Answer to reviewers

Review line numbers refer to the original manuscript, and the answer line and figure numbers refer to the new revised manuscript. All changes are highlighted in aquamarine in the revised annotated manuscript.

Editor

Dear Lenin Ávila-Barrientos, Luis A. Yegres-Herrera, Hortencia Flores-Estrella, M. Alejandra Nuñez-Leal, Hector Gonzalez-Huizar:

First of all, I'm truly sorry for the delay. We have finally reached a decision regarding your submission to Seismica, "Seismic site conditions of RESNOM network". We have decided "review and resubmit". We are attching the reviews that we received, and we encourage you to revise and resubmit the manuscript when you are ready.

Kind regards,

Pablo Heresi

Reviewer A:

The manuscript presents a preliminary assesment of seismic site conditions of the Northwest Seismic Netowork of Mexico (RESNOM) by the inversion of the shear wave velocity (Vs) from Horizontal-to-Vertical Spectra Ratio (HVSR) of seismic noise. Other useful parameters are obtained from the Vs profile, such as the depth of the rock layer, the average of Vs over the upper 30 m (Vs30), the fundamental frequency f0 and the corresponding avergae ampltiude at f0 (A0). Comparizons are made of the resulting Vs30 and descriptions of surface geology. In general, the manuscript is well written and presented, figures are clear and useful; however, some tables are too long and not clear to analyse and could be moved to supplemetary materials. The main issue that needs to be revised is the description of the inverse procedure: more information should be provided and figures comparing the data and predicted models should be presented; details are provided below.

Considering this, I recommend the manuscript to be revised and improved, leading to a more robust resubmission.

Issues in the inversion:

• Please provide details on the definition of number of layers and the criteria used to select the one that was finally used.

A. Regarding the details of the inversion process, within the software GEOPSY, a parametric analysis is performed. This analysis optimizes the inversion process, considering that the values of frequencies associated with spectral peaks are strongly dependent on layers velocities and thicknesses. We used the shape of the HVSR curve interpreted as the ellipticity curve to be inverted, starting with a simple velocity model, using at first the higher frequencies to model the near-surface layers, adding more layers at depth to model the peaks with lower frequencies. The parameters are modified in each iteration to reach the smallest misfit between the observed HVSR and the theoretical curves calculated for each shear wave velocity profile (Xia et al., 2003).

• Some discussion should be devoted to the sensitivity of the inversion procedure. For example, it

seems strange that it can reach 1000 m depth; please clarify.
A. The sensitivity of the inversion procedure is closely related to the frequencies and wavelengths that can be evaluated. Higher frequencies provide information about shallower subsurface layers with greater resolution due to shorter wavelengths. In contrast, lower frequencies are sensitive to deeper structures because of their longer wavelengths.

In this work, we observed that the ellipticity curve exhibits a peak at low frequencies, indicating a significant impedance contrast at greater depths, such as around 1000 meters. The inversion of the HVSR curves is performed in the complete frequency domain, i.e., all frequencies obtained from the HVSR curve calculation are considered. In this work, it can be observed that the HVSR curves are well-defined at low frequencies (long periods), so being able to invert at a depth of 1000 m is possible.

• Please comment if there is any trade-offs between the resulting models and the absolute values of Vs. Many of these techniques can adjust the resulting HVSR with several different models and require some Vs values to reduce this uncertainties.
A. Yes, a trade-off exists between the resulting models and the absolute values of Vs. Many inversion techniques, including the one used in our study, can fit the HVSR (Horizontal-to-Vertical Spectral Ratio) curve with multiple different models. This is a well-known issue in geophysical inversions, where different combinations of model parameters can produce similar fits to the observed data, leading to non-uniqueness in the solutions.

It is often necessary to incorporate priori information or constraints on Vs values to mitigate this uncertainty. These constraints can come from independent measurements, such as borehole data, or from well-established geological and geophysical knowledge of the area under study. By integrating these additional constraints, we can narrow down the range of possible models and improve the reliability of the inversion results. This is why we are proposing, at the end, to make at least other geophysical methods, like MASW, Arrays.

In our analysis, we carefully considered the potential trade-offs and incorporated available constraints on Vs to enhance the robustness of our models. We only have geological information, and we seek to correlate the velocity models obtained with ranges of values consistent with the present lithology.

• In the inversion procedure, are the HVSR errors considered? How is this done?
A. Yes, the errors were considered. The inversion process shows a misfit (error) color bar at the bottom of the figure for the inverted models. The error or misfit is explained in lines 212 to 221. The result will be the better-fitting models with the lowest misfit (Hobiger *et al.* 2013).

• Figures showing the fit of the predicted HVSR after the inversion and the data should be provided.
A. We added the fit for each station, figure S-1 (supplementary material), and added (line 226): "Figure S-1 (supplementary material) shows the fit for each station."

Minor comments:
• Lines 51-52: the inference made is not clear, please revise.

A. We modified lines 52-54

"The seismic stations characterization provides information about the seismic conditions of subsoil. The spatial distribution of these seismic conditions could have implications for the seismic hazard assessment."

• Line 87: please provide the classification referred.

A. The classification is referred to NEHRP (2020). The line (88) was modified according to Reviewer B.

"…V_S over the upper 30 m, V_{S30}; the depth to bedrock, H_{eng_bed}; as well as the surface geology."

• Line 123 and Table 1: it is not clear if they refer to broad bands or accelerometers, please clarify.

A. It refers to broad bands. We modified lines 123 to125, and Table S1 (supplementary material)

"Table S1 provides information on the station's location, dynamic range, frequency response, and geological site for the broad-band instruments."

"Table S1 List of the RESNOM broad-band stations and site geology according to INEGI (2023)*. SPIG station belongs to the SSN network (SSN, 2023). All stations are sampled at 100 samples per second (sps)."

• Table 1: this table is long and does not seems to provide relevant information for the manuscript, consider moving it to supplementary material.

A. The table was moved to supplementary material. Now Table S1 (line 104).

• Line 136: speccify if data comes from broad bands or accelerometers.

A. We modified line 133.

"The analysis was performed using only the broad-band seismometers."

• Line 136: only 1 day is considered, due to the low anthopogenic seismic noise; however, some tests should be done to prove that only this data is required.

A. According to SESAME (2004) recommendations, the minimum record duration ranges between 30 to 2 minutes. The time minimum to define the shallow conditions (20 – 150 m depth, which is mainly our target) will be around 20 minutes. The recording time employed is more than the minimum recommended.

• Line 164: b parameter of the Konno-Ohmachi filter is not in percentage, is just a number.

A. We modified line 162.

• Lines 174-175: it's not clear that all the resulting HVSR curve meet the Sesame criteria, please specify.

A. We confirm that all the resulting HVSR (Horizontal-to-Vertical Spectral Ratio) curves meet the SESAME criteria for reliability. Specifically, we have adhered to the following three criteria for a reliable H/V curve:

f_0 > 10 / lw: The fundamental frequency (f_0) is greater than 10 divided by the length of the time window (lw). We have ensured that this condition is met for all our processed data.

nc(f_0) > 200: The number of cycles at the fundamental frequency (f_0) exceeds 200. We have verified that for each processed station, the number of cycles at f_0 is well above this threshold, ensuring the stability and reliability of the identified peak frequency.

σA(*f*) Criteria:
For $f_0 > 0.5$ Hz: The standard deviation of the amplitude (σA(*f*)) is less than 2 for the frequency range 0.5 f_0 to 2 f_0.

For $f_0 < 0.5$ Hz: The standard deviation of the amplitude (σA(*f*)) is less than 3 for the frequency range 0.5 f_0 to 2 f_0. (While we were not as rigorous with the σA(*f*) criterion, we focused on using the HVSR curve above 0.5 Hz. We have rigorously checked that these conditions on σA(*f*) are satisfied for all the HVSR curves within the specified frequency ranges)

We have rigorously checked that these conditions on σA(*f*) are satisfied for all the HVSR curves, ensuring their reliability within the specified frequency ranges.

By meeting these SESAME criteria, we ensure the reliability and robustness of the HVSR curves used for the inversion process across all processed stations.

• Lines 185-189: some discussion on this assumption should be provided.
A. It is well known that the characteristics of HVSR curves, such as amplitude, dominant frequencies, etc.) are similar to site response curves, which depends on the geology and structure of the subsurface. Therefore, the characteristics of HVSR curves can be interpreted as a result of heterogeneities in the subsurface. This also resulted that in the 1980s, most of the articles using seismic noise were focused on obtaining the site response from the calculation of HVSR curves, then known simply as H/V (Bard, 1999).

Subsequently, in order to understand the physics of HVSR curves and explain how they reflect the subsurface structure, several authors (Malischewsky and Scherbaum, 2004; Malischewsky et al., 2010; Zor et al., 2010; Tuan et al., 2011; Flores et al., 2013; Wathelet et al., 2020) related them to the ellipticity curves of Rayleigh Waves. Therefore, it is advisable to invert the HVSR curves to obtain a velocity model from which to calculate the theoretical ellipticity curve, which is compared with the HVSR curves.

This is exactly the approach we use in this work, because it allows not only to give the fundamental frequency and amplitude of the HVSR curves, as in the 1980s, but also to obtain a model of velocities and its Rayleigh Waves Ellipticity Curve and thus a better knowledge and definition of the subsurface with a geophysical method.

• Lines 194-197: steps 1 y 2 should be shown (discussed before).
A. We modified line 200, the step 2 is mentioned in the next paragraph (lines 209 - 212)
"…calculate the HVSR curve for each station, explained before and results shown in Figure 2; (2)…"

We modified line 202-205

"… velocity V_P for each layer, starting with a simple and wide open velocity and depth model, using at first the higher frequencies to model the near surface layers, adding more layers at depth to model the peaks with lower frequencies; and (3)…"

• Table 2: minimum misfits > 1.0 should be discussed because it means that, in average, the difference between the observed and the predicted HVSR is larger tha 1 s, following equation (1).

A. The equation 1 refers to the root mean square value of the horizontal components; the misfit is determined by equation 3 and explained lines below.

We modified the lines 219-222

"A misfit one unity value represents that the predicted data fit to the observed data one standard deviation, in average (Gosselin et al., 2022), which means how far the generated model is from the observed data (Wathelet et al., 2004; 2008)"

Added the following references:

Gosselin, J. M., Dosso, S. E., Askan, A., Wathelet, M., Savvaidis, A., Cassidy, J. F. A review of inverse methods in seismic site characterization. J Seismol 26, 781–821 (2022). https://doi.org/10.1007/s10950-021-10047-8

Wathelet, M., Jongmans, D., Ohrnberger, M. Surface-wave inversion using a direct search algorithm and its application to ambient vibration measurements. Near surface geophysics, 2(4), 211-221, 2004.

Wathelet, M., Jongmans, D., Ohrnberger, M., Bonnefoy-Claudet, S. Array performances for ambient vibrations on a shallow structure and consequences over V s inversion. Journal of Seismology, 12, 1-19, 2008

• Lines 265-272: It seems that the authors are relating the amplitude of the HVSR A0 with the thickness of the sediments, please clarify and provide references to supprot this claim.

A. Indeed, the amplification (A_0) should not be interpreted or valued as site amplification. As per the SESAME guidelines, the HVSR technique provides accurate frequency information but not absolute amplitude. The A_0 value we obtain gives us an indication of the impedance contrast between two layers at depth. Specifically, a higher A_0 value suggests a greater impedance contrast between two layers, which occurs at a particular frequency related to the depth. This information is valuable for understanding subsurface layering and the contrasts in material properties, rather than for assessing site amplification directly.

We modified the paragraph, lines 280-282

"From Figure S-2 (supplementary material), we can observe that the thickness of the sediments is major in the deformation zone than those in the Pacific side and minor in the Sierra Juarez, at least for these stations."

• Lines 274-284: even though the information needed to compare Vs30 to geology is provided, it is no easily done due to the format used. Maybe some adjustments in the Tables could be made or provided as Supplementary Materials.

A. We added new figure indicating the V_{S30} value, Figure 5, also suggested by reviewer B, line 274

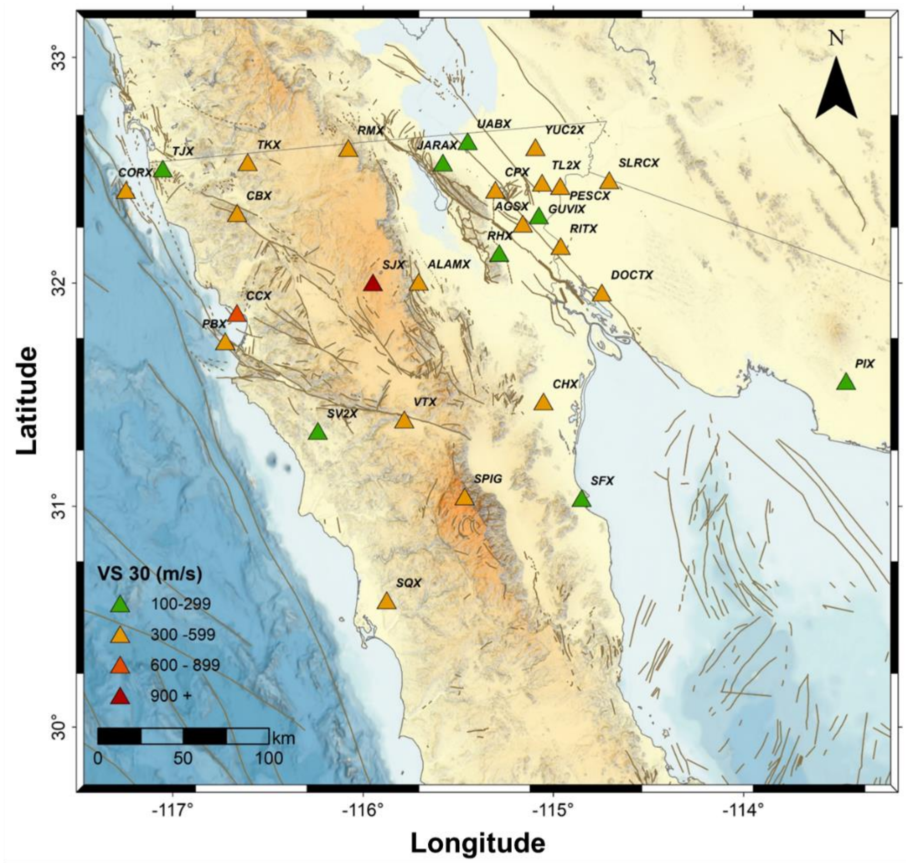

Figure 5 Broad-band seismological stations of the RESNOM seismic network and the V_{S30} values obtained for each station.

• Table 3: there seems to be no correlation between geology and site description based on Vs30 classification; please address this issue. For example, CBX is located at intrusive igneous bt described as very dense sand or hard clays, similar to CCX, CORX and CPX. Even more, PIX is described as loose sand or medium stiff clay, but was placed on mehtamorphic gneiss rocks before.
A. We explain this issue in lines 304 -306

"This can be explained because the rock in the site is weathered, as can be observed in Figure 6. Due to the weathered rock, different sites located on rock have properties more similar to sediments than healthy rock."

• Lines 307-309: the relation between strong crustal deformation and variations in depth to bedrok is not clear, please clarify.
A. We modified, lines 322-323

"which we speculate could be related to the heterogeneity in the zone due to the crust deformation by the interaction between the North American and Pacific plates."

• Lines 311-315: Please provide percentage of stations in each case.
A. We modified, lines 327-328

"…the rest of the stations (RMX, SLRCX, and TL2X), which represent the 30% of the C type, show depths <250 m. Most of the stations (66.66%) classified as CD have…"

• Figure 6: site class should be based on Vs30; hence, no changes in symbols should be required. Please revise this Figure.
A. Yes the site class are based on Vs30 value and the classification on the NEHRP (2020), we modified line 340

"**Figure 7** H_{eng_bed} versus V_{S30} for all stations. Different symbols represent the site classification based on the V_{S30} value following NEHRP (2020), shown in Table 2."

• Lines 328-329: this statement is not backed up with the presented results, please clarify.
A. We modified, lines 342-344

This study represents the first comprehensive attempt to determine the main proxies (f0 and A0) for all RESNOM stations using seismic noise analysis and HVSR curves inversion. Previous research has not provided such extensive data for these stations. Our analysis reveals that the f0 and A0 values align with expected ranges for seismological stations situated on rock substrates. For instance, Table 1 illustrates that f0 values predominantly ranging between (0.365 to 5.360) Hz, and A0 values clustering around (1.2 and 3.8).

The Mexicali and Peninsular regions show notable differences in the f0 and A0 parameters, especially at higher values. These variations support the heterogeneity of the zone, specially because the presence of high depth of sediments, which also is influenced by the complex interaction between the North American and Pacific plates in this region. This geological complexity is further evidenced by the varied amplification factors (A0) across the regions, indicating differing subsurface conditions and rock properties.

Reviewer B:

The paper presents and investigates the site conditions in the Northwest Seismic Network of Mexico (RESNOM), focusing on the Mexicali Valley and Peninsular Ranges regions. Through seismic noise analysis and the Horizontal to Vertical Spectral Ratio (HVSR) method, the study aims to determine parameters such as depth of the rock layer (*Heng_bed*), *VS30*, fundamental frequency (*f0*), and average amplitude (*A0*).

Notably, the findings reveal distinct variations in these parameters between the two regions, shedding light on their seismic characteristics and suggesting potential implications for seismic hazard assessment. The article presents an interesting contribution to the characterization of stations and provides more accurate information on the amplification of recorded seismic response. However, the various calculated parameters should be displayed in maps to facilitate any correlation and/or discussion (also between the results of the two regions under study). Even though the paper deals with an interesting topic it needs to be revised to improve the clarity of the presentation and address some technical questions (outlined below). The Authors should give a consistent reply to all the issues summarized in the following and revise the manuscript accordingly.

Abstract: The reported ranges concerning the variation of *VS30* are so wide that stating their equality doesn't make much sense; what matters is whether the spatial distribution is similar or not.
A. The V_{S30} spatial distribution is shown in the new figure 5. Line 274

Line 85: It should be noted here that the depth to bedrock is an optimal parameter (also calculated by the Authors later on in the paper).
A. We added in line 88.
"…V_S over the upper 30 m, V_{S30}; the depth to bedrock, H_{eng_bed}; as well as…"

Line 87: The statement made in line 87 is imprecise because the soil class is also determined based on the mentioned parameters.
A. We modified, line 88.
"…V_S over the upper 30 m, V_{S30}; the depth to bedrock, H_{eng_bed}; as well as the surface geology."

Methodology: "For seismological network stations, high impedance contrast is not expected; therefore, we do not expect sharp peaks within the HVSR curve". This sentence is unclear and needs further elaboration to add value to the content of the article, for example why for seismological network stations, high impedance contrast is not expected?
A. For seismological network stations, it is not ideal to expect high impedance contrasts because these stations are preferably installed on rock sites, where there are no sediments that could cause site effects. Site effects and high impedance contrasts between subsurface layers generally manifest as sharp peaks in the H/V curve. This is what we meant by "we do not expect sharp peaks within the HVSR curve."

However, it is not always possible to meet this ideal due to logistical reasons, access, communication, security, and other factors that can complicate the rigorous criteria for the ideal installation of a seismological station. Therefore, in some cases, the site conditions where a station is eventually installed are not ideal. Specifically, for our work, with the presence of the Mexicali Valley, where many RESNOM stations are located, there is the presence of significant sedimentary thickness (more than 5 km).

We added (lines 170 to 174):
"For seismological network stations, in the ideal conditions (installed on rock sites) high impedance contrast is not expected; therefore, we do not expect sharp peaks within the HVSR curve. The high impedance contrasts (presence of sediments) between subsurface layers generally manifest as sharp peaks in the H/V curve."

Line 175: Regarding the average amplitude at the fundamental frequency (A_0): as reported in the Sesame guidelines, the HVSR technique is capable of providing correct frequency but not amplitude. Therefore, the statement is incorrect and should be further elaborated.

A. We added the following text, lines 175-180

"Also, it is very important to keep clear the difference between the maximum amplitude observed in the HVSR peaks and the site amplification. Many times, it is an accurate reference to define the amplification in a site, related to a specific frequency (main peak of the HVSR curve), however, it is not as simple as directly the value of the maximum amplitude of the H/V ratio (Bonnefoy-Claudetetal.2006a)."

Indeed, the amplification (A_0) should not be interpreted or valued as site amplification. As per the SESAME guidelines, the HVSR technique provides accurate frequency information but not absolute amplitude. The A_0 value we obtain gives us an indication of the impedance contrast between two layers at depth. Specifically, a higher A_0 value suggests a greater impedance contrast between two layers, which occurs at a particular frequency related to the depth. This information is valuable for understanding subsurface layering and the contrasts in material properties, rather than for assessing site amplification directly.

Section 4: "For most stations, the fundamental frequency is up to 0.8 Hz, except for CHX and TJX". However as can be seen in Table 2 most of the stations exceed 0.8 Hz. Therefore, the English in the sentence is incorrect; it should be stated that most values in the table exceed 0.8 Hz.

A. We changed, line 253

"For most stations, the fundamental frequency exceeds 0.8 Hz except …"

Line 265: Again, no straightforward information can be directly linked to the H/V peak amplitude A_0. However, this value may be considered indicative of the impedance contrasts at the site under study: large H/V peak values are generally associated with sharp velocity contrasts, as per the Sesame guidelines. Accordingly the Authors can comment on this based on the obtained results.

A. We added the following text, lines 175-180

"Also, it is very important to keep clear the difference between the maximum amplitude observed in the HVSR peaks and the site amplification. Many times, it is an accurate reference to define the amplification in a site, related to a specific frequency (main peak of the HVSR curve), however, it is not as simple as directly the value of the maximum amplitude of the H/V ratio (Bonnefoy-Claudetetal.2006a)."

Indeed, the amplification (A_0) should not be interpreted or valued as site amplification. As per the SESAME guidelines, the HVSR technique provides accurate frequency information but not absolute amplitude. The A_0 value we obtain gives us an indication of the impedance contrast between two layers at depth. Specifically, a higher A_0 value suggests a greater impedance contrast between two layers, which occurs at a particular frequency related to the depth. This information is valuable for understanding subsurface layering and the contrasts in material properties, rather than for assessing site amplification directly.

Line 274: Maps (as the one reported in Figure 1) showing the spatial variation of the obtained parameters are missing, which would facilitate easy commenting in relation to velocity, frequency, and bedrock depth. Additionally, information indicated with different markers of parameters obtained prior to RESNOM should be included. Otherwise, comments such as " We observed that the *VS30* value for the stations located in the Mexicali Valley ranges from 173 m/s (UABX station) to 535 m/s (AGSX station)" do not add valuable content to the paper.

A. We added new figure indicating the V_{S30} value, Figure 5, line 274

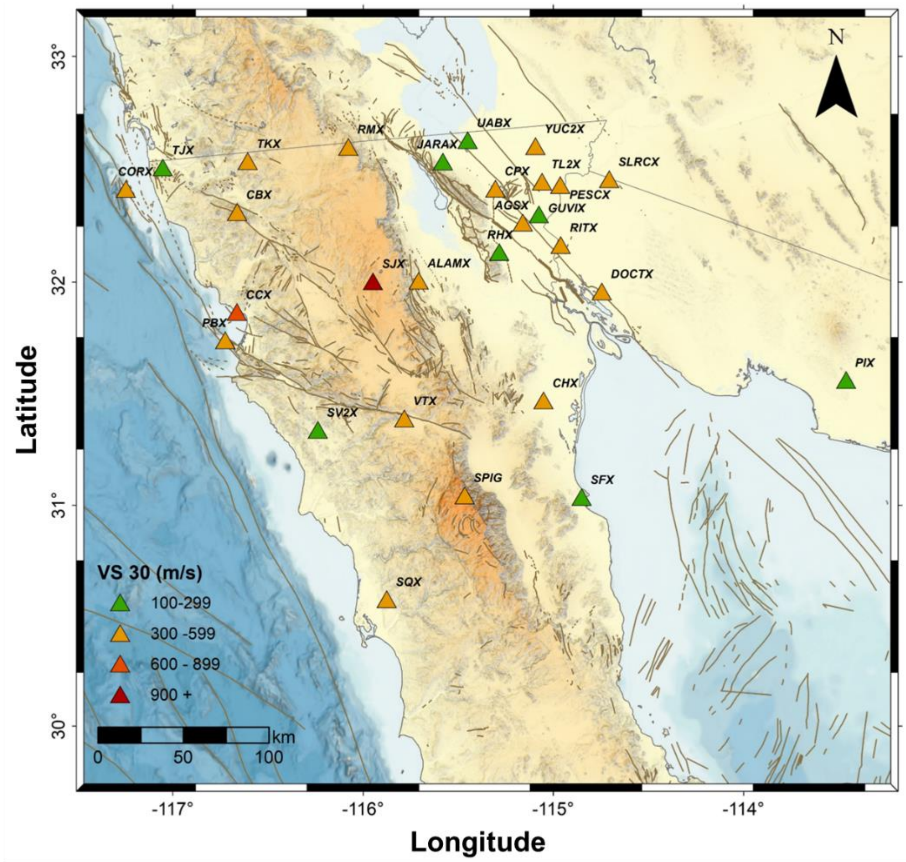

Figure 5 Broad-band seismological stations of the RESNOM seismic network and the V_{S30} values obtained for each station.

Answer to reviewers

Review line numbers refer to the original manuscript, and the answer line and figure numbers refer to the new revised manuscript. All changes are highlighted in aquamarine in the revised annotated manuscript.

Editor

Dear Lenin Ávila-Barrientos, Luis A. Yegres-Herrera, Hortencia Flores-Estrella, M. Alejandra Nuñez-Leal, Hector Gonzalez-Huizar:

I hope this email finds you well. I have reached a decision regarding your submission to Seismica, "Seismic site conditions of RESNOM network". Thank you once again for submitting your work to Seismica.

Based on reviews I have received, your manuscript may be suitable for publication after some minor revisions. Reviewer B accepted your revised version. However, Reviewer A still has some minor comments that should be addressed.

Kind regards,
Pablo Heresi

A. We appreciated your time and effort.

Reviewer A:

In general, the observations made were considered and answered accordingly, making a more robust manuscript. Only minor issues remain, that are describe below.

I recomend minor revisions and the publcation of the manuscript.

+ Strong arguments are made to support the capabilities of the method to reach very large depths (~`1000 m) using only information collected from the surface (HVSR). Even more, an interesting discussion is provided in the answers but not presented in the manuscript. Please include this discussion on the final version of the manuscript to enable the reader the fully understanding of the inversion sensitivity.

A. We added, lines 225 to 232:

The sensitivity of the inversion procedure is closely related to the frequencies and wavelengths that can be evaluated. Higher frequencies provide information about shallower subsurface layers with greater resolution due to shorter wavelengths. In contrast, lower frequencies are sensitive to deeper structures because of their longer wavelengths. In this work, we observed that the ellipticity curve exhibits a peak at low frequencies, indicating a significant impedance contrast at greater depths (~1000 m). The inversion of the HVSR curves is performed in the complete frequency domain, i.e., all frequencies obtained from the HVSR curve calculation are considered.

+ Another interesting discussion related to the trade-off between the resulting models and the absolute values of Vs. However, this was also ommitted from the manuscript. I think this arguments will provide the reader more information on the limitations of the present results. Please considering inlcuding it in the final version, along with some guidelines of the constraints incorporated.

As mentioned in the answer: "In our analysis, we carefully considered the potential trade-offs and incorporated available constraints on Vs to enhance the robustness of our models. We only have geological information, and we seek to correlate the velocity models obtained with ranges of values consistent with the present lithology."

A. We added, lines 234 to 245:
The inversion technique used can fit the HVSR curve with multiple different models. This is a well-known issue in geophysical inversions, where different combinations of model parameters can produce similar fits to the observed data, leading to non-uniqueness in the solutions. It is often necessary to incorporate priori information or constraints on Vs values to mitigate this uncertainty. These constraints can come from independent measurements, such as borehole data, or from well-established geological and geophysical knowledge of the area under study. By integrating these additional constraints, we can narrow down the range of possible models and improve the reliability of the inversion results. In our analysis, we carefully considered the potential trade-offs and incorporated available constraints on Vs to enhance the robustness of our models. As we only have geological information, we seek to correlate the velocity models obtained with ranges of values consistent with the present lithology.

Minor issue: in some parts of the text, the authors use H/V; are they referring to HVSR or is this another term completely? Please consider only using 1 term to avoid confusions to the readers.
A. We modified and used the term HVSR only.

Recommendation: Revisions Required.
A. We deeply appreciate your time, effort and recommendations, which helped to improve the manuscript.

Reviewer B:
The authors have addressed all the required revisions, and the article is now ready for acceptance.
Recommendation: Accept Submission
A. We deeply appreciate your time, effort and recommendations, which helped to improve the manuscript.
