A Probabilistic Procedure to Describe Site Amplification Factors for Seismic Design Codes

M. Abdullah SANDIKKAYA, Sinan AKKAR and Pierre-Yves BARD

Boğaziçi University
KANDİLLİ
Observatory and Earthquake Research Institute

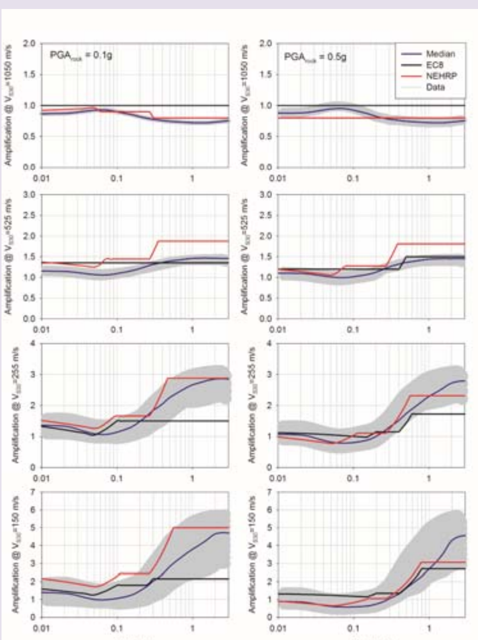
ISTerre

Abstract

A variety of site models and approaches yield different results for site factors (e.g., Seyhan and Stewart, 2014). This brings forward the importance of epistemic uncertainty in the determination of site factors. However none of the procedures employ exceedance probabilities of site amplification for site factors. To compute hazard-consistent site factors for seismic design codes, we extend the site-specific convolution approach of Bazzuro and Cornell (2004) that uses the probability distributions of reference rock hazard and site models to a regional scale. This way, the variations in seismic hazard over a region would be more properly reflected on the soil amplification by the computed site factors. The PSHA maps of the USGS (https://earthquake.usgs.gov/hazards; Petersen et al., 2008) are used to present case studies for two specific regions: southern California (moderate-to-high seismic activity) and western Arizona (low-to-moderate seismic activity). This study presents the probabilistic site factors of NEHRP E and D sites at 475-year and 2475-year return periods. A clear influence of regional seismicity and annual exceedance rate on site factors is observed. The regional site factors having this specific feature would properly reflect the differences in regional seismic activity. This observation may have different implications for seismic design codes as more realistic site factors can be provided. The hazard-consistent site factors and those of NEHRP provisions follow the same trends whereas EC8 site factors are generally different.

Evaluation of in-practice site factors

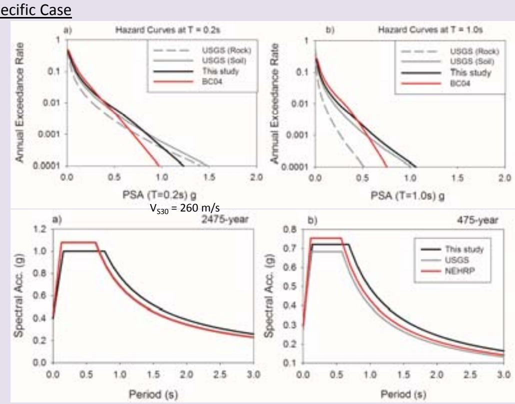
The following GMPEs and nonlinear site models are employed:
Akkar et al. (2014, ASB14): Sandıkkaya et al. (2013)
Boore et al. (2014, BSSA14): Seyhan and Stewart (2014)
Campbell and Bozorgnia (2014, CB14): Walling et al. [2008]
Chiou and Youngs [2014; CY14]



Probabilistic integration of earthquake occurrence and site amplification for code-based site factors

$$\lambda(PSA(T) > y) = \int P\left(SA(T) > \frac{y}{x}\middle|GMIM_{rock} = x\right)|d\lambda(GMIM_{rock} > x|$$

Site Specific Case



Region Specific Case

The procedure is as follows:

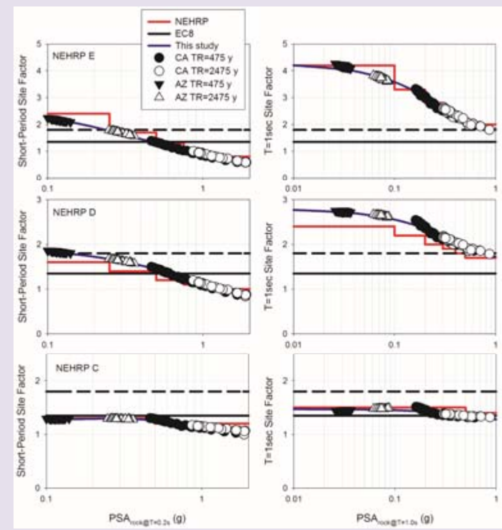
1. Given a GMIM (e.g., spectral acceleration at T = 1.0s) obtain the reference rock hazard curves at the centers of the grid cells spanning the entire region of interest (e.g., country).

2. Given a soil condition use Eq. (1) and obtain the hazard curves at the centers of the grid cells for the same GMIM. One can use a suite of empirical (or semi-empirical) site models to account for the epistemic uncertainty in soil amplification. The site models can attain different weights in accordance with their model limitations.

3. Given a pre-determined return period (e.g., 2475-year or 475-year return periods) normalize the weighted average of soil hazard curves obtained at step #2 with the reference rock hazard curves at each grid cell. The normalized amplifications at the end of this process would be the site factors of the given soil condition and designated return period.

4. Collect the computed site factors and the corresponding reference rock GMIMs to develop the code-based site factor relationship. Repeat this step for the rest of the soil conditions as well as the other GMIMs of interest (e.g., PGA, spectral acceleration at T = 0.2s, etc.) and return periods.

- SAB13, SS14, CB14 and CY14 site models are employed
- Three NEHRP site classes: NEHRP C: 360, 460, 560, 660 and 760m/s; NEHRP D: 180, 225, 270, 315 and 360m/s; NEHRP E: 120, 135, 150, 165 and 180m/s.
- The reference rock condition is represented by VS30 = 760m/s.
- Equal weights and median fractile (50th percentile) are used in the calculations.
- The short-period site factors [T = 0.1s, T = 0.2s and T = 0.5s]
- The T = 1s site factors [T=0.5s, 1.0s and 2.0s].
- The target return periods are chosen as 475-year and 2475-year in the computations.



Conclusion

- The trends in short-period (T < 0.5s) and long-period (T > 1.0s) amplifications differ from each other. This difference becomes more prominent at soft (VS30 = 255m/s) and very soft sites (VS30 = 150m/s)..
- The poorly constrained nonlinear soil behavior in EC8 as well as its outdated PGA-anchored spectral shape that fails to capture the actual spectral trends in the long periods can be the main sources behind these observations.
- The site factors computed from the proposed procedure indicate a clear influence of regional seismicity (low-to-moderate seismicity vs. moderate-to-high seismicity) and annual exceedance rate (475-year vs. 2475-year return period).
- Relatively high spectral amplitudes in California that invoke nonlinear soil behavior
- The full-probabilistic site factors and those of NEHRP provisions follow the same trends albeit comparable differences exist for T = 1.0s NEHRP D site class as well as for short-period NEHRP E and D site classes when reference rock (VS30 = 760 m/s) spectral amplitudes attain intermediate-to-low values.
- The EC8 site factors are insensitive to the variations in reference rock spectral ordinates and their period-dependent variation is poorly constrained since the spectrum envelope is only scaled by PGA. Besides EC8 site factors overlook nonlinear soil behavior
- For demonstration purposes, this methodology is implemented over a region by mesh gridding the entire area into cells to compute the site factor at each cell for the same annual exceedance probability for a given site condition.

References

- Akkar, S., M. A. Sandıkkaya, and J. J. Bommer. "Empirical ground-motion models for point-and extended-source crustal earthquake scenarios in Europe and the Middle East." Bulletin of earthquake engineering 12.1 (2014): 359-387.
- Bazzurro, Paolo, and C. Allin Cornell. "Nonlinear soil-site effects in probabilistic seismic-hazard analysis." Bulletin of the Seismological Society of America 94.6 (2004): 2110-2123.
- Boore, David M., et al. "NGA-West2 equations for predicting PGA, PGV, and 5% damped PSA for shallow crustal earthquakes." Earthquake Spectra 30.3 (2014): 1057-1085.
- BSSC, Building Seismic Safety Council. NEHRP Recommended Seismic Provisions for New Buildings and Other Structures, Washington D.C., 2015
- Campbell, Kenneth W., and Yousef Bozorgnia. "NGA-West2 ground motion model for the average horizontal components of PGA, PGV, and 5% damped linear acceleration response spectra." Earthquake Spectra 30.3 (2014): 1087-1115.
- CEN, Comité Européen de Normalisation. Eurocode 8, Design of structures for earthquake resistance—part 1: General rules, seismic actions and rules for buildings. European Standard NF EN 1998-1, Brussels., 2004.
- Chiou, Brian S-J., and Robert R. Youngs. "Update of the Chiou and Youngs NGA model for the average horizontal component of peak ground motion and response spectra." Earthquake Spectra 30.3 (2014): 1117-1153.
- NGA-West2 data and simulations." Earthquake Spectra 30.3 (2014): 1241-1256.
- Petersen, Mark D., et al. Documentation for the 2008 update of the United States national seismic hazard maps. No. 2008-1128. Geological Survey (US), 2008.
- Sandıkkaya, M. Abdullah, Sinan Akkar, and Pierre-Yves Bard. "A nonlinear site-amplification model for the next pan-European ground-motion prediction equations." Bulletin of the Seismological Society of America 103.1 (2013): 19-32.
- Seyhan, Emel, and Jonathan P. Stewart. "Semi-empirical nonlinear site amplification from NGA-West2 data and simulations." Earthquake Spectra 30.3 (2014): 1241-1256.
- Walling, Melanie, Walter Silva, and Norman Abrahamson. "Nonlinear site amplification factors for constraining the NGA models." Earthquake Spectra 24.1 (2008): 243-255.