Authors' response to reviews of

Nondestructive testing of railway embankments by measuring multi-modal dispersion of surface waves induced by high-speed trains with linear geophone arrays

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Seismica

Dear Editor,

We would like to express our gratitude to you and the reviewer for your thoughtful consideration of our manuscript. We greatly appreciate the constructive comments provided, which have been useful in enhancing the quality of our work.

We have addressed each comment with the detailed responses provided below. We have made significant revisions to the manuscript based on these feedback. Changes to the text and figures in the revised manuscript are highlighted in a marked version.

Thank you once again for the opportunity to improve our manuscript.

Sincerely,

José Cunha Teixeira and co-authors

Review 2

A. Reviewer A:

RC A.1: RC.J. can the authors then reduce the claims that this work contributes to rail or high speed rail so the readers focus more on the signal contribution, and are not in the understanding that this work can contribute to railroad traffic or railroad infrastructure. It is good that the signal is induced by trains, but the 2nd sentence in the abstract uses the reliability of railway services as motivation of their work.

Alternatively, can the authors explain why it is so important that the signal is collected from high-speed trains, but not to include that they are able to contribute to the safety and maintenance becuase it reads as their study is related to such decisions.

AR A.1: By "RC.J." we understand that the reviewer means RC J.1 of the first review.

We changed the first sentence of the abstract to : The characterization, imaging, and monitoring of mechanical properties in engineered structures are crucial for ensuring safety and maintaining the reliability of operations and services.

In this previous comment the reviewer asked us to clarify "which characteristic of importance to the high speed lines that they are identifying". As a consequence, we developed the fact that we are able to characterize the mechanical properties of important thin shallow layers of the railway embankment. As explained in the draft, the nondestructive control of the railway embankment is essential to detect anomalies and plan faster and optimized maintenance of the railway embankment, contributing in keeping a fluid railroad traffic.

Collecting the signal from high-speed trains allows for a constant monitoring since we have a regular source of seismic waves, it is the purpose of the article. While our study is focused on signal processing and embankment monitoring, the connection to railway infrastructure safety and maintenance is intrinsic, as effective monitoring can reduce traffic interruptions and enhance the safety of the infrastructure. Since monitoring and repairing railway embankments means infrastructure maintenance and safety, and making it faster and more precise means less traffic interruptions.

Therefore, we are unclear about the reviewer's concerns. It may be that the reviewer's interests are more focused on train operations than on the condition of the embankments.

RC A.2: RC J.3: can the authors modify their paper to address this concern in the potential reader in the future? My main concern is that the paper should include this in the updated version.

AR A.2: The essence of the response is already in the draft.

Lines 93 and 94: However, many investigations face limitations due to operational constraints and access restrictions, making continuous or periodic characterizations of REs difficult to deploy with active sources.

Added at lines 112 to 114: Even though the active method may be advantageous for one-time characterization, as it does not require long-term train recordings or automated data collection, the passive method is better suited for continuous or repeated monitoring since it eliminates the need for field interventions.

Lines 389 to 392 : Essentially, if the objective is to achieve results similar to those obtained with active seismic, then using v = 2 is more suitable. However, when the goal is to obtain an inversion that is well-constrained at high frequencies or to monitor VR for several modes, a higher v can provide additional information.

Lines 423 to 426 : The comparison between DIs generated by passive-MASW, utilizing HST induced waves, and DIs generated by classical MASW, using a hammer as an active source, reveals a significant coherence between the two methods. The superposition of the DCs from both methods is nearly perfect, but it appears possible to identify more modes of propagation and to achieve better mode continuity using passive-MASW.

Lines 429 to 431 : We demonstrated that being able to correctly discern higher modes with the passive method, enabled a better characterization the capping layer with realistic thicknesses and mechanical properties, making it possible to effectively monitor this layer over time.

Moreover, we believe that a financial study is out of the scope of a science research paper.

RC A.3: RC J.4: can the authors modify their paper to address this concern in the potential reader in the future? My main concern is that the paper should include this in the updated version.

AR A.3: The essence of the response is already in the draft.

Lines 414 to 417 : Therefore, selecting the appropriate receiver spacing is crucial in optimizing the trade-off between economical considerations and the desired resolution of the SW velocity estimation. A baseline investigation should be performed before any permanent survey, to determine the best configuration.

RC A.4: RC J.5: can the authors modify their paper to address this concern in the potential reader in the future? My main concern is that the paper should include this in the updated version.

AR A.4: The original reviewer comment is out of the scope of the article since we want to characterize the embankment and not the train itself. During the first review, we have already added that train information has no utility for geophysical imaging since we study the wave propagation on the ground.

Lines 244 to 247: One must also note that, although the signal induced by each HST is unique, varying with factors such as speed, weight, and number of cars, it does not fundamentally alter the outcomes of the cross-correlation, since the Green's function only represents the medium response to a punctual excitation.

RC A.5: RC J.7: can the authors modify their paper to address this concern in the potential reader in the future? My main concern is that the paper should include this in the updated version.

AR A.5: The essence of the response is already in the draft.

Lines 244 to 247: One must also note that, although the signal induced by each HST is unique, varying with factors such as speed, weight, and number of cars, it does not fundamentally alter the outcomes of the cross-correlation, since the Green's function only represents the medium response to a punctual excitation.

Moreover, we already cited the publications studying the train's seismic signal. A deeper explanation would be out of the scope of this article.

RC A.6: RC J.8: can the authors modify their paper to address this concern in the potential reader in the future? My main concern is that the paper should include this in the updated version.

AR A.6: We do not record passing trains as we would do in a video. We only record the seismic signal generated by trains. Adding this information in the article would be off topic.

B. Reviewer B (the editor):

RC B.1: In your response letter you stated "the active method encounters operational constraints due to access restrictions, which the passive method does not face. But the use of passive seismic methods may not be as advantageous for a one-time characterization, as it is more suited for continuous or repeated monitoring". However, the introduction is not as detailed as this comment and I encourage you to be as explicit in the introduction as you have been in this response.

AR B.1: We added the following comment to the introduction.

Lines 112 to 114: Even though the active method may be advantageous for one-time characterization, as it does not require long-term train recordings or automated data collection, the passive method is better suited for continuous or repeated monitoring since it eliminates the need for field interventions.

RC B.2: When you respond "In fact you could use 3/4 of the geophones and still have a high quality dispersion image as shown in Figures 12 and 13.", do you mean "1/4th"?

AR B.2: We apologize for the typo in RC J.10, we indeed meant 1/4th.

RC B.3: Typo: line 299: phase-wrighted

AR B.3: Done, thank you.

RC B.4: Typo: Title: no dash (-) in "surface waves"

AR B.4: Done, thank you.

RC B.5: In response to RC K.15 you wrote "We added a legend indicating the color scheme and the quantity represented". This is appreciated, even though "Amplitude" is not a physical quantity. Please be more precise.

AR B.5: The phase shift transform results presented in the manuscript are normalised. The phase-shift transform works in a similar way to the 2D Fourier transform to obtain dispersion images (in which the maxima should correspond to the most energetic parts of the wavefield, i.e. the guided/surface waves), by directly transposing the seismogram, recorded in the time-distance domain, into the phase-velocity frequency domain.

The amplitudes of the dispersion images therefore depend on the amplitudes of the seismograms themselves, which are generally not calibrated. The geophones we use provide vertical particle displacement velocity values (at the point where their metal peak is planted) in mV, depending on the analogue gains used in the equipment. When the transformation is applied as recommended by Mokhtar et al. (1988) for example, the image amplitude will show values proportional to the number of geophones (usually, each trace is first normalised after correction for geometrical spreading and the slant stack cannot exceed the maximum number of geophones).

But in general, a final normalisation is carried out as indicated above and as it can be seen in the first applications to near-surface geophysics, where dispersion images are used in this way and are well known to the community (Mokhtar et al., 1988, Park et al., 1999).

We have also checked, for example, articles published in Seismica which do not give dimensions for the amplitude of frequency-time analyses or dispersion images and/or which do not give a quantity name or color bar. See e.g. Amri et al (2023), and Czarny et al (2023).

RC B.6: The added equation of O'Neill shows that the DC uncertainties are theoretical rather than estimated from the data. The uncertainties depend on the reference model, the length of the array, and the frequency. They are defined to decrease with increasing frequency. In this context I recommend that you clarify the sentence in line 353, "However, it is crucial to approach the results with caution, as the uncertainty is relatively higher at these low frequencies", by stating that these uncertainties are theoretical and can be reduced by increasing the length of the geophone array.

AR B.6: We added the following comment in lines 336 to 338 : Note that the uncertainty is higher at low velocities but that the global uncertainty across all frequencies can be reduced by increasing the length of the geophone array. This reflects the typical compromise that has to be done between investigation depth (usually captured by lower frequencies), resolution, and the 1D approximation required for the inversion of dispersion data. On the one hand, lengthening the array naturally improves the resolution of the DI. Since uncertainties are dependent on resolution, this helps reduce potential errors at low frequencies and thus enhances the interpretation of deeper layers. On the other hand, extending the array too much may introduce significant lateral variations, invalidating the 1D assumption. This type of error has been highlighted by O'Neill, 2003 and others in the field of near-surface geophysics. Furthermore, large uncertainties at low frequencies can help minimize the influence of near-offsets effects (O'Neill, 2003; Zywicki and Rix, 2005; Bodet et al., 2009).

However, the uncertainty will remain higher for low frequencies as stated in lines 348 to 349 : However, it is crucial to approach the results with caution, as the uncertainty is relatively higher at these low frequencies.

RC B.7: Your response to point RC K.20 is fair, but the point was not sufficiently clearly articulated. The concern was less with the width of the "black bundles" and more with the fact that the best-fit models are not centralized within the bundles and instead are off to one side of the black bundles. Please add a few words and/or additional illustration to explain this result.

AR B.7: We apologize if our previous answer was not clear. We added the following information in lines 496 to 503.

The observation that the best-fit models are not centralized within the "black bundles" is indeed attributed to the significant uncertainty associated with the deepest layer. This layer has limited influence on the dispersion curves, only at lower frequencies, resulting in a wider range of potential models that might have a good fitting. Consequently, the inversion process tends to yield best-fit solutions that are less centered within the bundles, as these models reflect the uncertainty rather than a more definitive central tendency. The results in terms of velocity models therefore show many equivalences at depth. However, inferred velocities are very consistent in shallow layers (thanks to the strong a priori information available on the geometry of the RE).

The best-fitting models are centered in velocity for the shallow layers, which means that the parameter space has been correctly explored, whereas this is not always the case for the half-space. However, for the inversion and/or interpretation of dispersion data collected in this context (see e.g. Bergamo et al., 2016; Pasquet and Bodet, 2017; Foti et al; 2018; Burzawa et al., 2023), much attention is paid to the shallow layer while the half-space is considered unreliable most of the time.

While we could have tested additional models for greater velocities in the substratum to potentially generate "black models" on the right side, it is important to note that the best-fit solutions would still likely be dispersed. The underlying uncertainty would persist, leading to similar variability in the best-fit models.

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Review 1

J. Reviewer J:

RC J.1: ***The main question that I would like that is addressed in the updated version of this paper is if the authors can explain which characteristic of importance to the high speed lines that they are identifying. The first sentence of the abstract motivates this study, but I am not sure if "characterizing" could be enhanced on how their measurement can be used to benefit the railroad or high speed rail operations. This will increase their academic effort beyond and more impactful with societal impact. It is also recommended that they comment in their conclusions the impact of their finding for other applications (for example, maintenance, safety, repair?).***

AR J.1: We would like to thank the reviewer for this comment. We understand the need to highlight the practical benefits of our characterization, particularly in the context of high-speed rail operations.

We added a final sentence on the abstract (lines 33 to 35: This method enabled a precise characterization of the shear-wave velocity of thin layers with critical importance to the mechanical stability of the railway embankment, highlighting its potential for enhancing the mechanical testing and monitoring of railway embankments.), as well as in Section 2 (lines 147 to 150 : These shallow, thin layers are crucial to the mechanical stability of the railway and require careful monitoring and control. No standard V_S values are defined universally for healthy embankments, as these values can vary significantly depending on local geological and engineering conditions. However a decrease over time of V_S for the capping layer is generally considered indicative of potential issues with the stiffness or stability of the embankments (Burzawa et al., 2023)).

We also completed the results in section 6.1 (lines 361 to 365 : However, for site B, even if M_3^{PWS2} and M_4^{PWS2} still coherent with the modeled DCs, we were not able to obtain a satisfying inverted model with realistic velocities for the second layer (see Table 2 and Appendix C for detailed inversion results), which corresponds to the capping layer (see Fig. 1d). This indicates that neither the active nor the passive approach using a squared PWS provided sufficient resolution to accurately characterize this critical thin layer.), and the discussion in Section 7.1 (lines 376 to 378 : However, for site B, the velocity model shows now more realistic velocities, allowing for better differentiation of the capping layer (see Table 3 and Appendix C for more detailed inversion results).

Finally, we added the outcome of this approach in the conclusion (lines 440 to 442 : We demonstrated that being able to correctly discern higher modes with the passive method, enabled a better characterization the capping layer with realistic thicknesses and mechanical properties, making it possible to effectively monitor this layer over time.).

RC J.2: ***Finally, can the authors comment on future work or the value to use a model that can validate the characterization so the active vs. passive MASW can be further validated.***

AR J.2: Following your advice, we added a comment in the conclusion (lines 450 to 456 : Future work could build on this by exploring the potential of passive MASW for continuous monitoring of critical infrastructure, by either employing geophones or distributed acoustic sensing (DAS) with optical fibers (Bardainne et al., 2023b). Such advancements could enable real-time assessment of the mechanical stability of railway embankments, improving safety and maintenance efficiency. Additionally, integrating dynamic cone penetrometer (DCP) data could further validate the characterization of subsurface layers, proving further the accuracy and reliability of this method (Burzawa et al., 2023)).

RC J.3: ***The feasibility of employing a passive-MASW approach is not well supported with data: what makes passive-MASW more feasible? Cost of installation? Difficulty? Safety? Time? It appears that passive-MASW approach should be more feasible, is it perhaps accuracy of the data?***

AR J.3: We understand this comment. However, we currently lack sufficient data on the industrial outcomes of this method, as it is still in the development stage. Further research and field applications are needed to fully assess its practical implications and potential benefits in an industrial context.

If we were to implement continuous monitoring, the cost of the passive method could be higher due to the additional requirements for electrical infrastructure and data management operations. However, as mentioned in the introduction, the active method encounters operational constraints due to access restrictions, which the passive method does not face. But the use of passive seismic methods may not be as advantageous for a one-time characterization, as it is more suited for continuous or repeated monitoring.

RC J.4: ***Why 96 geophones? Are they too many? At the end the authors acknowledge that based on their results they could have gone with a 4th , but can they be chosen ahead of time how many?***

AR J.4: We appreciate the reviewer's question regarding the use of 96 geophones. This number was initially chosen as part of an exploratory approach to assess the feasibility and effectiveness of our method. Following the example of studies already conducted with research rather than production in mind (see e.g. Burzawa et al., 2023), we have deployed the maximum amount of equipment available. However, we acknowledge that this number may be excessive for practical applications. Our results have shown that a smaller number of geophones, such as a 4th, can still achieve the desired results while being more cost-effective.

As discussed in Section 7.2, the choice of array length and spacing intervals depends on both the maximum investigation depth and minimum wavelength one intends to measure, which in turn are influenced by the source frequency bandwidth and the shear-wave velocities in the subsurface (Socco & Strobbia, 2004). Therefore, while a larger number of geophones provided detailed insights during our exploratory phase, we recommend establishing a baseline investigation first, to determine the best configuration before installing a permanent geophone array.

RC J.5: ***Can other type of sensors in the track collect information of the train and loads to enhance their method?***

AR J.5: We appreciate the reviewer's suggestion regarding the use of additional sensors to enhance our method. It is worth noting that the seismic signal generated by each train is unique, and research has explored this aspect (Lavoué et al., 2020; Rebert et al., 2024). However, the results of each cross-correlation primarily depend on the intrinsic ground propagation velocities between the receivers, meaning that while the uniqueness of each train's signal can provide valuable insights about its speed, length, and weight, it does not fundamentally alter the cross-correlation outcomes, and will not provide useful information for this application.

Nonetheless, other approaches using track geometry recording cars equipped with accelerometers have been employed by the railway industry to monitor track deformation (Berggen et al., 2014; Nielson et al., 2018). This method provides valuable an dcomplementary data on surface-level track displacement and is easier to implement. However, it does not offer insights into the underlying causes of deformation within the subsurface.

RC J.6: ***Is it possible to replace "cess" with less jargon? Since they used it once, it may be easier for readers to read a different name.***

AR J.6: Done.

RC J.7: ***Figure 2 and Table 1: Can the authors comment on the input information of the trains: speed, length of cars, possibly weight? Is there any effect on different properties of traffic?***

AR J.7: We appreciate the reviewer's interest in the input information of the trains, such as speed, length of cars, and weight. Research is indeed ongoing into how these factors can be recognized from the raw recorded signals and their impact on the analysis. For instance, studies are exploring how variations in train attributes might influence the recorded seismic signals and their interpretation (Lavoué et al., 2020; Rebert et al., 2024).

The speed of the train influences the frequency range of the generated signal. Indeed, the faster the train moves, the higher the frequencies that are generated. This is due to the fact that an impulsion is generated at each sleeper (Lavoué et al., 2020).

However, in the scope of this article, the focus is on using interferometry to analyze the propagation of seismic waves between sensors rather than on the specific attributes of the trains themselves. The interferometric approach effectively averages out these variables, allowing us to concentrate on the seismic wave propagation characteristics. This method inherently accommodates the variability in train attributes by focusing on the signal propagation, which provides a more generalized but robust analysis of the subsurface properties. We made it more clear in Section 4.1.

RC J.8: ***At 500 Hz, if the train is about 300 kph, about 83.3 mps, it is about 5 points per meter. Can the authors comment on the sampling rate missing any detail and if higher sampling rate would be appropriate for high-speed rail?***

AR J.8: It is important to clarify that our goal is not to record the passing train directly but rather to capture the seismic waves propagating through the soil that are generated when the train is not within the array. This approach focuses on analyzing the residual seismic waves before the trains passes or after the train has passed. As depicted in Figure 2b, there is no significant seismic signal observed after 150 Hz. Please refer to Rebert et al. (2024) and ARJ.7.

RC J.9: ***Is there any discussion on the geometry of the track and the three sites, i.e. is this a tangent track, and how far is any curve? Zero slope?***

AR J.9: There is no curvature at the sites and the slope is zero. We added this information in Section 2 (line 152 : It is important to note that the sites in question have no curvature and a zero slope.)

More details can be found in Burzawa et al. (2023) and Bodet (2019).

RC J.10: ***Is there any concern on any of the 96 geophones not functioning correctly? It would be a good discussion to know more about the different effects of installation of those and if there was any lesson learned from field deployment.***

AR J.10: In the event that a geophone is not functioning correctly, the impact on the overall data quality would be negligible. This is because the phase-shift transform method used to generate the dispersion images relies on the redundancy of data collected along the geophone line.

The redundancy inherent in our setup ensures that even with a few non-functional geophones, the majority of the array continues to provide sufficient data for accurate analysis. This robustness is one of the strengths of the classical MASW, as it allows for reliable data processing even when minor issues arise during field deployment. This is why it is a method of choice for industrial applications. We added this comment on Section 7.2.

In fact you could use 3/4 of the geophones and still have a high quality dispersion image as shown in Figures 12 and 13. In that case, however, one would better start being vigilant for any disfunctional geophones. The approach is robust, but a minimum number of sensors is still required (see e.g. (Socco & Strobbia, 2004).

RC J.11: ***The finding that they can use four times less geophones is great. A discussion on how this could be guaranteed in the future for any site would benefit this conclusion (I.e. is this applicable for any site and type of traffic, for example).***

AR J.11: Each campaign should follow the same methodology, but the number of geophone depends on the geological and hydro-geological context as mentioned in AR J.4.

We added a sentence in conclusion (lines 456 to 458: Our findings suggest that this method could be adapted and applied to a wide range of site types, including outside of railway environments, making it a versatile and light tool for subsurface characterization in various geological and traffic conditions.).

RC J.12: ***Can the authors add recommendations for future actions that can advance the characterization and monitoring of mechanical properties to enhance the significance of this research (this can be under conclusions, or supported by their literature review by acknowledging other monitoring approaches such as computer vision or non-contact sensors).***

AR J.12: We appreciate the reviewer’s suggestion. Indeed, other sensors are employed for monitoring railway embankments. For instance, trains equipped with georadars provide a global subsurface imaging (Li et al., 2023). Additionally, accelerometers attached to trains measure vertical acceleration and displacements, providing further insights into the performance and stability of the railway infrastructure (see AR J.5). However these methods are not in the scope of this article and do not give insights on the mechanical properties of the embankment.

In AR J.2 we also added the recommendation to integrate dynamic cone penetrometer (DCP) data to help advancing the characterization and monitoring of mechanical properties of the railway embankment.

K. Reviewer K (the editor):

RC K.1: ***This is an innovative paper, demonstrating that seismic methods on an active high-speed train track can help assess the rigidity of earthworks beneath the track, without needing a seismic source beyond the trains themselves. As behooves solid research, the paper goes beyond simply demonstrating an application and includes assessment of the impact of using different numbers of geophones, different powers in the phase-weighted stacking, applies the method to three different locations, and benchmarks all data against shot gathers from hammer shots. However, the paper stops short of providing actual insight into the obtained layer properties. Do the inferred values for density, P-, and S-velocity indicate the expected stiffnesses of earthworks? I understand that this paper's focus is the methodology, but a few sentences or paragraphs about the meaning of the findings are necessary.***

AR K.1: We appreciate the reviewer’s positive comments on the innovative aspects of our paper and the thorough evaluation of different methodological approaches. We understand the importance of providing insight into the inferred layer properties.

Additional information was added to the discussion and conclusion, please refer to AR J.J. However, it is important to clarify that standard values for density, P-wave velocity, and S-wave velocity specific to healthy earthworks are not universally defined. These values are contextual to the particular sites studied and should be interpreted within the framework of the local geological and engineering conditions.

However, the method we have developed is particularly valuable for ongoing monitoring. By using this method over time, it is possible to track changes in these properties, such as decreases in S-wave velocity, which could signal emerging issues or deterioration in the earthworks (Burzawa et al., 2023).

We added this information in Section 2.

RC K.2: ***There are many acronyms in this paper and they are all introduced in different places. I propose that you make a table or list for all acronyms and their meanings, so they're easy to look up.***

AR K.2: Done

RC K.3: ***The title would better orient a Seismica audience to the paper's content if it included "rail" or "train" and if it did not contain the adjective "passive" in front of "measurement", given that it does not exactly apply to how the measurement is made and is not appropriate for how the waves are generated (high-speed trains). For example "Using linear geophone arrays to test railway earthworks by measuring dispersion of multi-modal surface waves generated by high-speed trains".***

AR K.3: We would like to thank the reviewer for this comment. We initially hesitated to emphasize the railway context in the title, fearing it might limit the appeal of the paper. However, we now recognize that a more precise title will improve the paper's relevance and accessibility to the intended audience.

We changed the title to: Nondestructive testing of railway embankments by measuring multi-modal dispersion of surface-waves induced by high-speed trains with linear geophone arrays.

AR K.4: ***l.17 Do you mean "active-SOURCE seismic technique"?***

AR K.4: Done.

RC K.5: ***l.21 Do you mean "linear arrays of GEOPHONES"?***

AR K.5: Done

RC K.6. ***l.26 Do you mean "traditional MASW with an active hammer source"?***

AR K.6: Done.

RC K.7: ***Please conclude the abstract by summarizing your findings.***

AR K.7: We added a final sentence on the abstract (lines 32 to 34 : This method enabled a precise characterization of thin shallow layers with critical importance to the mechanical stability of railway embankments, highlighting its potential for enhancing the mechanical control of railway embankment.).

RC K.8: l.38-42 it is not necessary to use articles before the listed methods. In other words, you may remove several "the" from this sentence.

AR K.8: Thank you for pointing this out.

RC K.9: ***l.86 remove -ly from previous.***

AR K.9: Done.

RC K.10: ***In the caption for Fig 2 -- I would call the time in the blue and orange boxes "segments", not lapses. A lapse is the time between segments of interest, such as the time between the blue and orange boxes.***

AR K.10: Thank you, done.

RC K.11: ***50 Hz spikes: Please elaborate how the geophones generate noise spikes at 50 Hz (and overtones) -- Is it unique to how they are deployed, the specific brand of geophones, all geophones, etc.?***

AR K.11: We appreciate the reviewer's question regarding the 50 Hz spikes observed in the data.

French high-speed railway is electrified with 25 kV, 50 Hz current. Since, the running rails are used as the return conductor for the traction current, the 50 Hz spikes, along with their overtones, seen in the geophone measurements are attributed to stray current in the soil.

This has been corrected in the caption of Figure 2 (French HSLs are electrified with a 25 kV, 50 Hz alternating current. Therefore, the peaks observed at harmonics of 50 Hz correspond to stray currents originating from the traction system, which travel along the rails and through the soil, serving as the return conductor.).

RC K.12: ***l.196-198 "This assumption ... after another.": While source-receiver alignment is necessary for your study that uses strong sources, such alignment is not necessary for the Green's function to appear from cross-correlation of diffuse wave fields.***

AR K.12: Thank you for your comment, which shows that we haven't been clear enough in this section. We updated the sentence (lines 233 and 234: In a one-dimensional, non-diffuse wavefield scenario, this approximation relies on the precise alignment of the geophones and the source, as well as the sequential propagation of waves from the source through each geophone.).

RC K.13: ***At some point after eqn (5) you need to say something about S(x,t) approximating a delta function, such that C_AB ~ G_AB*.**

AR K.13: Thank you for the observation. We agree that it is important to clarify that.

RC K.14: ***l.208-211: Time domain normalization is necessary for helping wave fields to not only be spatially diffuse, but also comparable in power. Given that you are not using a diffuse wave field but rather a strong source that is aligned with the receivers, it is expected, rather than being a surprise, that time domain normalization is not needed.***

AR K.14: Thank you for the comment. It has been added to the main text (lines 264 to 265: This is expected, given that we use a strong source in close proximity to our geophones.).

RC K.15: ***Fig 6 needs a legend for the colors used. It seems as if the colors change in value with frequency ("normalized by frequency") so they are likely not the same between plots either. At a minimum we need to know what quantity is colored.***

AR K.15: Thank you for pointing this out. The normalization was performed by frequency to enhance the visibility of higher modes. Consequently, the amplitude in the dispersion images is scaled from 0 to 1. We added a legend indicating the color scheme and the quantity represented.

RC K.16: ***l.276-277 This sentence doesn't tell a reader anything if they don't know what role "guided compression waves" play in either gather. Please either elaborate or delete the sentence.***

AR K.16: We appreciate the reviewer's observation. To maintain clarity and avoid potential confusion for readers unfamiliar with the role of "guided compression waves," we have decided to delete the sentence.

RC K.17: ***l.287 Again, more details are needed on error calculation. A reader should not have to first find and read O'Neill (2003). Moreover, the method of error calculation is crucial as the calculated errors are later used to all but disregard the low-frequency measurements.***

AR K.17: The equation was added.

RC K.18: ***l.358-367 (in Conclusions) This is essentially an abstract, not conclusions. You may start this section at line 368. That said, the first part of the actual abstract reads a bit like an introduction. I suggest moving the abstract text from conclusions to abstract and introductory text from the abstract to the introduction.***

AR K.18: Done.

RC K.19: ***l. 424 ration --> ratio***

AR K.19: Done.

RC K.20: ***Figs 15 and 16 e) and f) show a large number of reasonably fit models (dark grey) well away from the best fit ones. This is very different from a)-d) which show the best fit lines within the dark grey "bundles". I feel this needs additional explanation.***

AR K.20: Thank you for highlighting this point . The large number of reasonably fit models (dark grey) in Figs. 15 and 16 (e) and (f) compared to the tighter clustering seen in a)-d) is due to the dispersion curves providing less information at lower frequencies. This reduced frequency range makes it more challenging for the inversion process to converge to a minimal misfit at greater depths. Consequently, a wider range of models, including those farther from the best fit, were explored.

We included this explanation in the revised manuscript to clarify the observed differences (lines 510 to 512 : Please note that due to the DCs providing less information at lower frequencies for sites B and C, the inversion process converged less quickly to a minimal misfit at greater depths. This variability is evident in Figures 15e,f and 16e,f, where the grey shading indicates a wider range of models far from the best fits.).

RC K.21 : ***The Nebieridze reference was very hard to find. The reference should be updated with a DOI, the correct publication year, and the paper title in French.***

AR K.21: Thank you for the feedback. We added the missing DOI.

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