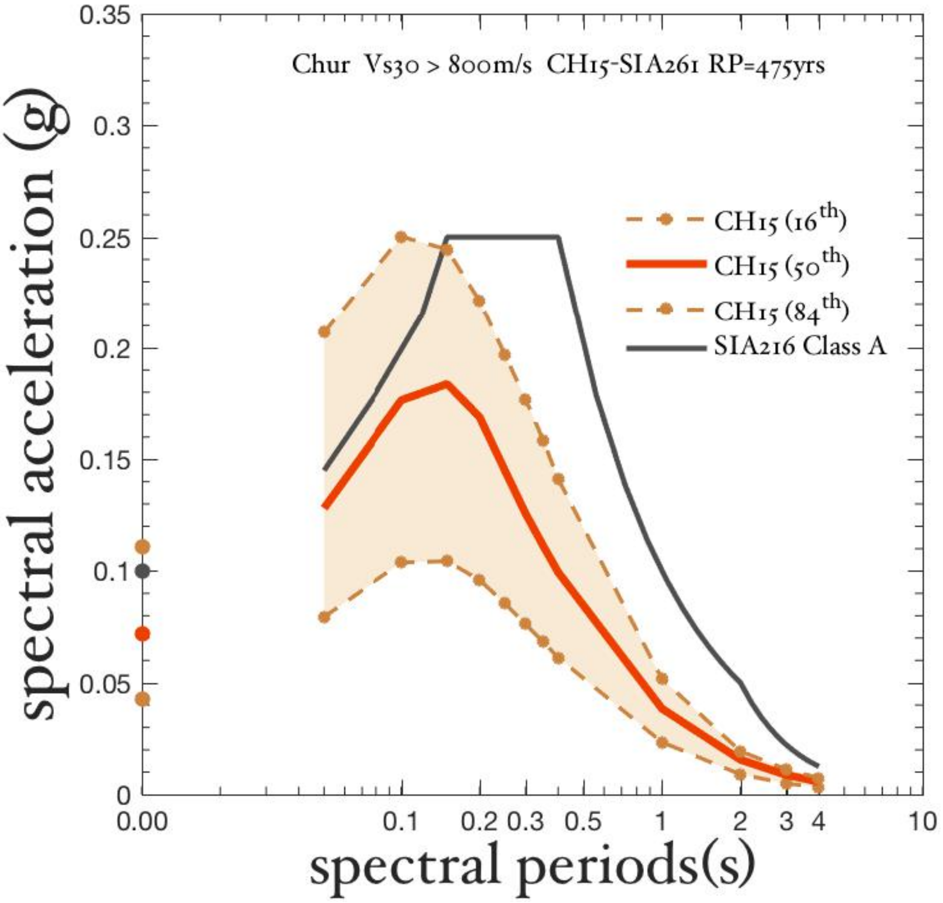
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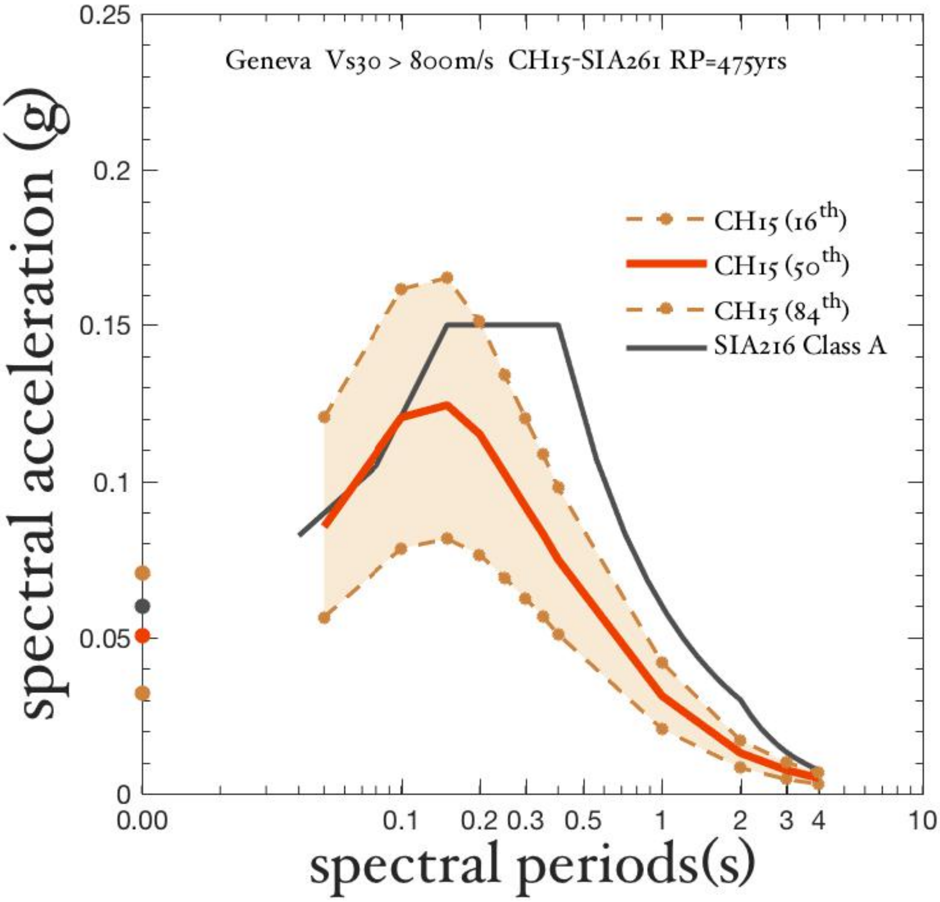
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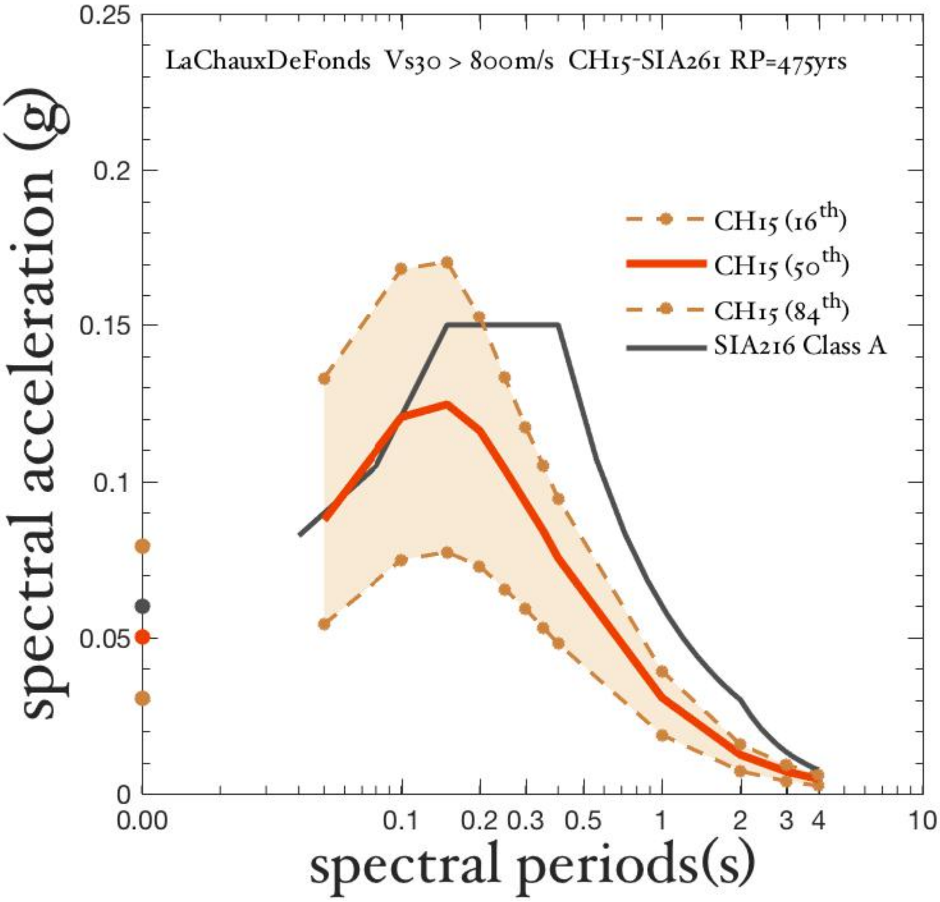
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spectral periods(s)
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SIA216 Class A
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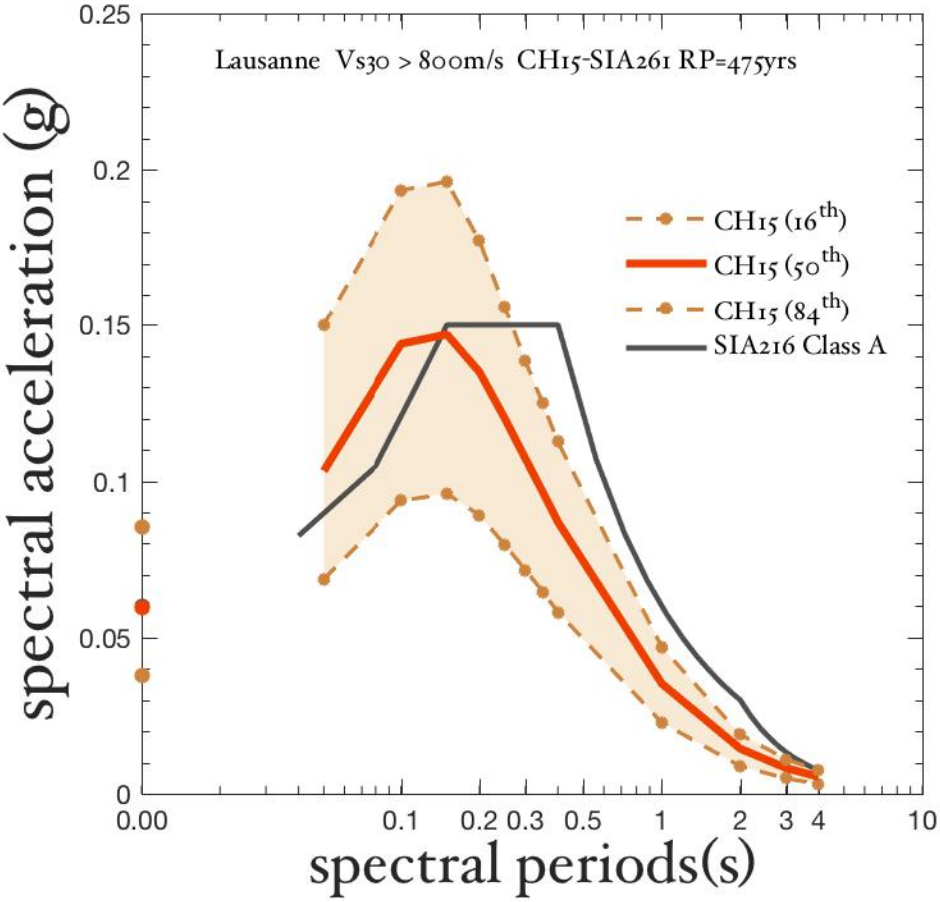
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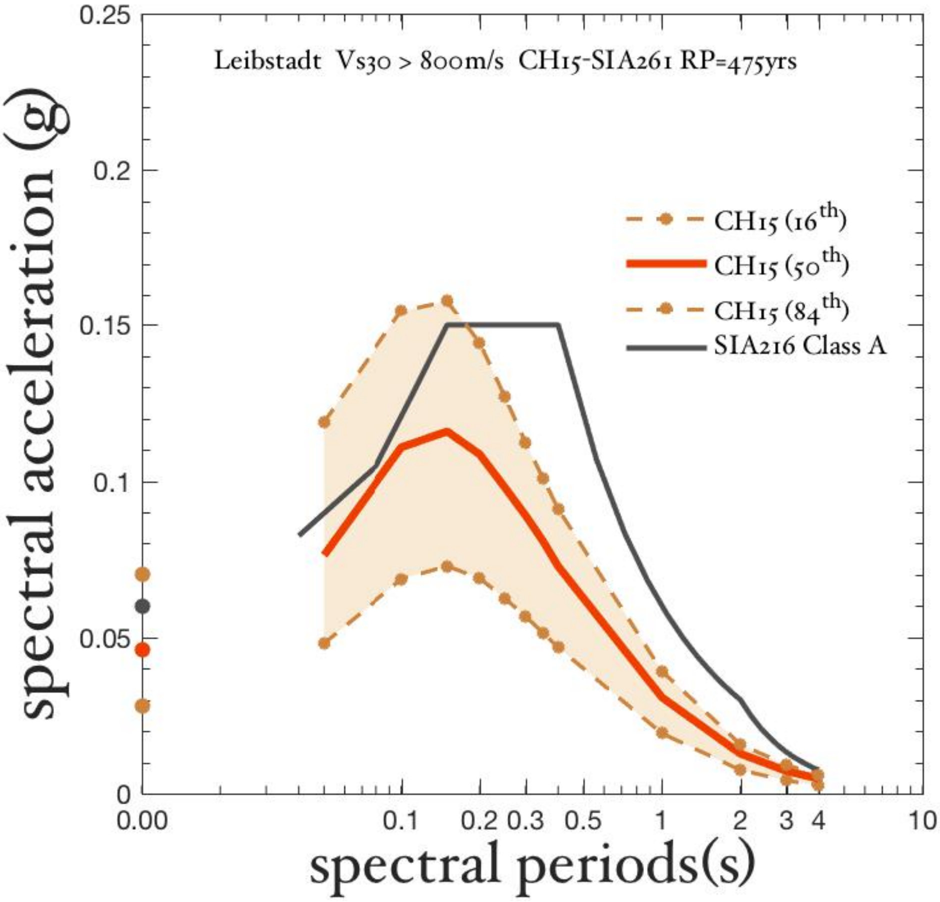
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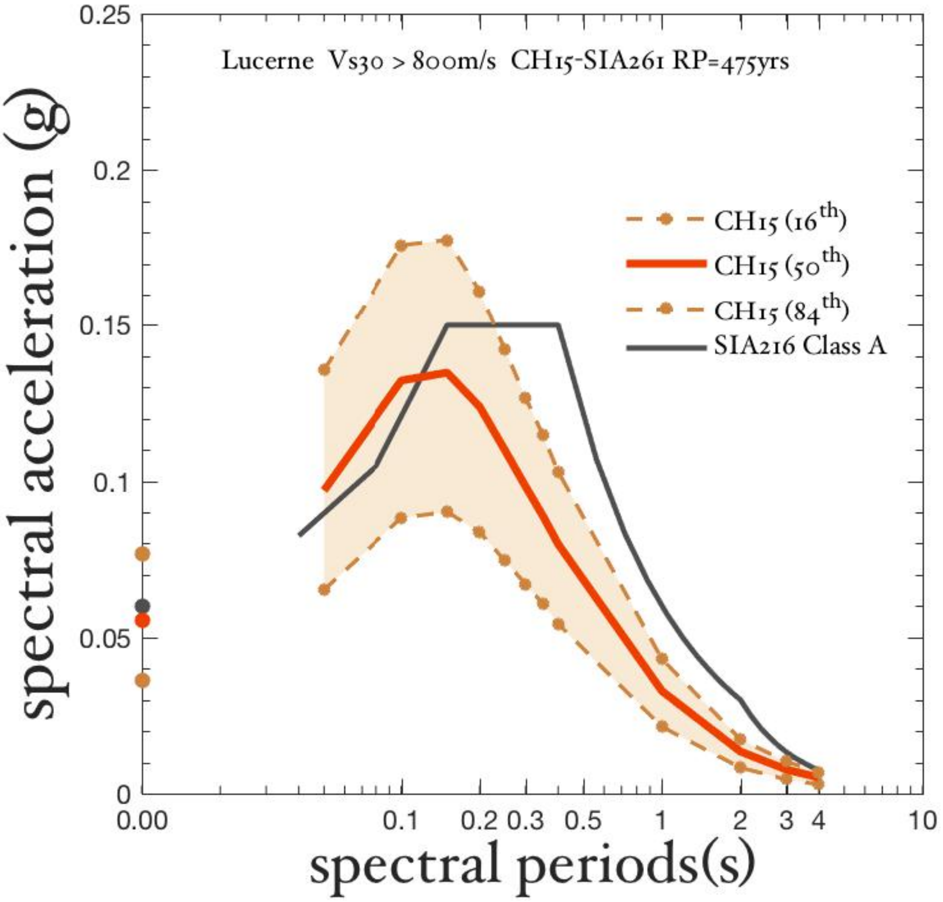
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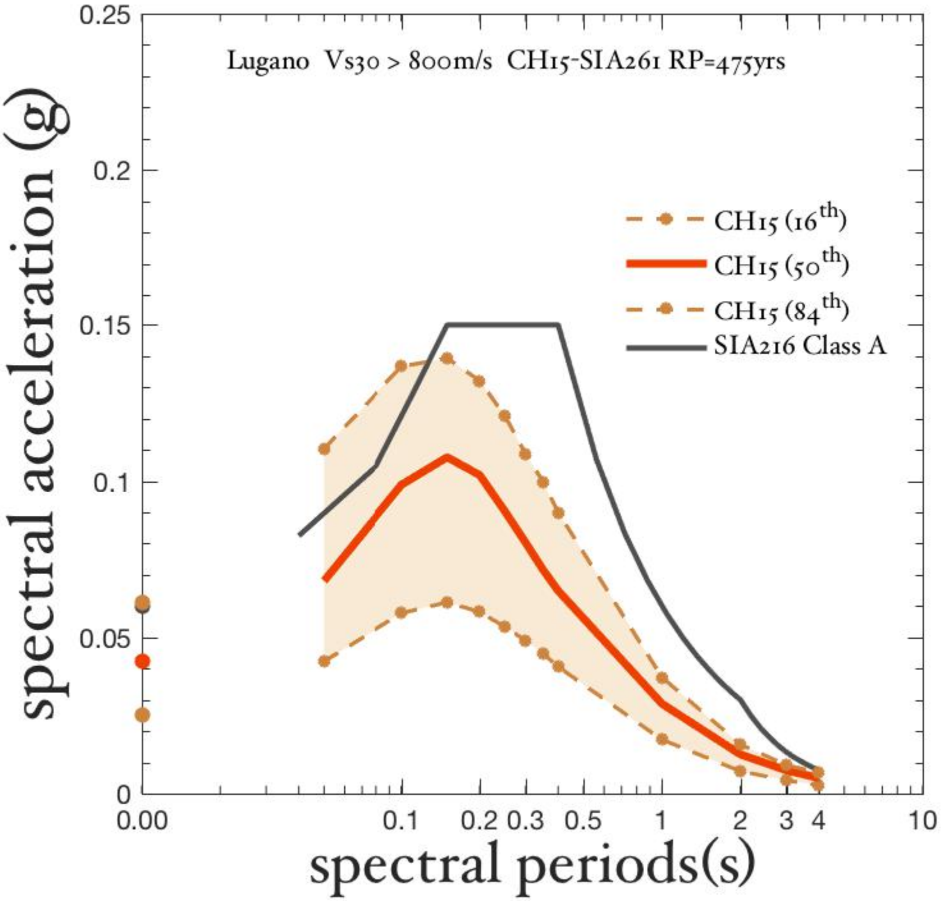
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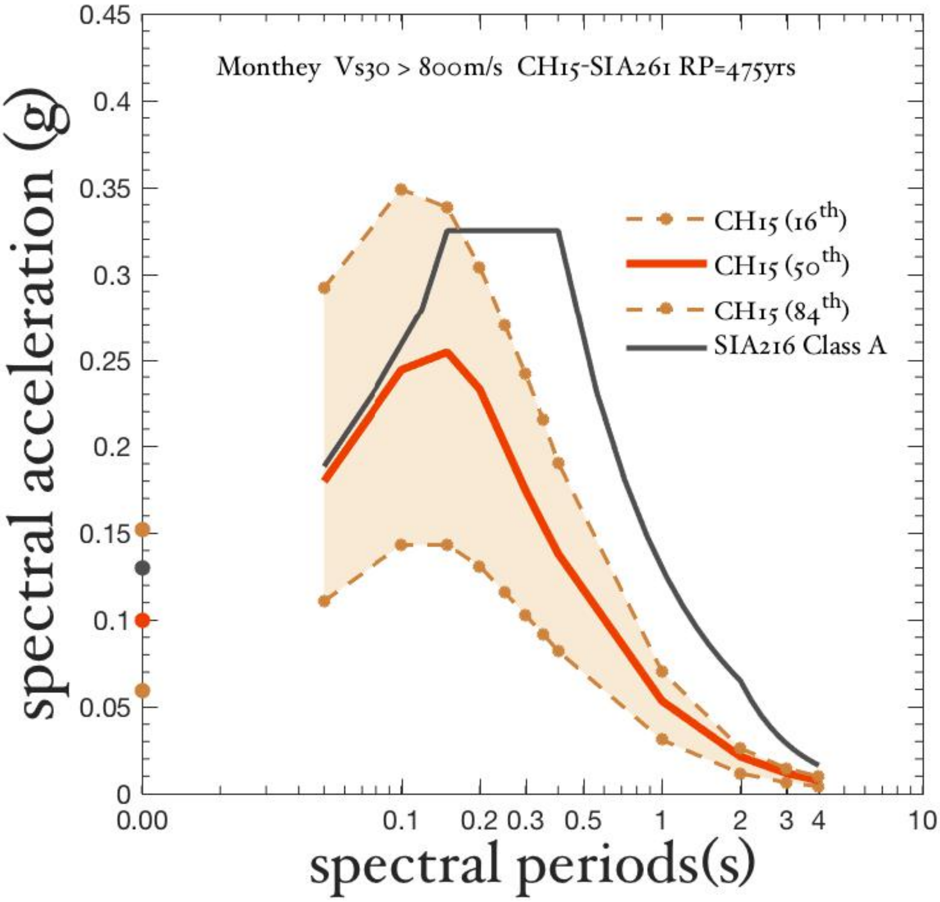
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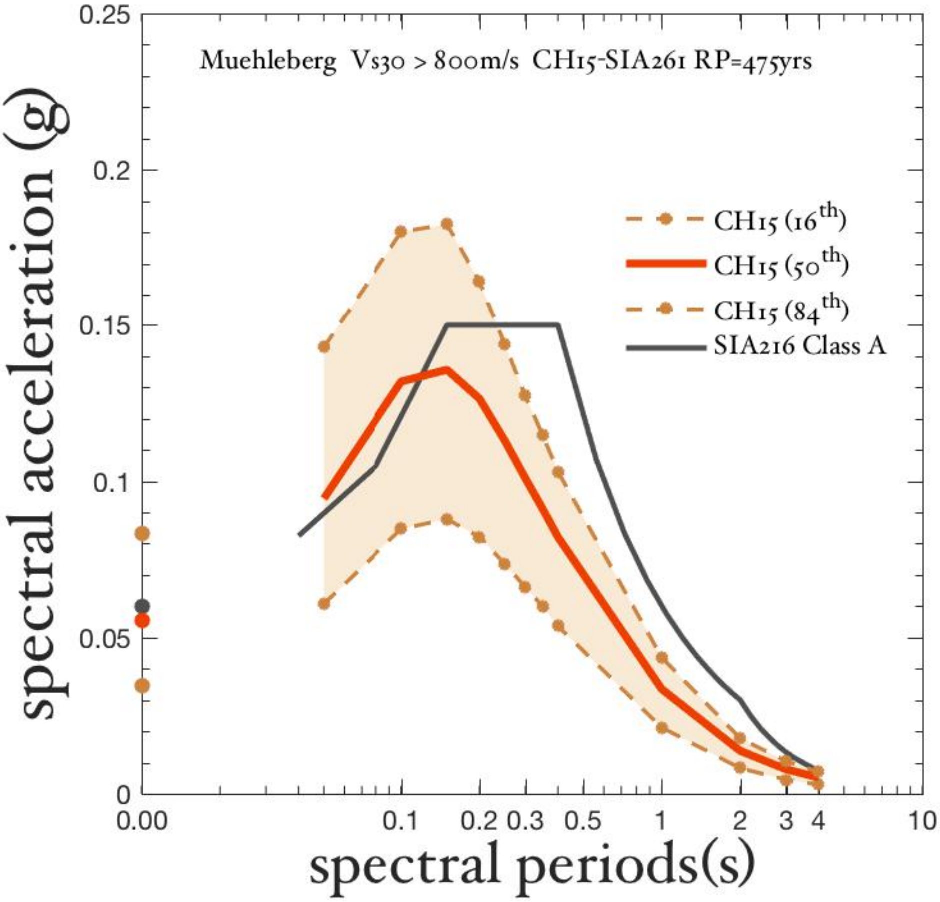
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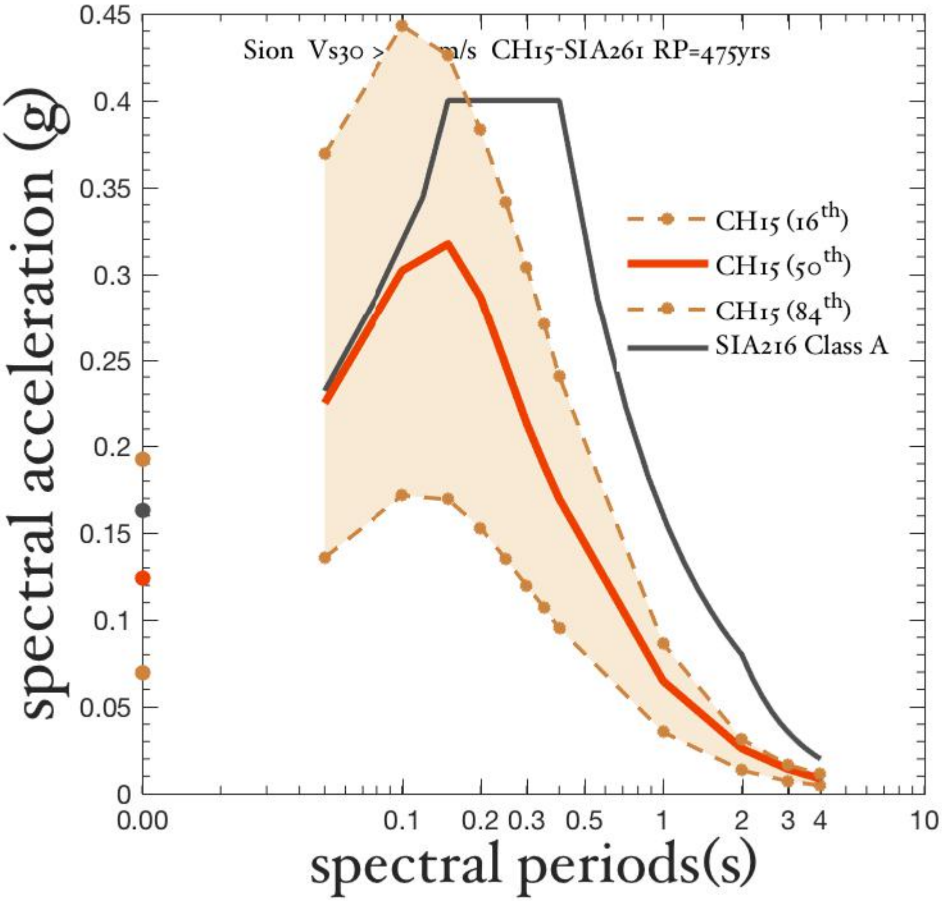
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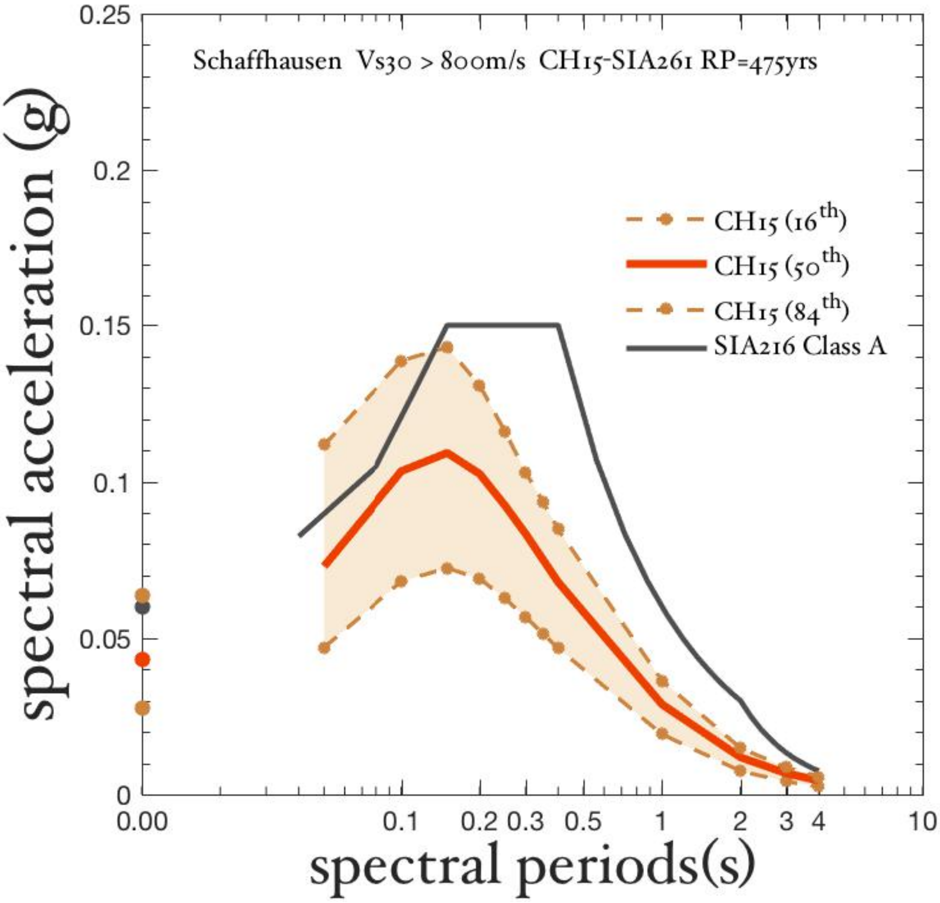
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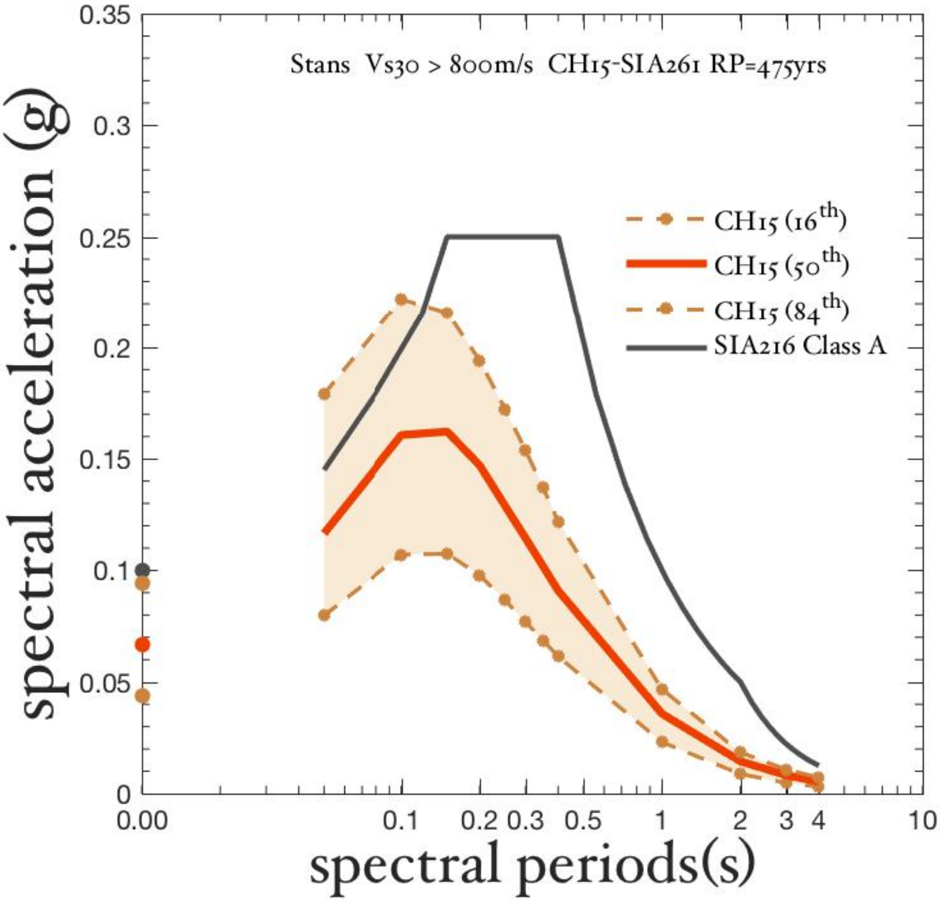
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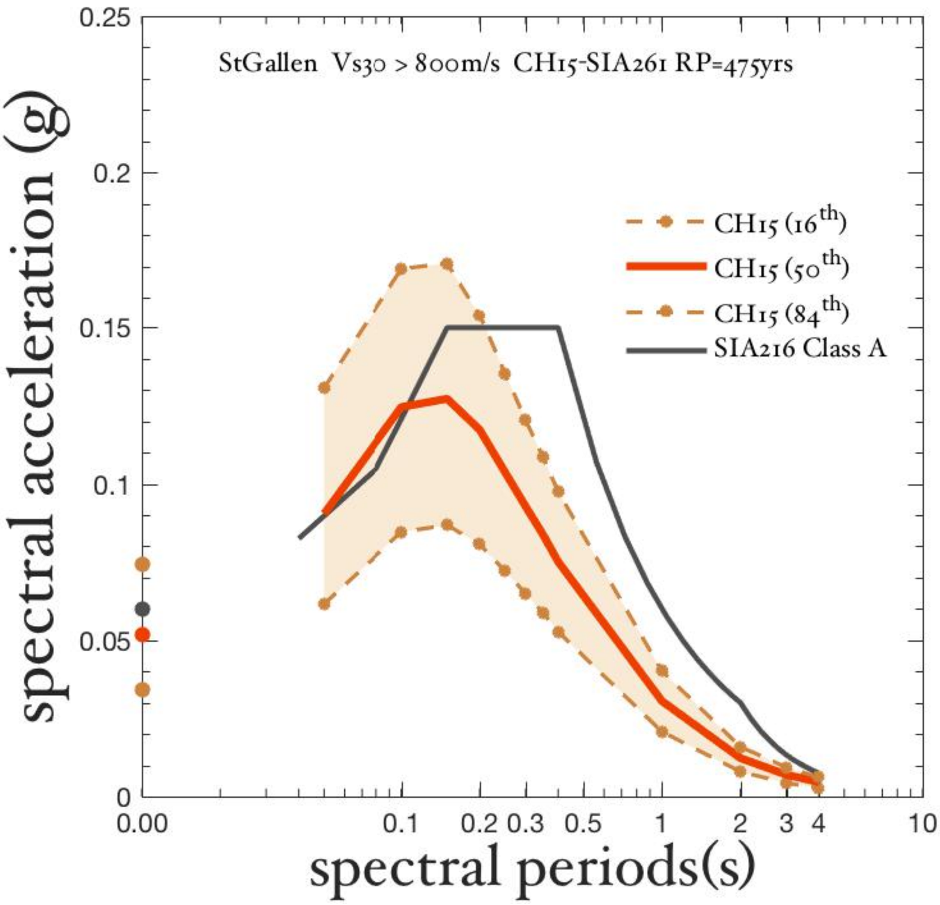
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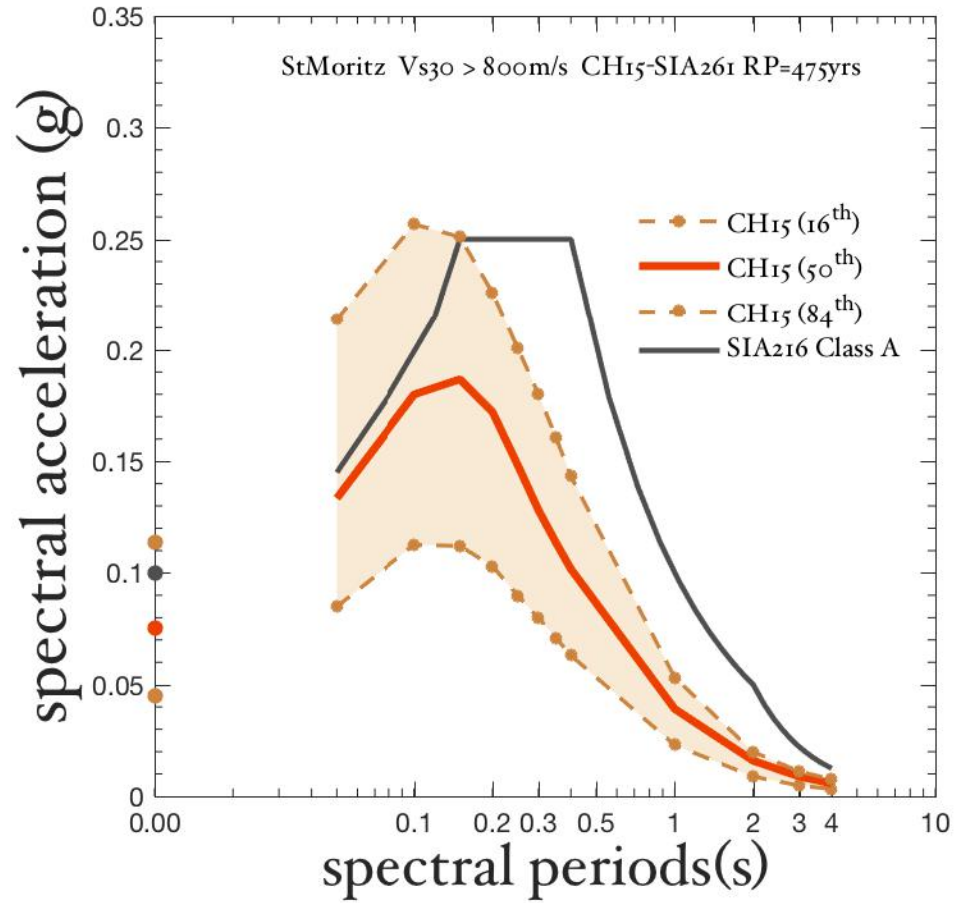
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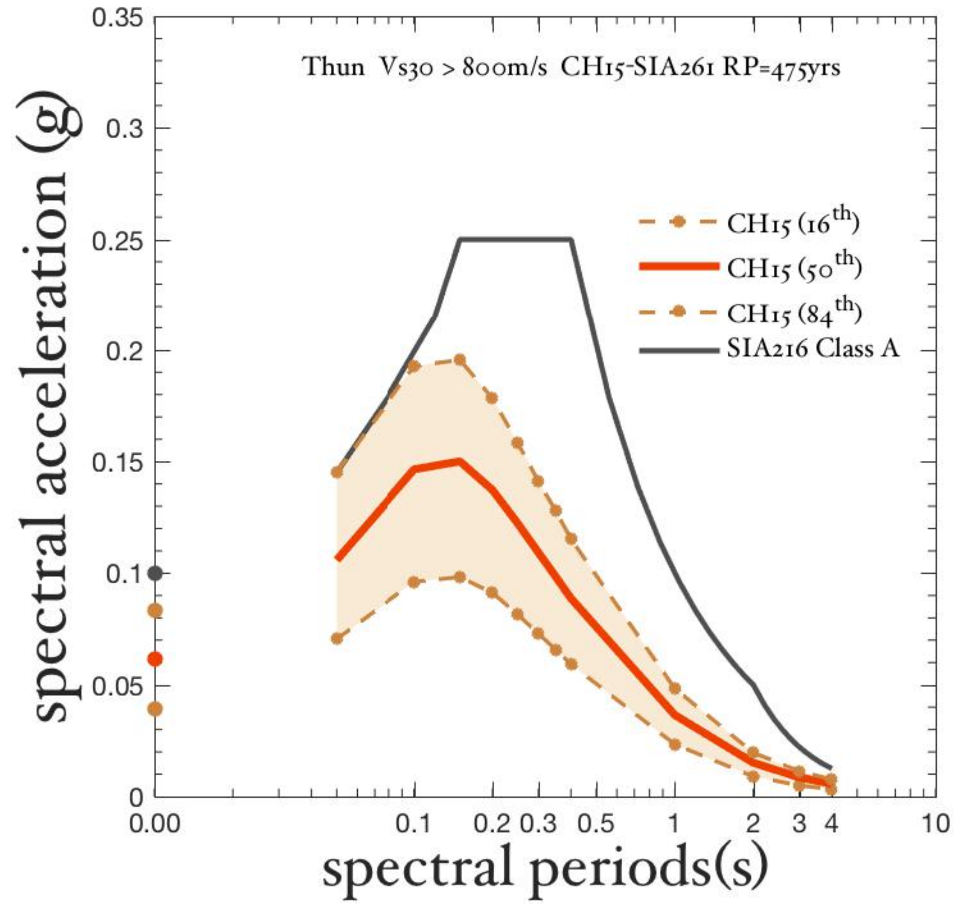
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spectral acceleration (g)
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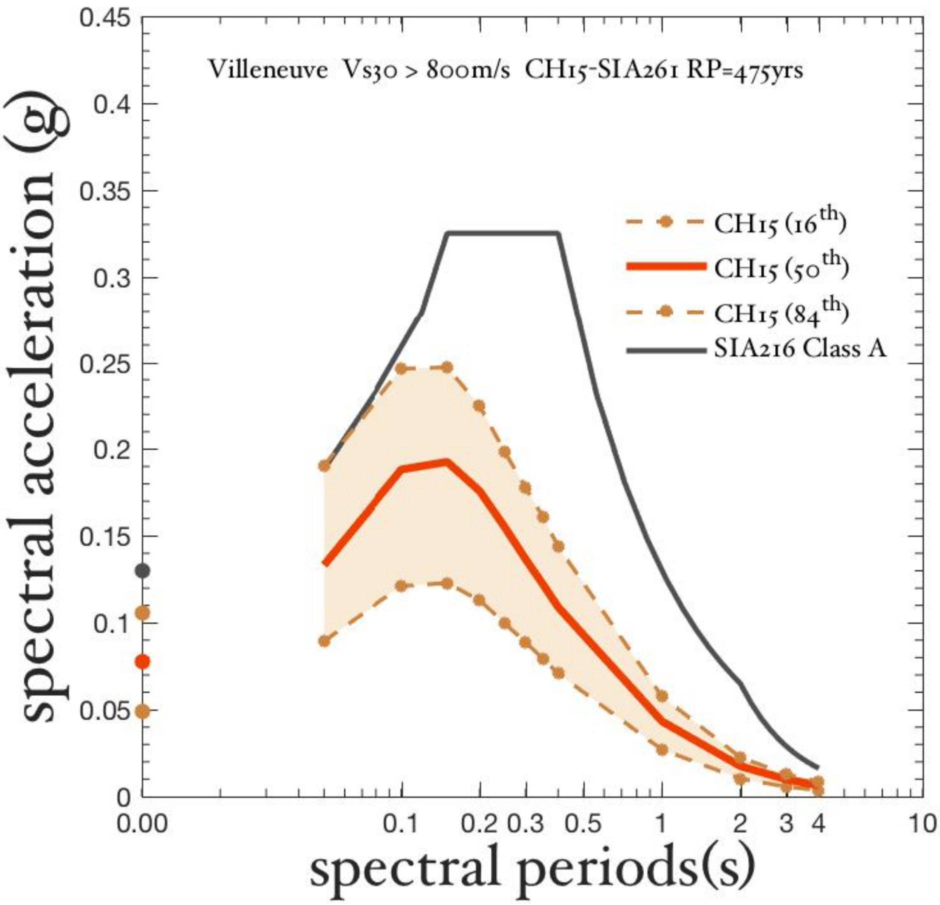

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SIA216 Class A
spectral acceleration (g)
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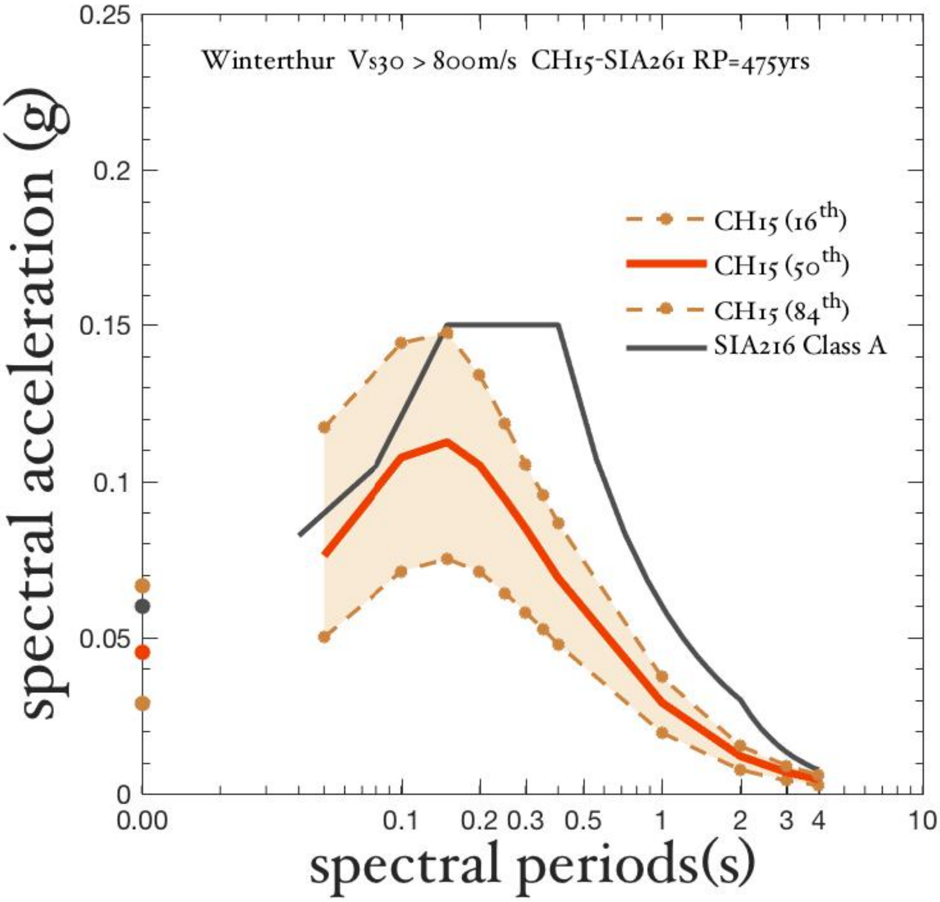

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CH15 (50th)
CH15 (84th)
SIA216 Class A
spectral acceleration (g)
spectral periods(s)
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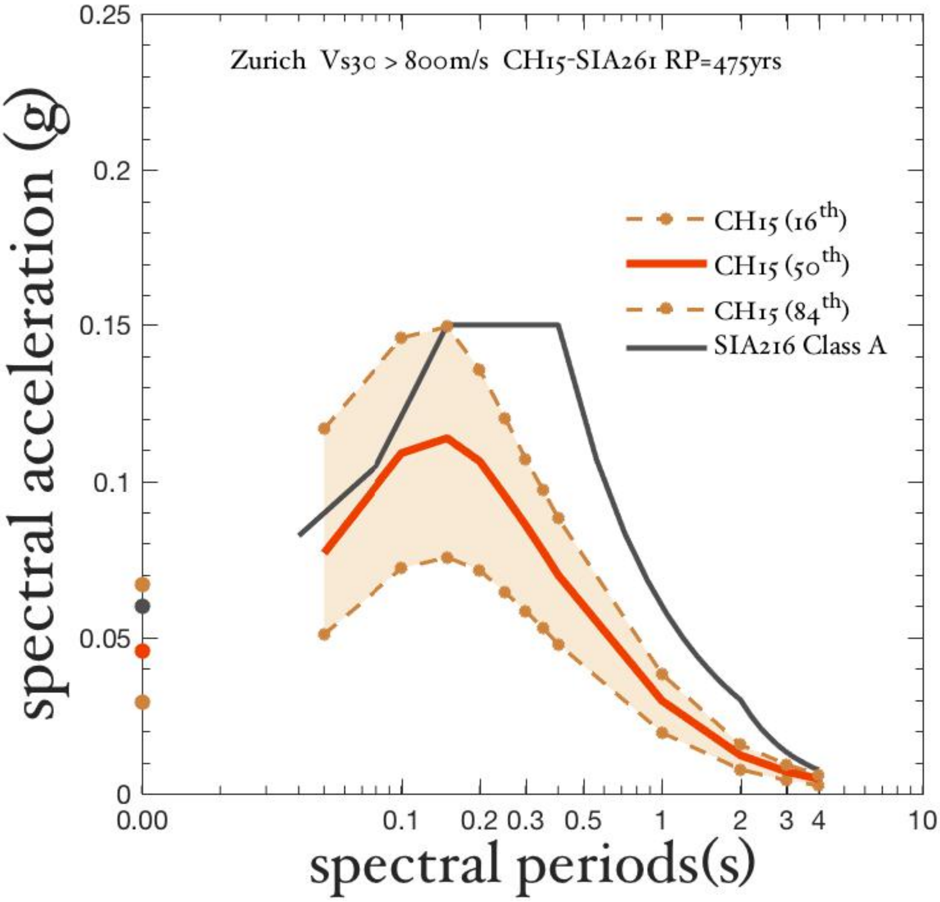

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CH15 (50th)
CH15 (84th)
SIA216 Class A
spectral acceleration (g)
spectral periods(s)
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4 References

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5 APPENDIX

Adjustment factors (ratios) with constant kappa - reference rock *Vs30=1100 m/s, kappa = 0.016.*

Periods(s)	**Vs30= 500**	**Vs30= 600**	**Vs30= 700**	**Vs30= 800**	**Vs30= 900**	**Vs30= 1000**	**Vs30= 1100**
0.01	1.2294	1.1454	1.0899	1.0525	1.0264	1.0097	1.0000
0.05	1.0965	1.0465	1.0191	1.0046	0.9978	0.9972	1.0000
0.10	1.2880	1.1947	1.1308	1.0844	1.0492	1.0221	1.0000
0.15	1.3690	1.2559	1.1757	1.1158	1.0691	1.0312	1.0000
0.20	1.4078	1.2838	1.1959	1.1302	1.0774	1.0351	1.0000
0.25	1.4299	1.3007	1.2084	1.1384	1.0834	1.0380	1.0000
0.30	1.4398	1.3085	1.2139	1.1423	1.0855	1.0394	1.0000
0.35	1.4437	1.3118	1.2167	1.1441	1.0867	1.0396	1.0000
0.40	1.4440	1.3121	1.2172	1.1450	1.0865	1.0401	1.0000
1.00	1.3431	1.2431	1.1704	1.1143	1.0689	1.0316	1.0000
2.00	1.1971	1.1436	1.1028	1.0704	1.0434	1.0202	1.0000
3.00	1.1358	1.1012	1.0736	1.0508	1.0317	1.0151	1.0000
4.00	1.1053	1.0789	1.0577	1.0400	1.0250	1.0117	1.0000

Periods(s)	**Vs30= 1200**	**Vs30= 1300**	**Vs30= 1400**	**Vs30= 1500**	**Vs30= 1600**	**Vs30= 1700**	**Vs30= 1800**	**Vs30= 1900**
0.01	0.9954	0.9949	0.9991	1.0066	1.0180	1.0323	1.0489	0.9954
0.05	1.0048	1.0117	1.0194	1.0276	1.0359	1.0441	1.0523	1.0048
0.10	0.9816	0.9663	0.9535	0.9417	0.9315	0.9217	0.9132	0.9816
0.15	0.9741	0.9508	0.9309	0.9136	0.8979	0.8832	0.8699	0.9741
0.20	0.9692	0.9438	0.9205	0.8999	0.8816	0.8648	0.8494	0.9692
0.25	0.9682	0.9400	0.9154	0.8938	0.8737	0.8562	0.8398	0.9682
0.30	0.9667	0.9380	0.9125	0.8901	0.8696	0.8511	0.8344	0.9667
0.35	0.9662	0.9370	0.9113	0.8884	0.8678	0.8492	0.8322	0.9662
0.40	0.9661	0.9368	0.9109	0.8880	0.8673	0.8485	0.8315	0.9661
1.00	0.9729	0.9492	0.9282	0.9093	0.8924	0.8768	0.8626	0.9729
2.00	0.9823	0.9669	0.9526	0.9394	0.9275	0.9164	0.9061	0.9823
3.00	0.9867	0.9752	0.9641	0.9540	0.9444	0.9362	0.9279	0.9867
4.00	0.9894	0.9797	0.9708	0.9628	0.9555	0.9484	0.9415	0.9894

Periods(s)	Vs30= 2000	Vs30= 2100	Vs30= 2200	Vs30= 2300	Vs30= 2400	Vs30= 2500
0.01	1.0921	1.1185	1.1470	1.1785	1.2139	1.2492
0.05	1.0680	1.0747	1.0807	1.0869	1.0915	1.0961
0.10	0.8974	0.8907	0.8833	0.8766	0.8704	0.8637
0.15	0.8462	0.8348	0.8249	0.8149	0.8055	0.7970
0.20	0.8224	0.8101	0.7983	0.7874	0.7771	0.7675
0.25	0.8107	0.7981	0.7856	0.7745	0.7635	0.7532
0.30	0.8047	0.7913	0.7788	0.7670	0.7562	0.7458
0.35	0.8020	0.7885	0.7759	0.7641	0.7531	0.7426
0.40	0.8013	0.7878	0.7752	0.7635	0.7524	0.7420
1.00	0.8373	0.8260	0.8155	0.8056	0.7963	0.7873
2.00	0.8876	0.8792	0.8713	0.8637	0.8566	0.8497
3.00	0.9131	0.9066	0.9002	0.8939	0.8882	0.8829
4.00	0.9295	0.9241	0.9188	0.9138	0.9091	0.9047