When 1D Response Analysis Fails: Application of Earthquake HVSR in Site-Specific Amplification Estimation

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Empirical Correction to HVSR

\[ HVSR(f) = \frac{H(f)}{V(f)} \quad SBSR(f) = \frac{H(f)}{H_b(f)} \]

\[ HVSR_b(f) = \frac{H_b(f)}{V_b(f)} \quad SBSR_v(f) = \frac{V(f)}{V_b(f)} \]

\[ HVSR(f) = \frac{H(f)}{H_b(f)} \cdot \frac{H_b(f)}{V_b(f)} \cdot \frac{V_b(f)}{V(f)} = \frac{HVSR_b(f)}{SBSR_v(f)} \cdot SBSR(f) \]

\[ H_b(f) = V_b(f) \text{ or } HVSR_b = 1.0 \]

\[ SBSR(f) = HVSR(f) \cdot SBSR_v(f) \]

\[ pSBSR(f) = HVSR(f) \cdot <SBSR_v(f)> \]
**Data Selection**

**Fig.** (a) Spatial distribution of earthquakes and 207 KiK-net stations used in this study, and (b) Mw-Rrup distribution of the 1840 selected earthquake recordings.
Fig. (a) k-means clustering of the 90 KiK-net sites, and (b) average SBSRv for each cluster, i.e., $\langle SBSRv \rangle$. 
Correction Spectra

**Fig.** Evaluation of techniques used in site effects quantification.
pSBSR vs. TTF

Fig. HVSR, TTFStrata and pSBSR at sites (a) TCGH07 and (b) IWTH04.
# Goodness-of-fit (GoF) metrics

<table>
<thead>
<tr>
<th>Goodness-of-fit metric</th>
<th>Expression</th>
<th>Range</th>
<th>Measure</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson's $r$</td>
<td>$\frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$</td>
<td>[-1, 1]</td>
<td>Linear relationship</td>
<td>Measure the closeness in shape (alignment of peaks and troughs)</td>
</tr>
<tr>
<td>Spearman's $\rho$</td>
<td>$\frac{\text{cov}(rg_x, rg_y)}{\sigma_{rg_x} \sigma_{rg_y}}$</td>
<td>[-1, 1]</td>
<td>Ordinal relationship</td>
<td></td>
</tr>
<tr>
<td>Kendall’s $\tau$</td>
<td>$\frac{2[\sum_{i&lt;j} \text{sgn}(x_i - x_j) \text{sgn}(y_i - y_j)]}{n(n-1)}$</td>
<td>[-1, 1]</td>
<td>Ordinal relationship</td>
<td></td>
</tr>
<tr>
<td>Index of Agreement $d$</td>
<td>$1 - \frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(</td>
<td>y_i - \bar{y}</td>
<td>+</td>
<td>x_i - \bar{x}</td>
</tr>
<tr>
<td>Mean Absolute Error $\text{MAE}$</td>
<td>$\frac{\sum_{i=1}^{n}</td>
<td>y_i - x_i</td>
<td>}{n}$</td>
<td>-</td>
</tr>
</tbody>
</table>
pSBSR vs. TTF

(a) $r > 0.6$
- pSBSR: 81%
- TTF Strata: 27%

(b) $\rho > 0.6$
- pSBSR: 76%
- TTF Strata: 29%

(c) $\tau > 0.6$
- pSBSR: 48%
- TTF Strata: 7%

(d) $d > 0.6$
- pSBSR: 80%
- TTF Strata: 37%

(e) $\mu \pm \sigma$
- pSBSR: 0.20±0.09
- TTF Strata: 0.23±0.08

Fig. Histograms of correlation coefficients (a) Pearson’s $r$, (b) Spearman’s $\rho$, (c) Kendall’s $\tau$, (d) Index of Agreement $d$, and (e) Mean Absolute Error MAE (log10) between pSBSR and ETF (blue) in the frequency range from $f_0$ to 25 Hz for the 90 KiK-net sites. Hisograms for TTF Strata (red) are superimposed.
# pSBSR vs. TTF

**Table.** Success rates of TTFStrata and pSBSR in reproducing SBSR under different definitions of “good match”

<table>
<thead>
<tr>
<th>Estimation</th>
<th>$r&gt;0.60$</th>
<th>$r&gt;0.60$ $d&gt;0.60$</th>
<th>$r&gt;0.65$ $d&gt;0.65$</th>
<th>$r&gt;0.60$ MAE&lt;0.25</th>
<th>$r&gt;0.65$ MAE&lt;0.20</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTF</td>
<td>27%</td>
<td>27%</td>
<td>18%</td>
<td>22%</td>
<td>14%</td>
</tr>
<tr>
<td>pSBSR</td>
<td>81%</td>
<td>76%</td>
<td>68%</td>
<td>62%</td>
<td>50%</td>
</tr>
</tbody>
</table>
Summary

The empirical correction to HVSR is highly effective and achieves a “good match” in both spectral shape and amplitude at the majority of the 90 KiK-net sites, as opposed to less than one-third for the 1DSH modelling. In addition, the empirical correction does not require a ground model as GRA and thus has great potentials in seismic hazard assessments.
Thank you very much!