

# Supporting Information for: Observed Ground Motions that Exceeded Design Response Spectra in the Western United States

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The two-period spectral response acceleration is constructed using site-specific parameters (in this case,  $S_{MS}$  and  $S_{M1}$ ) developed based on the multi-period response spectrum following Section 21.4 and the formulas in Section 11.4.5 of the ASCE 7-22 [1]. A comparison between the two-period target spectra and an example recording is shown in Figure A.1.

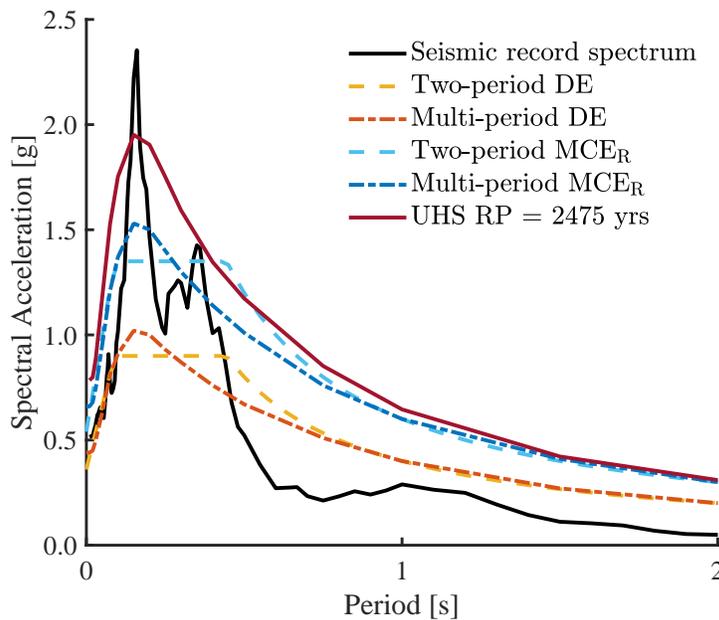


Figure A.1: Comparison of the UCSC Lick Observatory recording spectrum from the 1989 Loma Prieta earthquake with the target spectra at the recording location.

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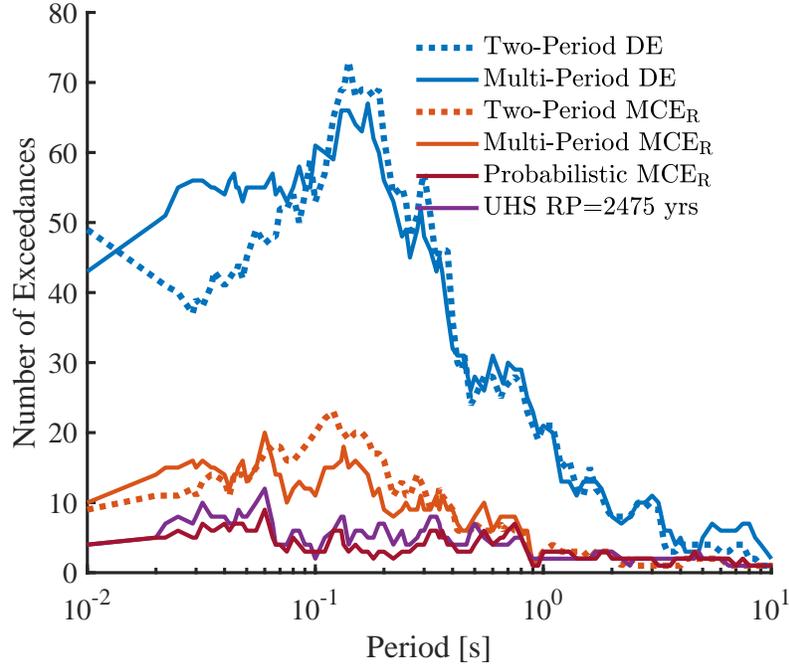


Figure A.2: Number of records that exceeded the target spectra at a given period.

Figure A.2 shows that the two-period and multi-period spectra exhibit comparable exceedance counts, except for periods below 0.1 s. This discrepancy arises due to differences in spectral shapes at short periods, with the two-period spectrum incorporating a constant acceleration platform, as can be seen in Figure A.1. In addition, Figure A.2 reveals that most exceedances occur in all cases at shorter periods than 1.0 s.

A small subset of exceedances arises from aftershocks, identified using the  $CR_{JB} < 20$  km criterion of Wooddell and Abrahamson [3]. Most are associated with the 1975 Oroville and 1983 Coalinga sequences. The Oroville exceedances stem from a single aftershock, potentially linked to denser post-mainshock instrumentation and reservoir-induced stress changes [2]. In contrast, the Coalinga exceedances are produced by multiple aftershocks tied to the region’s complex faulting behavior [4].

A comparison between observed earthquake parameters at stations where the  $MCE_R$  response spectrum is exceeded and the corresponding disaggregation-based causal mean parameters for a 2,475-year return period is shown in Figure A.3. Compared with Figure 9 in the main text, Figure A.3 shows a greater number of exceedances at short periods of vibration. Moreover, lower spectral accelerations of the  $MCE_R$  at short periods due to the deterministic cap cause lower total residuals  $\varepsilon$ . Some individual recordings are highlighted as they might be of interest to the reader; however, due to space constraints, their spectral acceleration curves are not plotted herein.

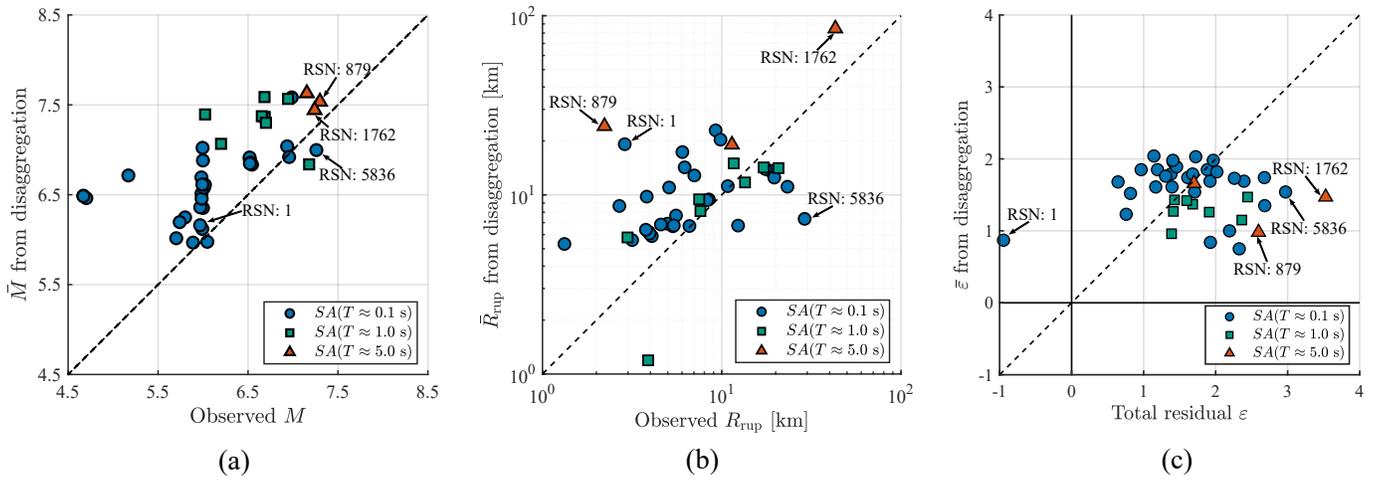
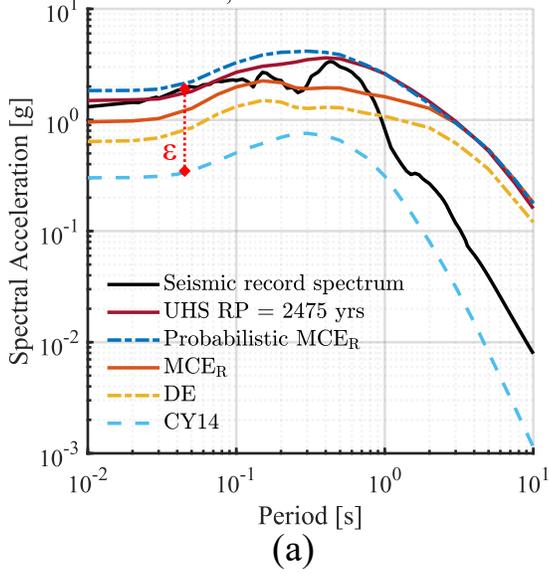
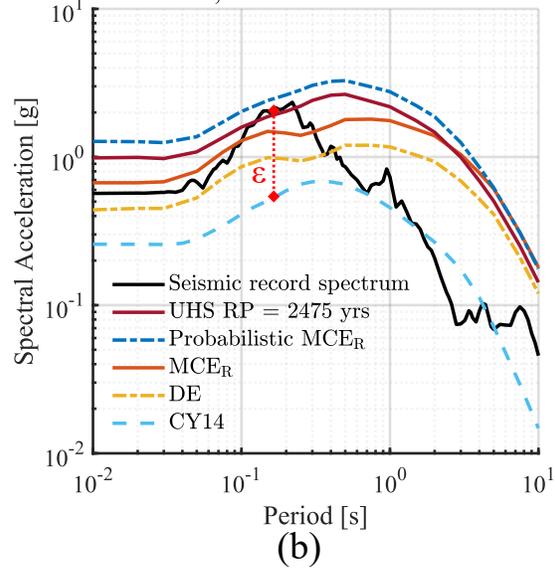


Figure A.3: Comparison of observed earthquake parameters at stations where recorded ground motions exceed the  $MCE_R$  response spectrum and the corresponding 2475-years seismic hazard disaggregation-based causal mean parameters: (a) observed earthquake magnitude  $M$  versus causal mean magnitude  $\bar{M}$ ; (b) observed source-to-site distance  $R_{rup}$  versus causal mean distance  $\bar{R}_{rup}$ ; and (c) observed total residual  $\epsilon$  versus causal mean epsilon  $\bar{\epsilon}$ . All comparisons are shown for events where the observed spectral exceedance periods closely match those selected for disaggregation analysis. Record sequence numbers for selected recordings are annotated to facilitate discussion in the text.

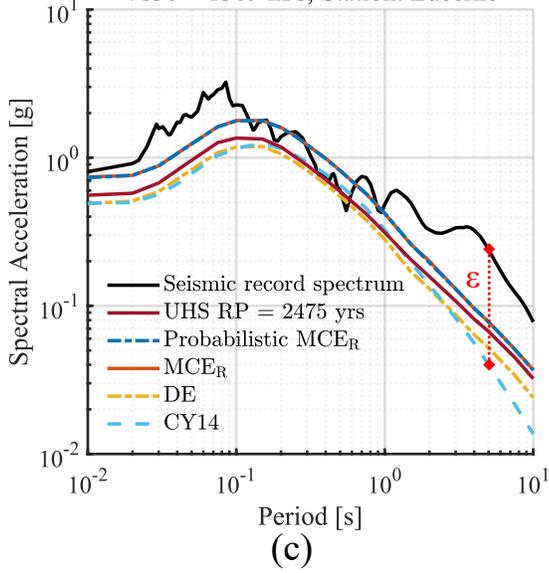
RSN: 4116; EQ: Parkfield-02, CA; M = 6; Rrup = 8.81 km  
 Vs30 = 246.07 m/s; Station: Parkfield - Fault Zone 14



RSN: 5985; EQ: El Mayor-Cucapah; M = 7.2; Rrup = 23.42 km  
 Vs30 = 202.26 m/s; Station: El Centro Differential Array



RSN: 879; EQ: Landers; M = 7.28; Rrup = 2.19 km  
 Vs30 = 1369 m/s; Station: Lucerne



RSN: 1762; EQ: Hector Mine; M = 7.13; Rrup = 43.05 km  
 Vs30 = 382.93 m/s; Station: Amboy

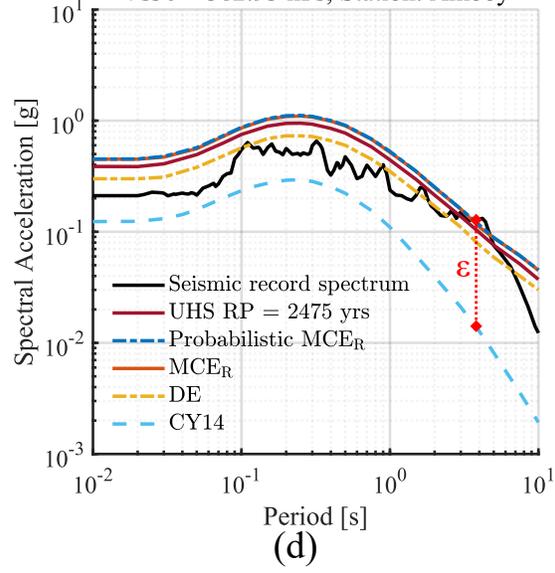


Figure A.4: Sample of recorded ground motions that exceed the UHS. The period and spectral acceleration difference at which the maximum total residual  $\epsilon$  occurs are noted.

## References

- [1] ASCE (2021) Minimum Design Loads and Associated Criteria for Buildings and Other Structures. URL <https://doi.org/10.1061/9780784415788>.
- [2] Lahr KM, Lahr JC, Lindh A, Bufe CG and Lester FW (1976) The August 1975 Oroville earthquakes. *Bulletin of the Seismological Society of America* 66(4): 1085–1099. URL <https://doi.org/10.1785/BSSA0660041085>.
- [3] Wooddell KE and Abrahamson NA (2014) Classification of Main Shocks and Aftershocks in the NGA-West2 Database. *Earthquake Spectra* 30(3): 1257–1267. URL <https://doi.org/10.1193/071913EQS208M>.
- [4] Zoback MD and Wentworth CM (1989) Structure of the Coalinga area and thrust origin of the earthquake. *United States Geological Survey, Professional Paper* 1487. URL <https://www.osti.gov/biblio/5542486>.