Assessing Site Response Complexity Using Single Station HVSR: Mexico City Case Study

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ABSTRACT

Sedimentary basins have high impedance contrasts which cause significant shaking during earthquakes and as a result, pose risk to infrastructure and local populations. The SH1D site response transfer function is used to model the response of a soil column to an earthquake and predict ground amplification and frequency of shaking. It assumes vertically propagating shear waves through horizontal, laterally homogenous soil systems with frequency independent damping and strain independent shear modulus. In real soil systems, however, these assumptions tend to break down due to wave scattering through heterogenous materials, significant attenuation, non-vertical incidence, and other complexities in the subsurface. In work by Thompson et al. (2012), the authors developed a taxonomy using surface-downhole spectral ratios from weak ground motions for classifying a site's resonant behavior referenced to the SH1D condition. They found that often, the SH1D assumptions were not valid and thus the SH1D transfer function poorly modeled site response. Though this analysis provides the user with a good feel for site response complexity, it is designed for application on surface-downhole transfer functions and thus is not widely applicable as coupled borehole stations are scarce. In this work, we apply the Thompson et al. 2012 taxonomy to single station recordings in Mexico City, a case study where basin effects are well documented, by using the horizontal to vertical spectral ratio (HVSR) (Nakamura, 1989) as a first estimate of the site empirical transfer function (Lermo and Chávez-Garcia, 1994) using a theoretical transfer function derived from inversion. The HVSR clearly identifies resonance in the basin; however, the shape of the HVSR changes from the transition zone (at the edge of the basin) into the lake bed sediments (within the basin). We observed variation in shape of the HVSR across the basin and measured it using the half power bandwidth of each HVSR. We extend the taxonomy by looking at the simple spectral ratio and its relation to the HVSR in addition to the interevent variability and goodness of fit to the SH1D transfer function. We identify six stations out of 70 that, by the Thompson et al. 2012 statistics, can be considered SH1D but concluded that interevent variability is the most transferable statistic from surface-borehole spectral ratios to the HVSR as an indicator of complexity.

Thompson et al. 2012 Taxonomy

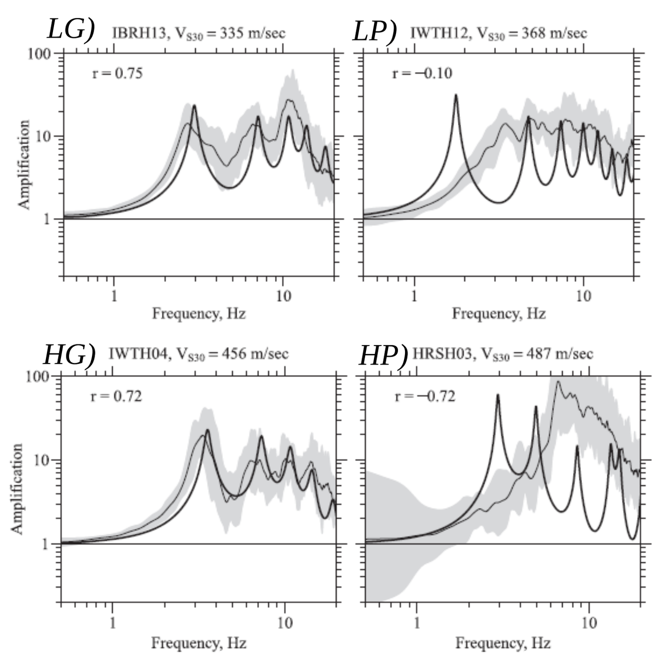


Figure 1. Examples of the four Thompson et al. 2012 site classifications on stations from the KiK-net database. Figure from Thompson et al. (2012).

Two Statistics

1) Interevent variability: the lognormal standard deviation (Eq. 3) of all ETFs at a station between the 1st and 4th peaks of the TTF.

2) Goodness of fit to the SH1D transfer function: Pearson's r between the TTF and ETF between the 1st and 4th peaks of the TTF.

Four Classifications

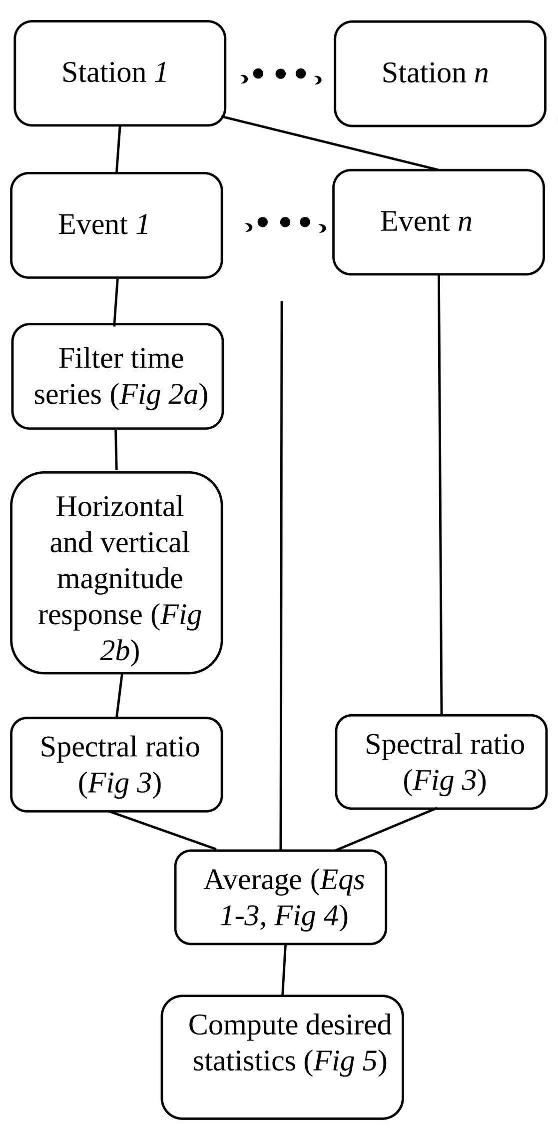
LG: Can be used to calibrate and validate 1D constitutive models.

LP: can be used for non-linear modeling after dentification of misfit due to things like soil heterogeneity or mismeasurement of soil properties.

HP: Can't be used for non-linear models unless source and path effects are accounted for.

HG: Difficult too interpret.

Data Processing



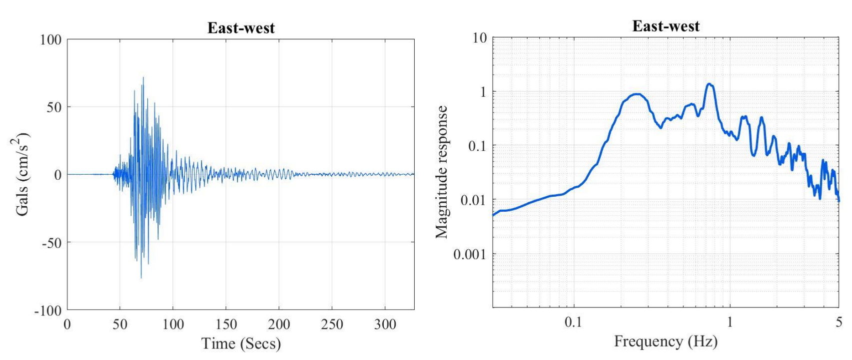


Figure 2. Horizontal time series of the 2017 Puebla event at a lake zone station and its magnitude response.

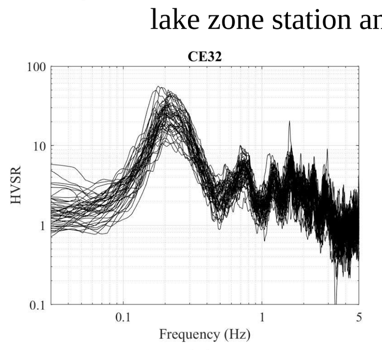
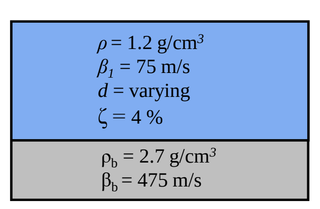


Figure 3. All HVSRs at station CE32.



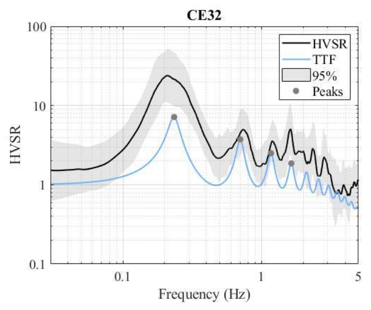


Figure 4. a) Averaged HVSRs at station CE32. b (above) Assumed soil profile used to invert for TTF

$$HVSR_{avg}(f) = exp\left(\frac{1}{n}\sum_{i=1}^{n}\ln[HVSR_i(f)]\right) \quad (1)$$

$$exp\left(\ln\left[HVSR_{avg}(f)\right] \pm z_{1-\alpha/2} \times \sigma_{ln}(f)\right) \quad (2)$$

$$\sigma_{ln}(f) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\ln[HVSR_i(f)] - \ln[HVSR(f)])^2} \quad (3)$$

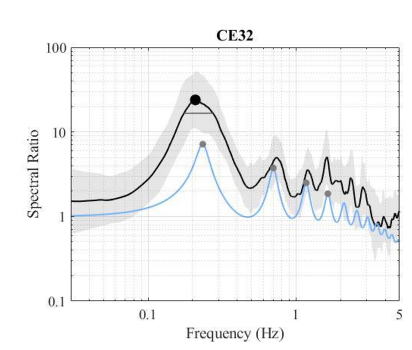


Figure 5. HVSR statistics at station CE32.

Mexico City RACM Dataset

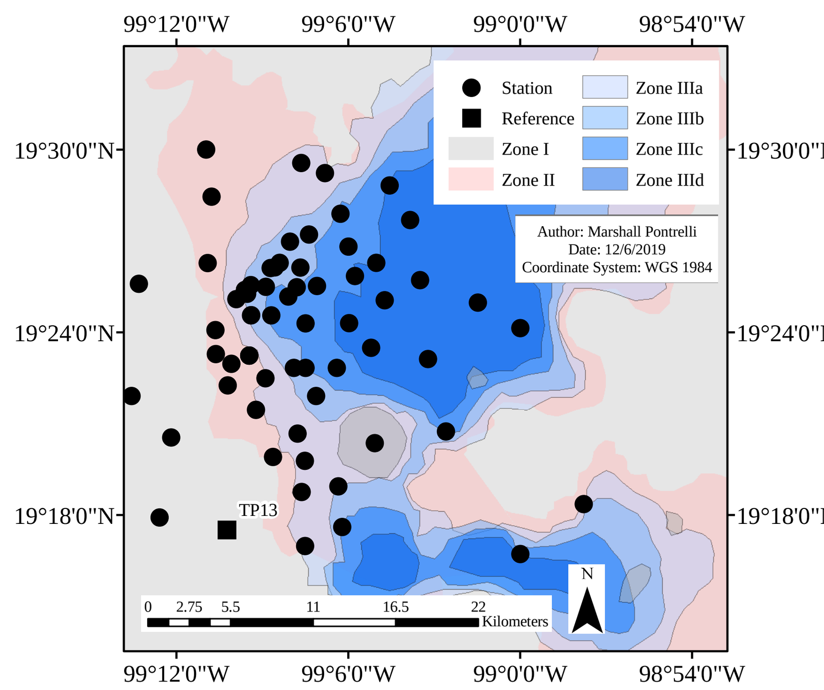


Figure 6. Mexico City RACM network stations with corresponding geotechnical zone. Map was based on Çelebi et al. 2018.

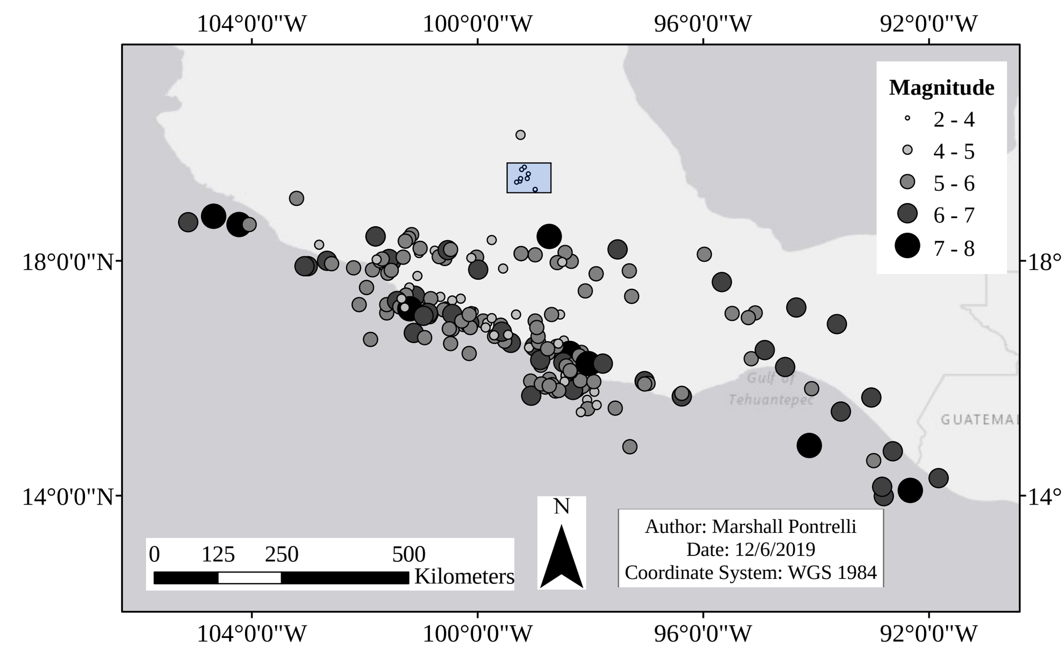


Figure 7. Earthquakes used in this study with Mexico City indicated by square.

HVSR statistic spatial variability

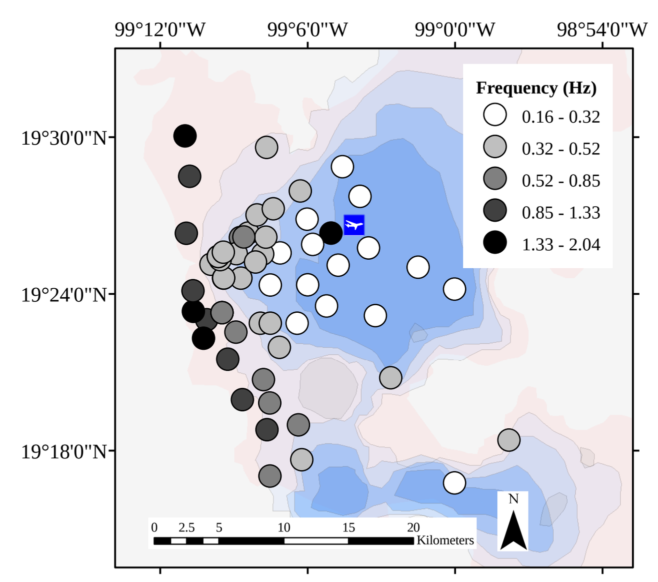


Figure 8. Fundamental frequency

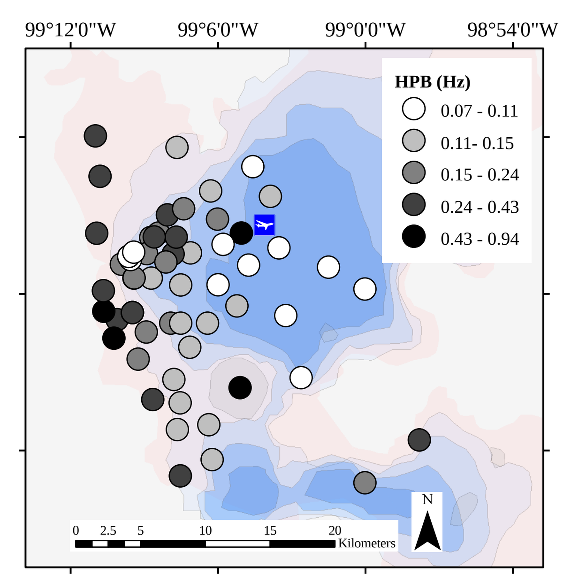


Figure 9. Half power bandwidth

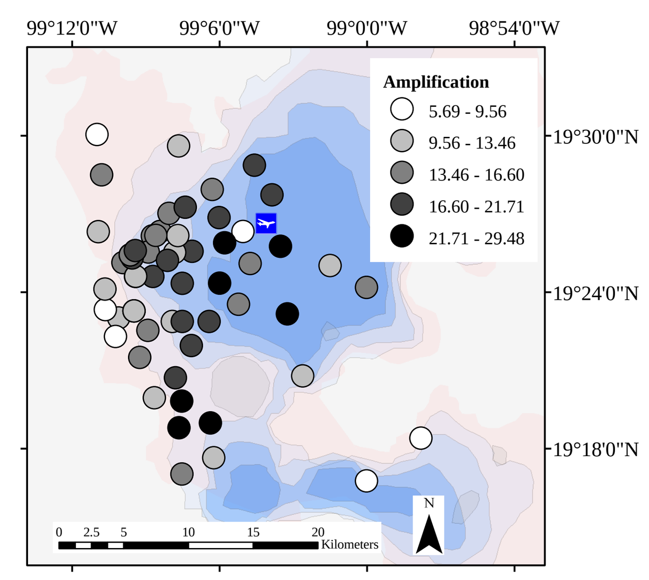


Figure 10. Amplification

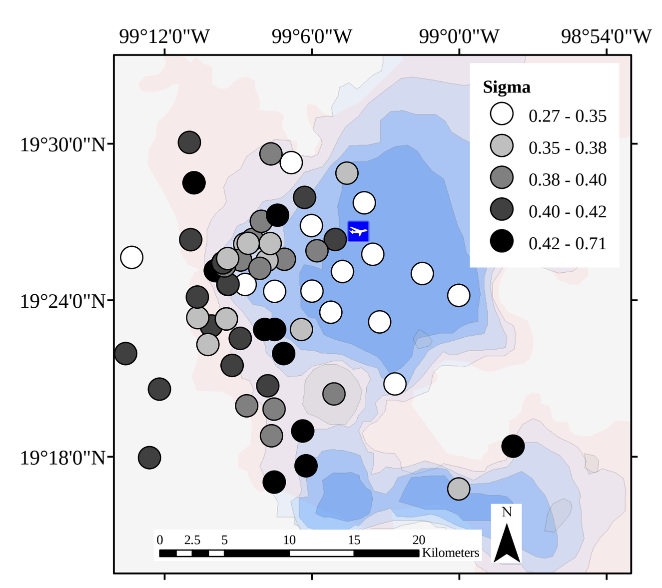


Figure 11. Interevent variability

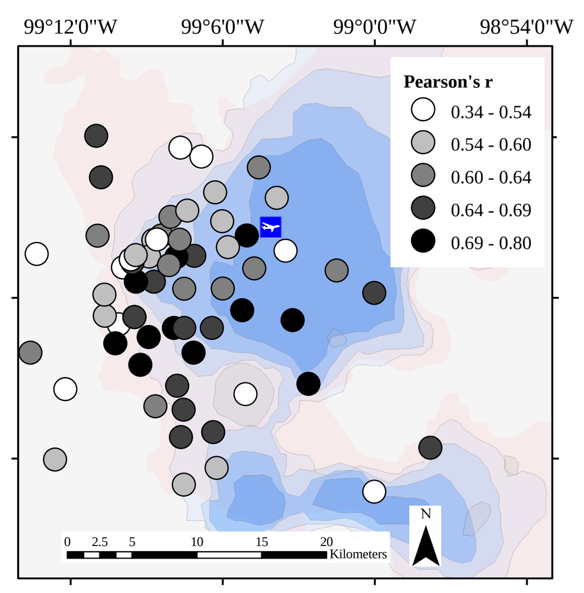


Figure 12. Goodness of fit to the SH1D transfer function

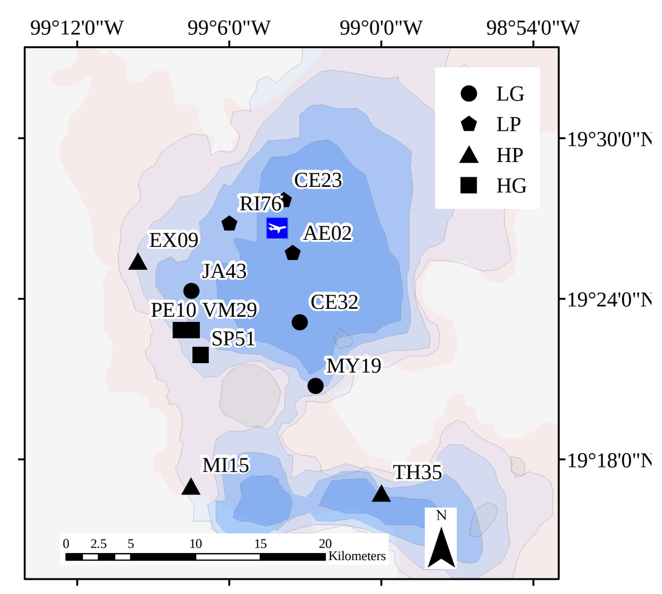
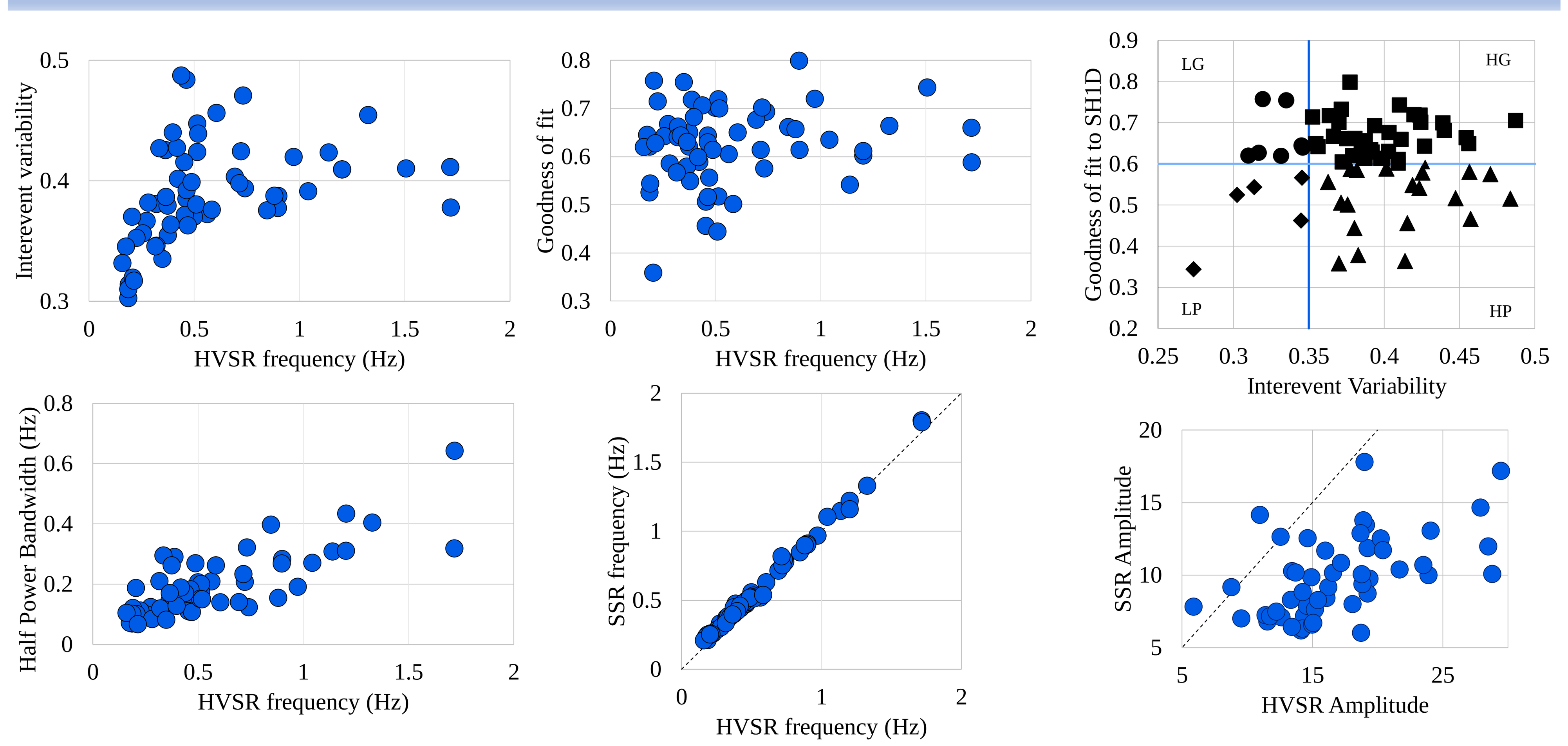


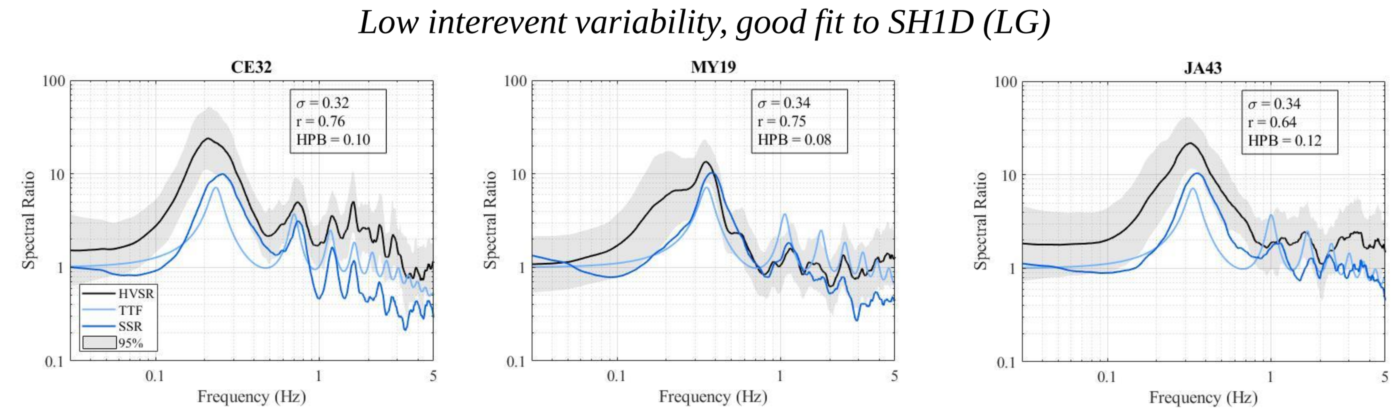
Figure 13. Selected Thompson et al. 2012 classifications

Statistics

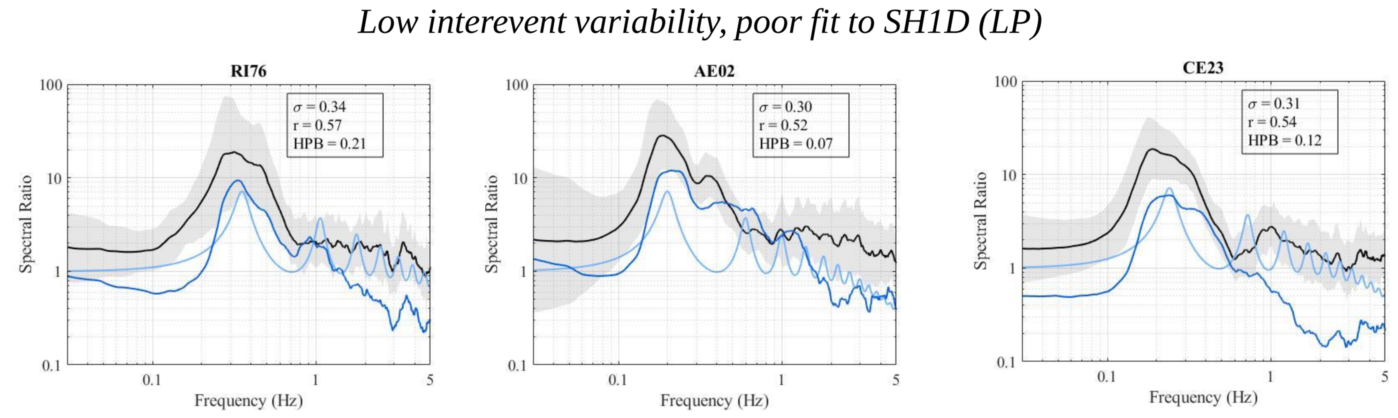


Spectral Ratios

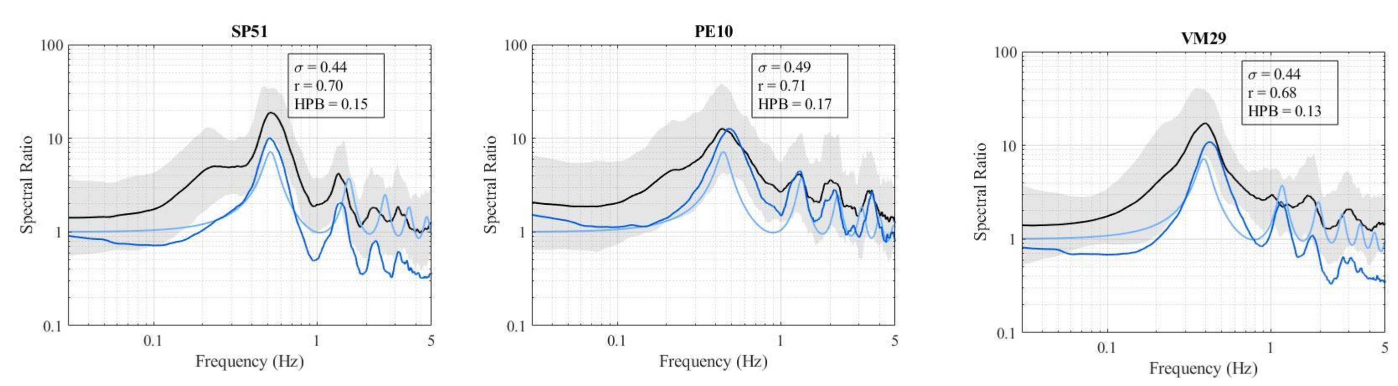
Low interevent variability, good fit to SH1D (LG)



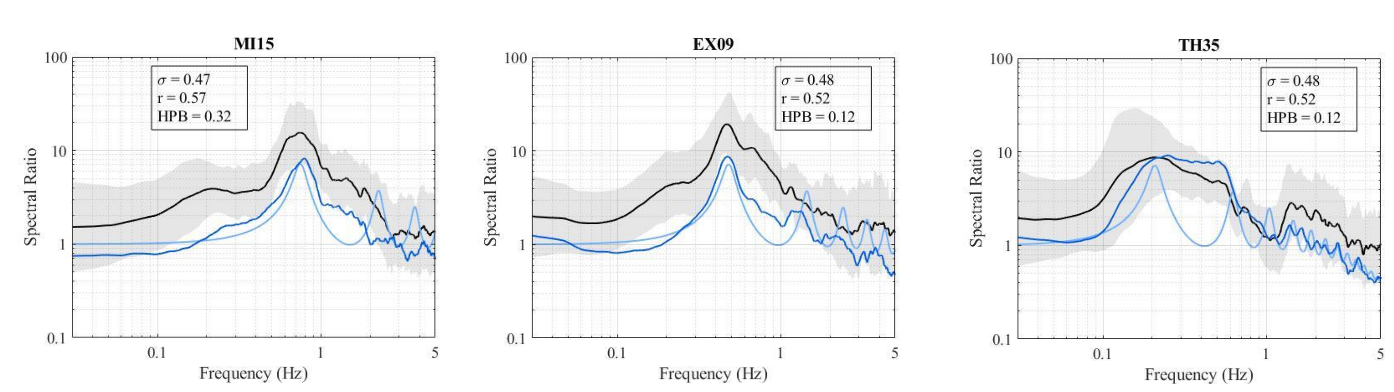
Low interevent variability, poor fit to SH1D (LP)



High interevent variability, good fit to SH1D (HG)



High interevent variability, poor fit to SH1D (HP)



Conclusions

(1) The Mexico City Basin increases in complexity from the lake zone to the transition zone caused by the sloping half space which increases wave scattering.

(2) The interevent variability is the best indicator of complexity when using the HVSR, however, it's threshold may need to be tweaked from the Thompson et al. 2012 threshold based on the basin of interest.

(3) The use of goodness of fit to the SH1D transfer function applied the HVSR is limited for two reasons: theoretically, the HVSR only images the fundamental peak, not higher modes in all cases and the availability of a site transfer function isn't always available. Despite the lack of site transfer functions in this study however, **we were able to obtain good fits to the fundamental peak using a simplified soil column.**

(4) Most stations in Mexico City have HVSRs with one clear peak. Some, however, display higher harmonics which map well onto the TTF.

(5) The halfpower bandwidth is a good measure for the width of the fundamental peak of the HVSR and tends to increase linearly with increasing frequency.

(6) Our results agree with those of the SESAME project on the amplification of the HVSR: that the HVSR tends to overpredict the amplification compared to the SSR when using earthquake data.

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