Evaluation of nonlinear site amplification on selected sites in the Marmara Region with comparison to TBEC 2018 and EC8

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Introduction

Local soil conditions can cause a significant increase in earthquake ground motion amplitudes, also known as nonlinear site amplification. The level of site-specific amplification can be quantified using site amplification factors (AF), which are defined as the ratio of any ground motion intensity measure on soil site with its counterpart reference rock site (GMIMSoil/GMIMRock). Even though nonlinear site amplification is mainly accepted in engineering and seismological community, only a handful empirical ground motion prediction equations (GMPEs) have implemented site amplification terms. In this study we evaluate nonlinear site amplification factors on three well defined sites located in the Marmara Region (Turkey) and compare the results with the recently updated Turkish Building Earthquake Code (TBEC,2018) and the Eurocode 8 (EC8) provision which is currently under revision.

Dataset

We select three sites with increasing mean peak-ground-acceleration values on reference rock (PGA_{Rock}) located in Istanbul, Sariyer (41.183°N, 28.933°E), Atatürk-Airport Istanbul (40.979°N, 28.819°E) and Kocaeli (40.769°N, 29.933°E). The reason we chose sites located in different areas is to evaluate site dependent nonlinear ground response presented by different hazard levels. The sites are assumed to correspond to reference rock site condition with V_{s30} = 800 m/s. For the calculation of the ratios the counterpart condition was chosen as stiff-soil/soft clay condition V_{s30} = 200 m/s. The mean PGA values for selected sites for given return periods of RP = 475y and RP = 2475y are listed in Table 1 and are taken from the Turkish National Seismic Hazard Map (https://www.turkiye.gov.tr/afad-turkiye-deprem-tehlike-haritalari).

Table 1. Seismic hazard levels for selected sites

Return period	Site 1 PGA [g]	Site 2 PGA [g]	Site 3 PGA [g]
RP = 475y	0.265	0.505	0.675
RP = 2475y	0.557	0.841	1.130

Methodology

We apply the non-data driven methodology proposed by Cotton et al. (2006) and select GMPEs, which are appropriate for our study area according to given quality criteria (e.g. tectonic environment, database etc.). Accordingly, our final logic-tree (NL LT) consists of four GMPEs, namely Kale et al. (2015), Akkar et al. (2014), Chiou and Youngs (2014) and Boore et al. (2014), whereby each GMPE is weighted equally (0.25) in the logic-tree. The nonlinear site amplification model proposed by Sandikkaya et al. (2013) is used in the GMPEs of Kale et al. (2015) and Akkar et al. (2014), whereby the model of Chiou and Youngs (2008) and Seyhan and Steward (2014) is implemented in the NGA-West2 models Chiou and Youngs (2014) and Boore et al. (2014), respectively.

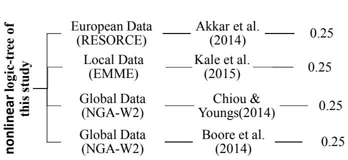

Figure 1. Ground motion logic tree used in the present study, represented by GMPEs with implemented nonlinear site amplification term. Each GMPE has been weighted equally with 0.25.

The earthquake source model provided by EFEHR online and developed by the Earthquake Modelling of the Middle East (EMME) project has been used for the entire hazard analysis. The provided input files were easily implemented into the provided modules of the OpenQuake GEM software. The background seismicity model, which is weighted with 0.4 in the EMME logic-tree was ignored for all selected sites and only the area source model is used for the calculations.

Hazard Curves

The initial step of the calculation of Uniform Hazard Spectra for selected return periods is the determination of Hazard Curves for each selected site and different probabilities of exceedance rates. Figure 1 shows the hazard spectra for each site of the present study area and increasing return periods. The values obtained from each of these hazard curves are in the following used for the calculation of the uniform hazard spectra.

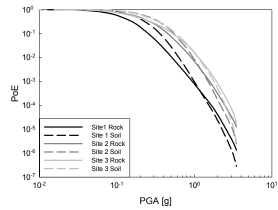

Figure 2. Seismic hazard curves for selected sites located in the Marmara Region.

Uniform Hazard Spectra

We use the earthquake source model of EMME with an investigation time of 50 years and a probability of exceedance rate of 2% and 10%. The maximum source-to-site distance is set to 200 km. The site conditions are adopted from the EMME input file with V_{s30} = 800 m/s for reference rock site and V_{s30} = 200 m/s for soil site.

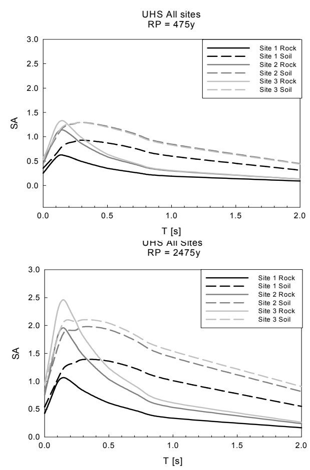

Figure 3. Uniform hazard spectra for RP=475y (first row) and RP=2475y (bottom row)

Site amplification factors

For evaluation of site response the site amplification ratios, defined as UHS_{Soil}/UHS_{Rock} are calculated for spectral periods up to 2s, since nonlinearity is expected to diminish for higher periods. We calculate amplification ratios represented by reference rock site condition (V_{s30} = 800 m/s) and counterpart soil site (V_{s30} = 200 m/s) for target return periods of RP = 475 y and RP = 2475 y since both periods are widely used in engineering community for design response analysis. The ratios are calculated for each GMPE individually to demonstrate probable uncertainties between different ground motion models . The results depict that uncertainties between the selected GMPEs are period-dependent with increasing discrepancies for T > 0.6 s at both return periods. Here, the selection of appropriate GMPE plays an increasing role. At a return period of RP = 475y (left plots), site amplification obtained using the proposed ground-motion logic-tree (NL LT) and site factors obtained using TBEC are surprisingly similar for periods of up to 0.6 s. The discrepancy increases for periods T > 0.6 s, especially for sites with higher mean PGA levels (Site 2 and 3). At both return periods, site amplification decreases with increasing ground motion level, yielding higher soil nonlinearity for sites located in high-seismicity areas. In contrasts, site amplification factors obtained using TBEC increase until a threshold period of ~ 0.5 s.

Site amplification factors vs TBEC 2018

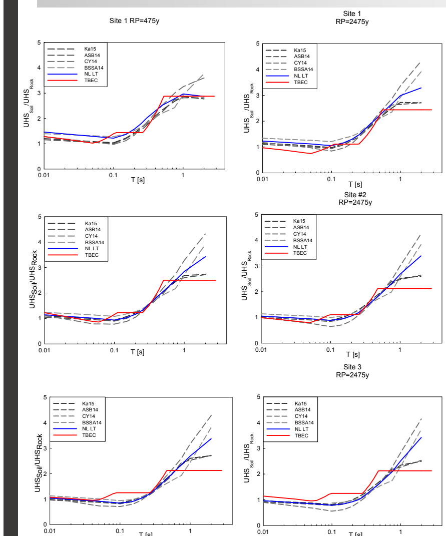

Figure 4. Period dependent UHS elastic response spectral ratios obtained from TBEC and proposed ground-motion logic tree for return periods of RP = 475y (left column) and RP = 2475y (right column) and Site 1 (first row), Site 2 (middle row) and Site 3 (bottom row).

Comparison with EC8 and TBEC 2018

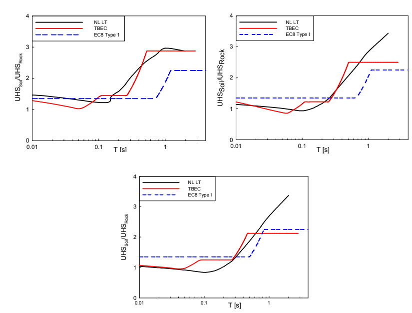

Figure 5. Period dependent UHS elastic response spectral ratios obtained from TBEC 2018 (red curve), EC8 (Blue dashed curve) and the present GMPE logic tree (NL LT, black curve).

Conclusion and Discussion

We propose a ground-motion logic-tree consisting of most recent ground-motion prediction equations with implemented nonlinear site amplification terms for the evaluation of nonlinear ground response for three sites in Marmara Region with increasing hazard level. Our results clearly demonstrate that site amplification factors used in the recently updated TBEC (TBEC, 2018) are similar to site factors obtained using our proposed ground-motion logic-tree. Thus, the recent TBEC accounts for nonlinearity, at least for a period of up to 0.6s. For periods higher than 0.6s the uncertainty between each GMPE, our proposed logic-tree and the amplification factors obtained from the elastic response spectra of TBEC increases significantly. The results further conclude that especially for higher periods (T > 0.7 s) the selection of appropriate ground-motion models plays a significant role in the hazard calculations. Our results confirm previously published studies that seismic intensity plays an important role in the variation of site factors and consequently on nonlinear ground response (Sandikkaya et al. 2018). Even though this study proved the consistency of amplification factors obtained from recently updated TBEC and the proposed ground-motion logic-tree, it is worth noting that for higher periods (T > 0.6 s) large discrepancies are present and must be evaluated in future studies.

For further questions please do not hesitate to contact: etuerker@uni-potsdam.de