Shear-wave velocity measurements and their uncertainties at six industrial sites

THE HEBREW UNIVERSITY OF JERUSALEM

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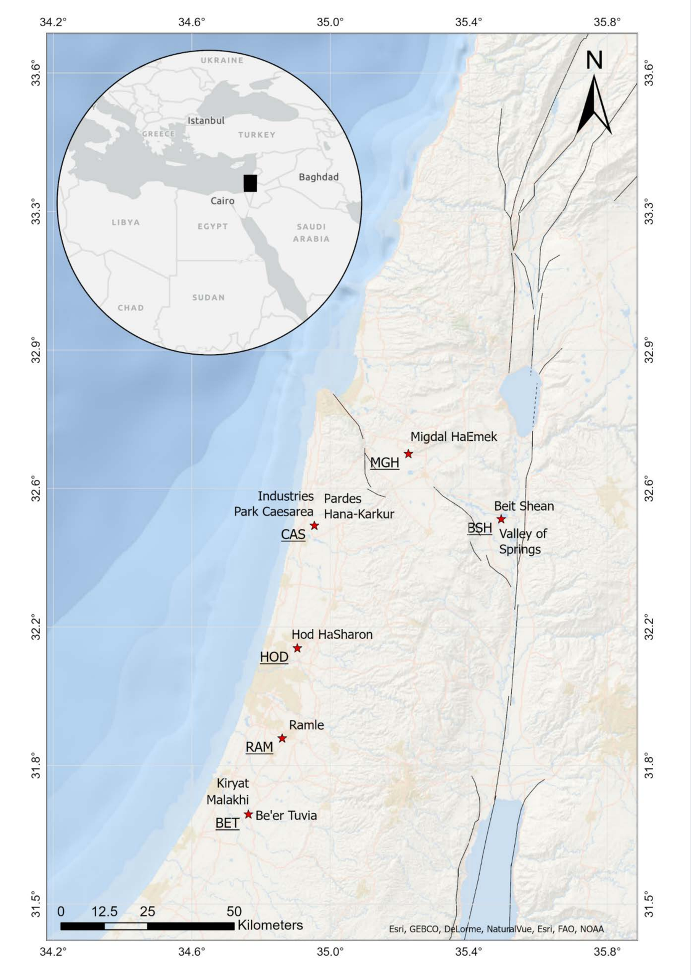
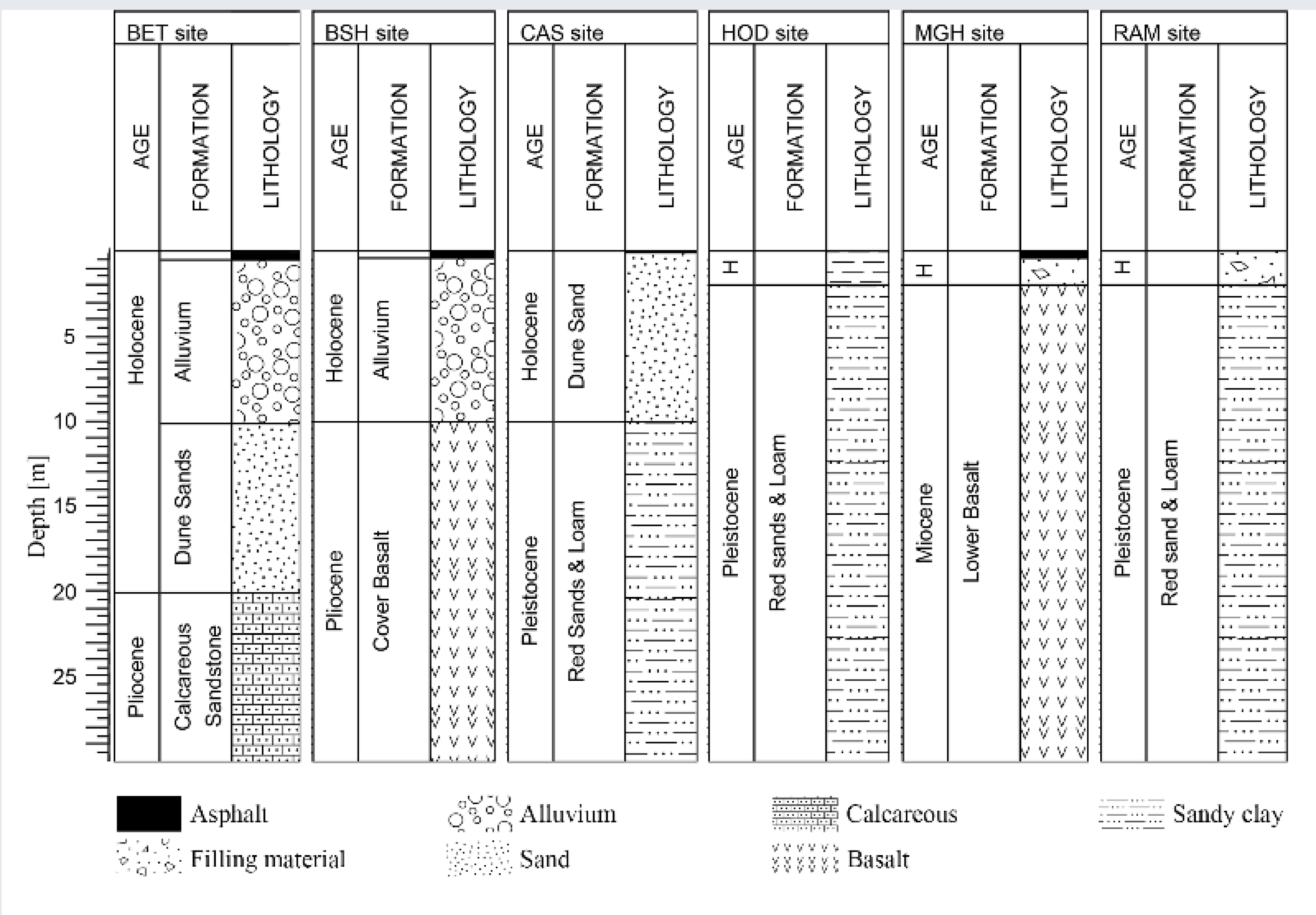
1. Introduction

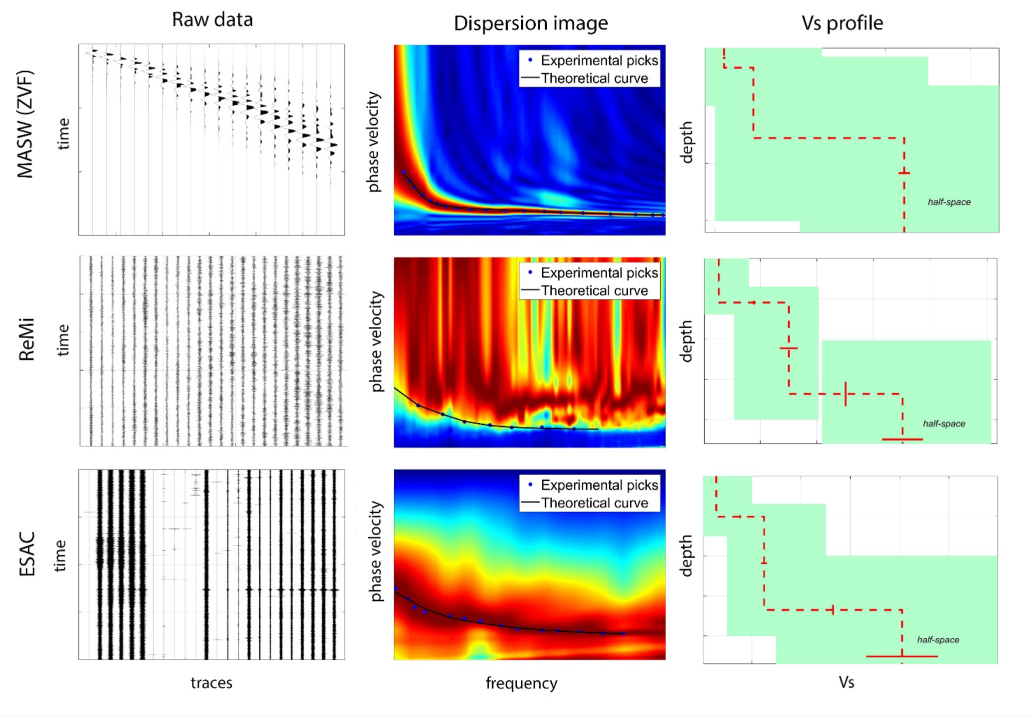
Shear-wave velocity (V_S) is commonly used to calculate the expected ground motion and predict earthquake damage (e.g. Boore, 2006; Horike, 1996; Moss, 2008). Thus, an in situ survey of V_S is one of the most crucial measurements for earthquake-related geotechnical engineering, and seismic response studies. Hence, the accuracy of a test and its proper interpretation are critical. The estimation of the V_S profile in areas subject to environmental noise, such as in industrial areas, near roads, and in cities, is more challenging. This is due to the random (often stationary) broadband noise sources from machines, cars, trucks, pumps, buildings, and so on.

In this study, I focus on six sites and estimate the uncertainties associated with measuring and interpreting the near-surface V_S profile in challenging environments, where random or continuous sources of noise dominate the wave field.

2. Measured sites







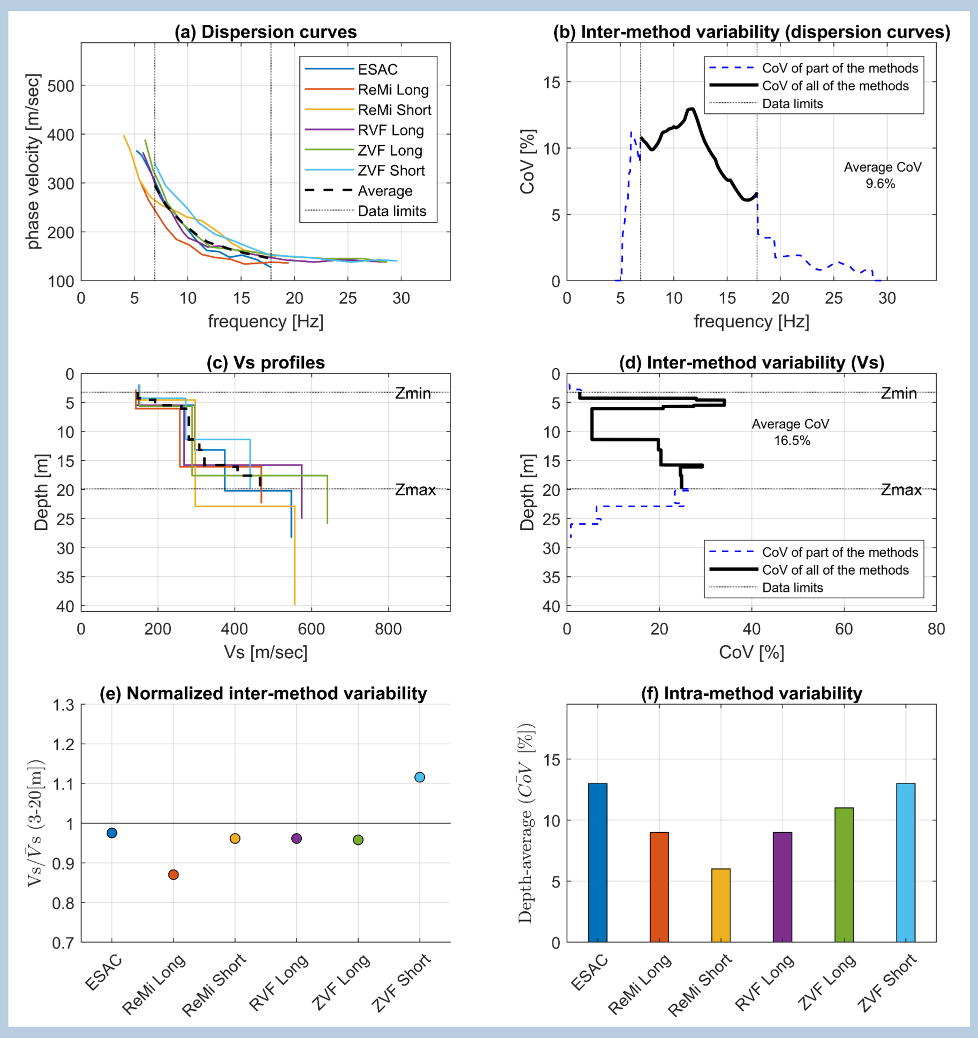
Data processing. In the upper section: the first column is the raw signal. The second column is the dispersion image after transformation from the time distance domain. The third column is the marginal posterior probability density (MPPD) (Dal Moro et al., 2007), which is defined as the mean shear-wave profile. The green areas represent the model boundary.

Acquisition. "L"-shaped array in the Ramle site).

3. Methods

Most surface-wave methods are based on three main steps: (1) acquisition of experimental data, (2) signal processing to obtain the experimental dispersion curve, and (3) 1D inversion to estimate V_S (e.g. Dal Moro, 2014; Foti et al., 2014). In this research, I used Multichannel Analysis of Surface Waves - MASW (Park et al., 1999) to acquire both the vertical and the radial components of Rayleigh waves and the transverse component of Love waves (by Dal Moro's notation (2014): ZVF, RVF, and THF, respectively). I also acquired data from the Extended Spectral Auto-Correlation - ESAC (Ohori et al., 2002) and the Refraction Microtremor - ReMi (Louie, 2001) methods. To calculate which frequencies bias each site, and if there are preferential directions to the noise in the wavefield, and how these noise properties vary with time, I used the Horizontal-to-Vertical Spectral Ratio – HVSR method.

4. Results



Example results from BET

(a) the family of dispersion curves picked from each of the different methods, the average dispersion curve, and the frequency boundaries for inter-method comparison (between methods).

(b) the inter-method variability of the theoretical dispersion curves. The variability of the results is evaluated through a coefficient of variation (CoV) which defined as $(\sigma/\mu)\cdot 100\%$ where σ is the standard deviation and μ is the mean value of the population of results.

(c) is the same as (a) but refer to the shear-wave profiles.

(d) is the same as (b) but refer to the shear-wave profiles.

(e) the normalized inter-method variability is defined as: $\left(Vs_{Z(max)}^{Z(min)}\right)/\left(\overline{Vs}_{Z(max)}^{Z(min)}\right)$, where the numerator is the time-averaged shear wave velocity for the investigation depth range. The denominator is the average value of all V_S measured at a specific site.

(f) the intra-method variability (the variability within the method) for each method is defined as the depth-average of the CoV from the minimum to the maximum investigation depth

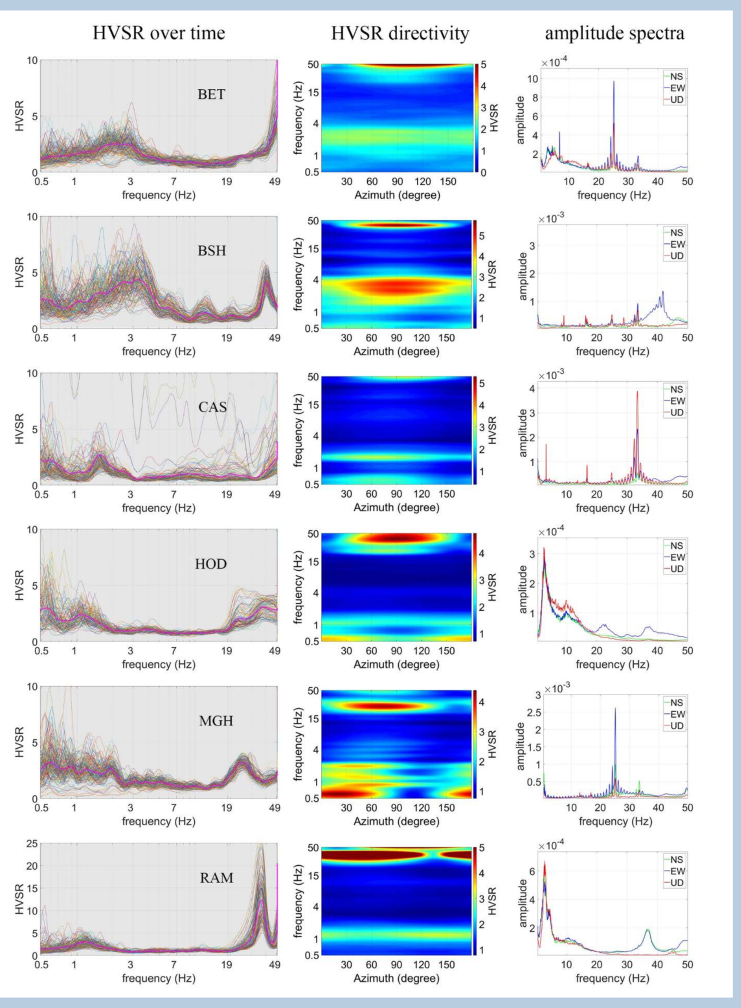
Table 2. Summary of the results

Site	# of tests	*Zmin* to *Zmax* (m)	V_S Inter-method variability (%)			Dispersion curve inter-method variability (%)		Intra-method variability, $\overline{CoV}$ (%)
			Maximum CoV (%)	Average CoV (%)	Maximum normalize $V_{S,Z(max\text{-}min)}$	Maximum CoV (%)	Average CoV (%)	
BET	6	3–20	35	16.5	0.88	12.5	9.6	6–13
BSH	5	6–27	35	16.1	0.92	13	5.2	4–14
CAS	3	4–26	20	11.6	1.06	8.3	2.5	6–10
HOD	9	4–15	25	13.4	0.9	8.0	6.0	4–10
MGH	5	4–18	28	12.7	1.15	13.5	12.6	4–8
RAM	5	5–28	35	12.7	0.86	12.5	9.7	6–9

CoV: coefficient of variation.

Background "Noise" analysis.

Each row represents a site. The first column is the HVSR over time, in which each curve is a sample representing a window of 20–30 sec. The second column is the HVSR directivity, and the third column is the amplitude spectra.



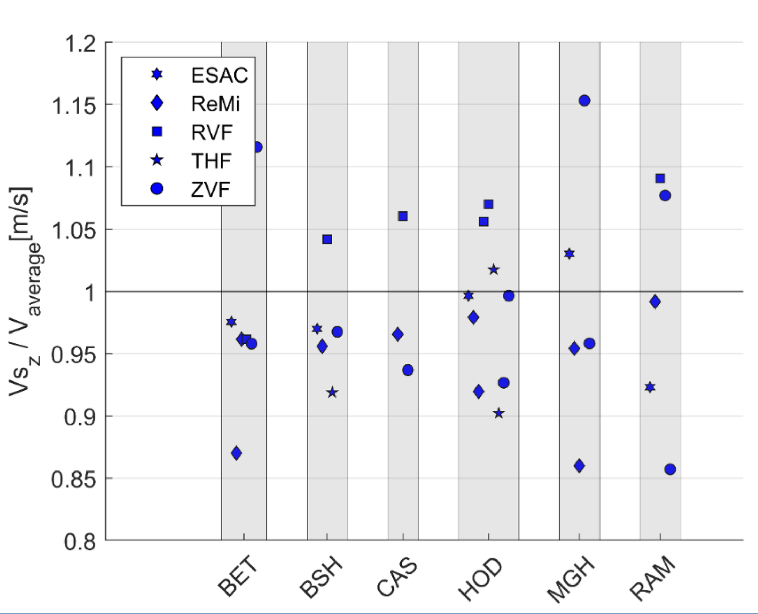
All data processing done by the WinMASW® Academy software.

5. Conclusions

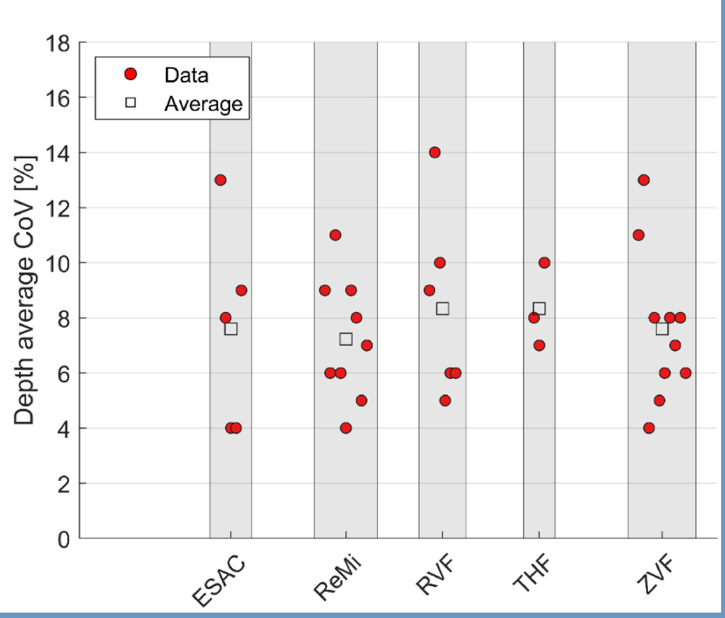
While the average CoV of the different dispersion curves is up to ~13% at specific frequencies, the frequency-averaged CoV is always less. The same concept holds for the CoV of the V_S profile, which peaks at 35% for specific depths. However, for the various sites, the depth-averaged CoV ranges from ~12% to ~17%. The variation of the normalized inter-method variability is low compared to the depth-dependent CoV. Therefore, the influence of anomalies within each V_S profile is lower. This indicates the robustness of the surface-wave methods for the computation of $V_{S,Z}$ and for the global parameter, $V_{S,30}$.

The uncertainty for each test (intra-method variability), of the 33 acquired, varies from 4% up to 14%, and there is no correlation between the test type and the CoV. These findings imply that while there is no preferred method, it is still advisable to use several methods to collect data.

Although the study focuses on surface-wave measurements in noisy environments, it aligns with comparable shear-wave studies and falls within the acceptable uncertainties in the results. This suggests that such tests are also applicable in industrial zones where the signals processed may be affected by noise.



Inter-method variability - the normalized $V_{S,Z}$ of each method at all sites.



Intra-method variability - the CoV of each method at all six sites which reflect only the inversion processing stage.

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References: All reference can be found in: **Darvasi Y. Shear-wave velocity measurements and their uncertainties at six industrial sites. Earthquake Spectra. March 2021. doi:10.1177/8755293020988029**