SUPPLEMENTING SHEAR WAVE VELOCITY PROFILE DATABASE WITH MICROTREMOR-BASED H/V SPECTRAL RATIOS

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Abstract

Frequency-dependent horizontal-to-vertical (H/V) spectral ratios (HVSR) can provide information on one or more site resonant frequencies and relative levels of amplification at those frequencies. Such information is useful for predicting site amplification but is not present in site databases that have been developed over the last 15–20 years for the Next-Generation Attenuation (NGA) projects, which instead use the time-averaged shear-wave velocity (V_S) in the upper 30 m of the site (V_{S30}) as the primary site parameter and are supplemented with basin depth terms where available.

In order for H/V-based parameters to be used in future versions of site databases, a publicly accessible repository of this information is needed. We adapt a relational database developed to archive and disseminate V_S data to also include H/V spectra. Our intent with the database is to provide relevant H/V data and supporting metadata, but not parameters derived from the data. We consider the relevant data to be the frequency-dependent HVSR, where the horizontal component is taken from the geometric mean of as-recorded azimuths. Relevant metadata includes site location information, details about the equipment used to make the measurements, and processing details related to windowing, anti-trigger routines, and filtering. We describe the database schema developed to organize and present this information.

We also describe and illustrate routines that can be used to derive parameters from the data that are implemented in Python on a Jupyter Notebook enabled by DesignSafe-CI. These routines compute H/V spectral ratios based on the median horizontal component, and polar plots that present azimuthal dependence of spectra. For median-component spectra, additional routines fit pulse functions that provide frequency, amplitude, and pulse width parameters. These routines interact with the database via cloud computing, but are not directly part of the database.

Introduction

A site amplification model that accounts for the effects of these features on site amplification is non-ergodic [e.g., 1]. One common feature of non-ergodic site response is resonance at one (fundamental site frequency, f_0) or more site frequencies (f_d) [2], which produce peaks that are smoothed out in ergodic models. The use of the horizontal-to-vertical (H/V) component Fourier amplitude vs. frequency plots have the potential to add this site-specific attribute to predictions of ergodic site response at low cost (relative to non-ergodic procedures). While V_{S30} provides a reasonable, first-order estimate of site response over a wide frequency range, f_0 can be effective at describing site amplification for frequencies proximate to f_0, but it has limited utility elsewhere. Hence, the two parameters serve different purposes and we postulate that they can be most effectively utilized together. This poster concerns the development of a database to store horizontal-to-vertical spectral ratios (HVSR) data. The database includes the raw data as-recorded signals in time domain and the processing parameters used to derive the spectral ratios.

Data

While in California around 1,700 V_S profiles are publicly available via the profile database (PDB), fewer data exist for microtremor recordings [3] (Figure 1).

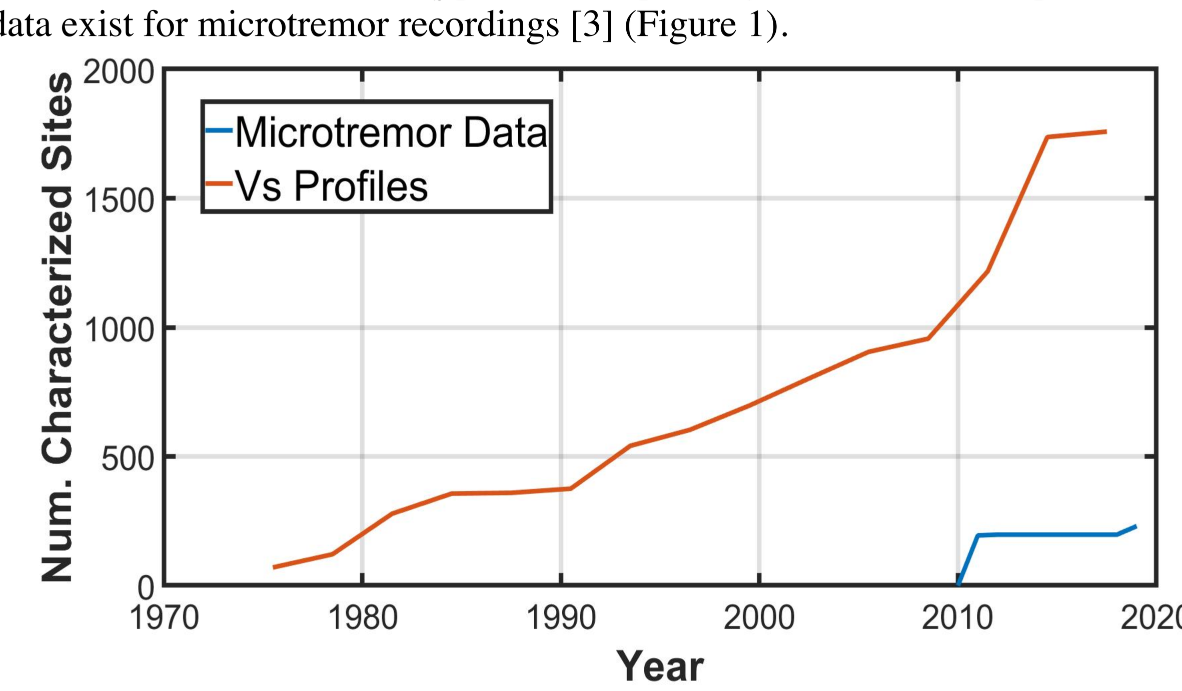

Figure 1 – Cumulative distribution of Vs profiles and microtremor data in California versus time.

The database was structured to allow entry of HVSR data from three sources: microtremor array measurements (MAM), pre-event noise from three-component earthquake seismograms, and seismic signals (Figure 2). MAM data is preferred because it matches the data type that would generally be used in forward applications.

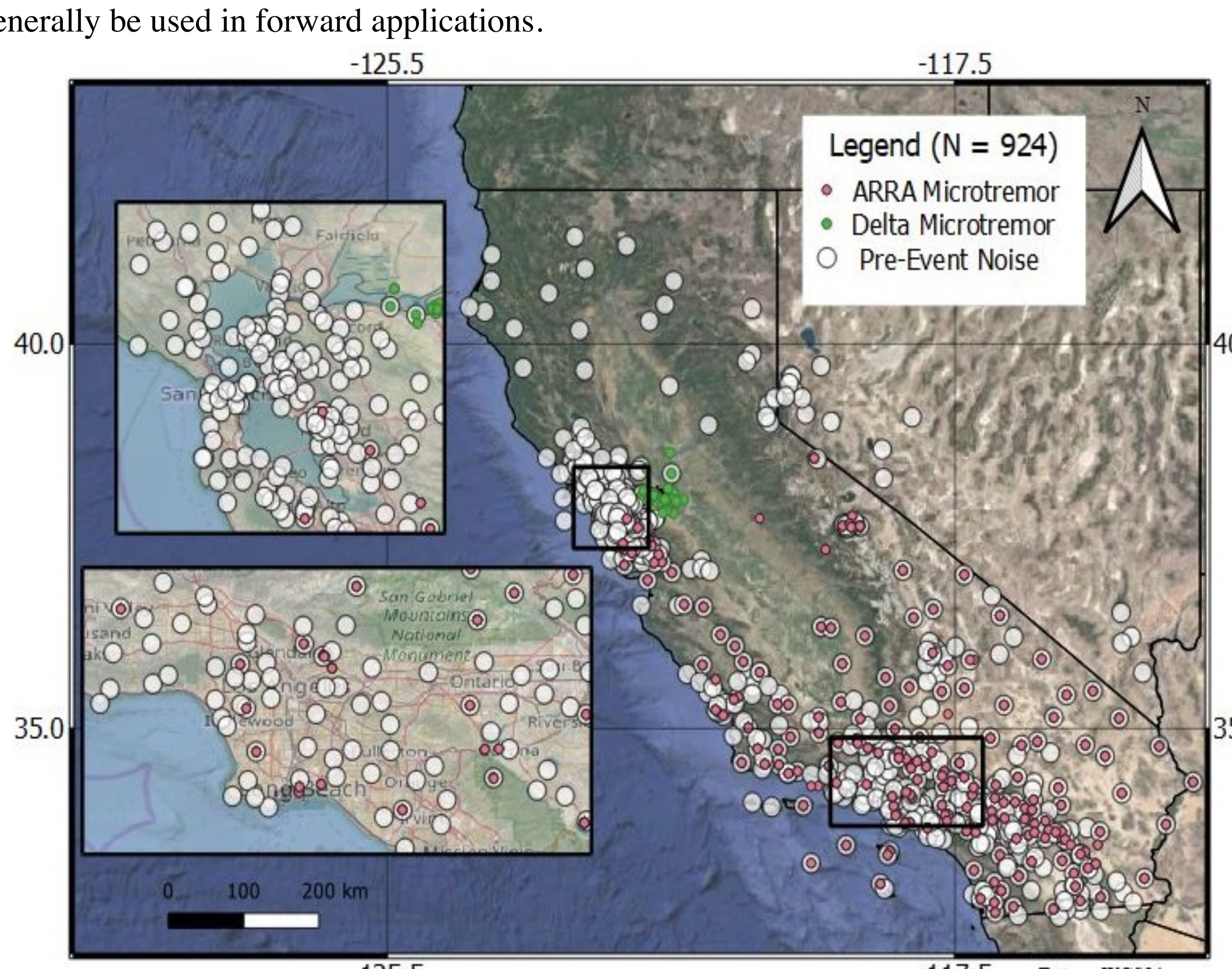

***Figure 2–** Locations of sites in PDB with HVSR from either pre-event noise or microtremor sources.*

Processing Parameters

These procedures borrow heavily from **S**ite **E**ffect**S** assessment using **AM**bient **E**xcitations (SESAME) guidelines [4] and protocols used with some geophysics specialists in California (K. Hayashi, A. Martin, personal communication, 2018, 2019). We assume that Geopsy [5] is the standard platform used to process data in this database.

Microtremor Array Measurements (MAM):

- Number of Windows and Cycles (Table 1; $N_{cyc}=T_{win} f_0 N_{win}$ and $T_{sig} = N_{cyc} / f_0$)
- Window Overlap; Taper Width and Type of Window
- Anti-Triggering
- Bad Sample Tolerance and Threshold
- Filter
- Smoothing Type and Constant
- Horizontal Component Combination Method
- HVSR Calculation

***Table 1** – Recommended recording duration, assuming at least N_{cyc} = 200 and N_{win} = 10 [4].*

f_0 [Hz]	Minimum value for T_{win} [s]	Recommended minimum record duration T_{sig} [s]
0.2	50	1800
0.5	20	1200
1	10	600
2	5	300
5	5	180
10	5	120

Pre-Event Noise:

We first obtain the data from a seismic ground motion data archive, such as IRIS [6]. Next, we identify the pre-event noise segment from each processed earthquake ground motion time series. Figure 3 illustrates the P-wave arrival and the selected window for HVSR analysis using pre-event noise. We identify the P-wave arrival time visually (figure 3).

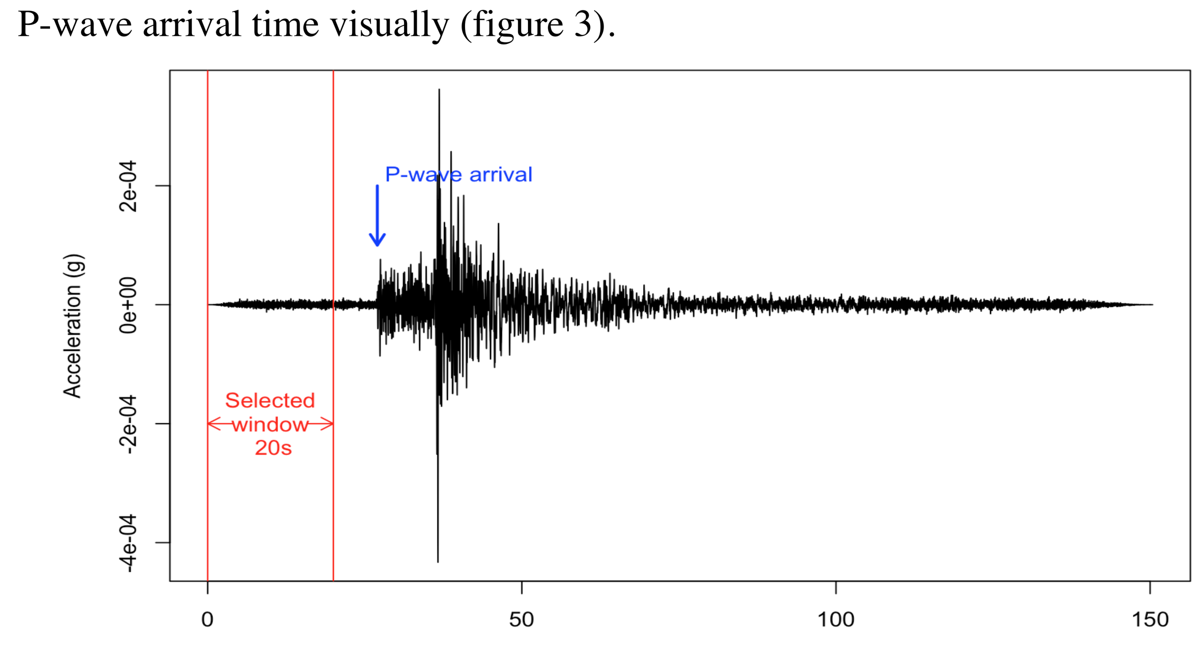

***Figure 3 –** Example of pre-event noise and P-wave arrival from IRIS earthquake strong motion data.*

Database Schema

The tables related to HVSR data in the PDB are listed in Figure 4 along with the specific fields and the primary and foreign keys in each table.

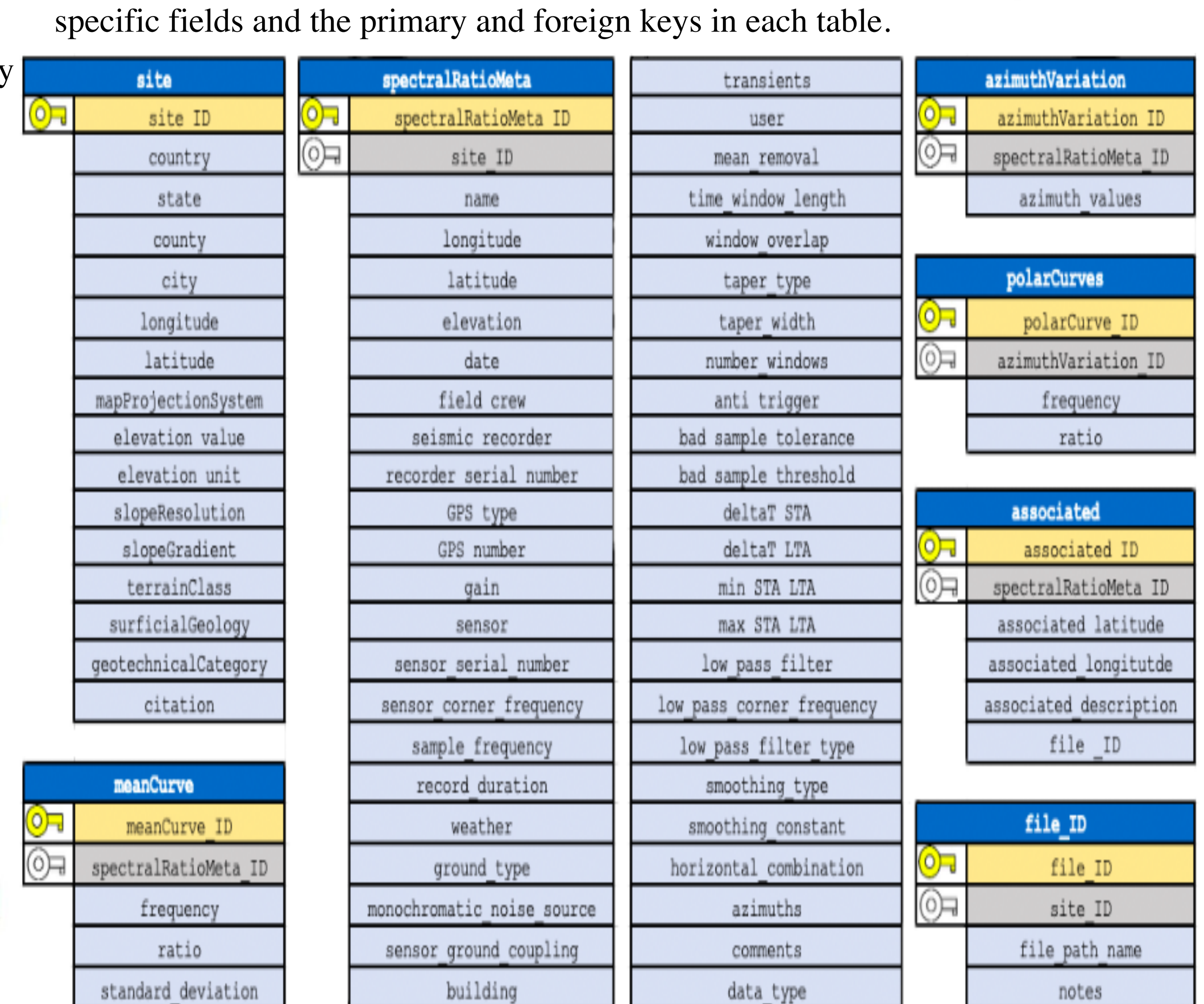

***Figure 4 –** Tables, fields, and primary (gold) and foreign (white) keys in HVSR database schema. Site table is taken from the V_S Profile Database schema developed by Ahdi et al. [7] and Sadiq et al. [8].*

Data Interpretation

The interpreted parameters include (1) identification of features as peaks; (2) analysis of HVSR based on median horizontal components (RotD50); (3) plots of azimuthal variations of HVSR (figure 5) ; and (4) for each peak in the median-component HVSR, fitting of a pulse function to evaluate peak frequency, peak amplitude, and width of peak.

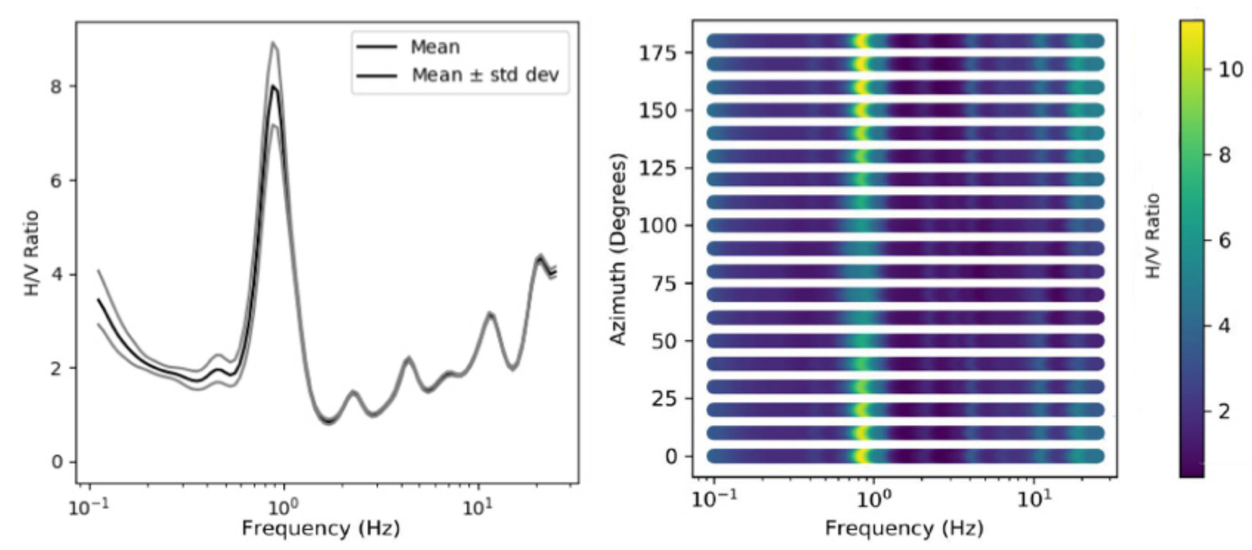

***Figure 5 –** A site in the Sacramento-San Joaquin Delta. Left: frequency versus H/V Ratio from a microtremor recording; right: azimuthal variation of the same recording.*

HVSR plots can generally be classified as containing no peaks, one peak, or multiple peaks [9]. To decide whether a feature in a plot such as Figure 5 is a peak or not, we require that the peak amplitude exceed 2.0 and that its amplitude exceed 1.5 times the geometric mean of the HVSR curve [10]. For mean HVSR plots with a peak, we fit a Gaussian pulse function defined as follows [11, 12]:

$$\ln(F_{H/V,i}) = \ln(a_{pi}) \exp\left(-\left(\frac{\ln(f/f_{pi})}{w_i}\right)^2\right)$$

where f_{pi} is the fitted at-peak frequency, a_{pi} is pulse amplitude, w_i represents pulse width, i is the order of peak, and f is frequency in Hz. This Gaussian pulse function estimates a pulse amplitude, frequency, and width for each peak. Figure 6a demonstrates the fit of the pulse to data for Figure 5. Figures 6b-c show results for other sites with two peak and no peaks, respectively.

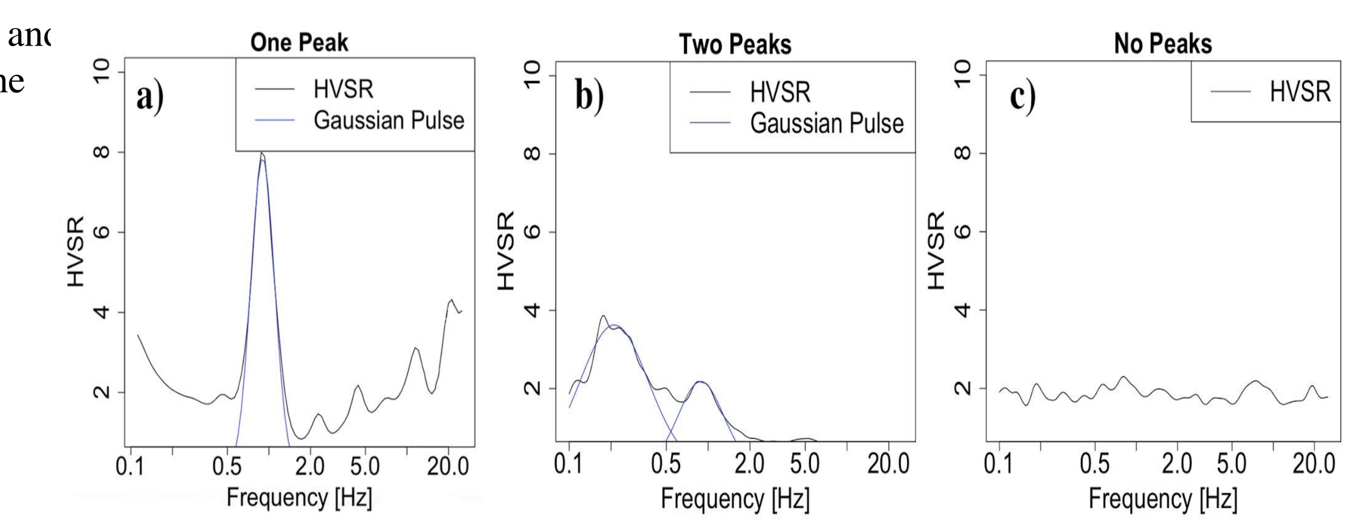

***Figure 7 –** HVSR spectral ratios versus frequency where the Gaussian pulse function is applied to sites on our database. The function identifies peaks of one, two, and no peaks for a (site CE.13929 sensor 507) ,b (site CE.11023 sensor 507), and c (site NC.BBGB sensor 453), respectively.*

Conclusion

We created an open-source relational database of HVSR and associated processing parameters and incorporate this information into an existing Community V_S Profile Database in the United States. Users can utilize and analyze the processed records through interactive Jupyter Notebook tools. The addition of the H/V site parameter is a valuable resource for future studies and will pave the way for H/V-based parameters to be included in the site database used in future NGA-type ground motion model development projects. We anticipate that this data will also prove useful over time for site-specific ground motion studies in the US.

References

[1] Stewart, JP, K Afshari, CA Goulet, 2017. Non-ergodic site response in seismic hazard analysis, *Earthquake Spectra*, **33**, 1385-1414.

[2] Di Alessandro, C, LF Bonilla, DM Boore, A Rovelli, and O Scotti, 2012. Predominant-period site classification for response spectra prediction equations in Italy, *Bull. Seismol. Soc. Am.* **102**, 680–695.

[3] Ahdi, S.K., O. Ilhan, S. Sadiq, Y. Bozorgnia, Y.M.A. Hashash, D. Park, A. Yong, J.P. Stewart (2018). Development of a United States Community Shear Wave Velocity Profile Database, *5th Conference on Geotechnical Earthquake Engineering and Soil Dynamics (GEESD-V)*, June 10–13, 2018, Austin, Texas.

[4] SESAME, 2004, Guidelines for the Implementation of the H/V spectral ratio technique on ambient vibrations—Measurements, processing and interpretation: European Commission, Project No. EVG1-CT-2000-00026, accessed September 2012, at http://sesame-fp5.obs.ujf-grenoble.fr/

[5] Wathelet M. (2006). Geopsy Manual.

[6] "Incorporated Research Institutions for Seismology (IRIS), IRIS Earthquake Browser, http://ds.iris.edu/ieb/index.html, last accessed <01/07/2019>

[7] Ahdi, S. K. (2018). An Improved Framework for the Analysis and Dissemination of Seismic Site Characterization Data at Varying Resolutions. *UCLA*. ProQuest ID: Ahdi_ucla_0031D_17519. Merritt ID: ark:/13030/m54f6nxb. Retrieved from https://escholarship.org/uc/item/6p35w167

[8] Sadiq, S., O. Ilhan, S.K. Ahdi, Y. Bozorgnia, Y.M.A. Hashash, D. Park, A. Yong, J.P. Stewart (2018). A Proposed Seismic Velocity Profile Database Model. *Eleventh U.S. National Conference on Earthquake Engineering (11NCEE)*, June 25–29, 2018, Los Angeles, California, Paper No. 1342.

[9] Kwak, D. Y., Stewart, J. P., Mandokhail, S. U. J., & Park, D. (2017). Supplementing VS 30 with H/V spectral ratios for predicting site effects. *Bulletin of the Seismological Society of America*, *107*(5), 2028-2042.

[10] Hassani, B and GM Atkinson, 2016. Applicability of the site fundamental frequency as a V_{S30} proxy for Central and Eastern North America, *Bull. Seismol. Soc. Am.* **106**, 653–664.

[11] Di Giulio G., Cara F., Rovelli A., Lombardo G., and Rigano R. (2009). Evidences for strong directional resonances in intensely deformed zones of the Pernicana fault, Mount Etna, Italy. Journal of Geophysical Research, 114, B10308.

[12] Ghofrani, H and GM Atkinson, 2014. Site condition evaluation using horizontal-to-vertical response spectral ratios of earthquakes in the NGA-West2 and Japanese databases, *Soil Dynam. Earthq. Eng.* **67**, 30–43.

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