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Multichannel Analysis of Surface Waves with a Passive Roadside approach at a tailings dam

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RESUMO: O método sísmico MASW (*Multichannel Analysis of Surface Waves*) é um procedimento geofísico para obtenção do perfil de velocidade das ondas de cisalhamento (ondas S) nas camadas estratigráficas em subsuperfície, que está relacionado ao módulo de rigidez. Nesse procedimento, a escolha da fonte sísmica é fundamental para obtenção de resultados de alta qualidade. Fontes ativas (por exemplo, marretas) geram sinais de frequências mais altas, fornecendo informações sobre camadas rasas. Em contraste, fontes passivas (por exemplo, ruído ambiente) geram ondas de frequências mais baixas, oferecendo detalhes sobre camadas profundas. Idealmente, a combinação de dados ativos e passivos pode produzir uma resposta abrangente à pesquisa. Porém, na prática, existem dificuldades logísticas em trabalhar com fontes passivas. A abordagem denominada *Passive Roadside* é uma alternativa que utiliza o tráfego de veículos (fonte ativa) para induzir sinais de frequências intermediárias. Usando essa estratégia, apresentamos um estudo de caso no qual realizamos a investigação MASW em uma barragem de rejeitos no Brasil, utilizando um veículo passando por uma lombada portátil para gerar as ondas sísmicas, o que é incomum na indústria de mineração. No entanto, a estratégia apresentou resultados superiores em comparação com os dados obtidos por fonte ativa (marreta), que é a prática padrão. Consequentemente, concluímos que a abordagem *Passive Roadside* é aconselhável em levantamentos MASW sempre que possível.

PALAVRAS-CHAVE: MASW, *Passive Roadside*, Ondas S, Barragem de Rejeito.

ABSTRACT: The MASW (Multichannel Analysis of Surface Waves) seismic method is a geophysical procedure to obtain the velocity profile of shear waves (S waves) in the subsurface stratigraphical layers, which is related to the modulus of rigidity. The choice of the seismic source is critical to obtain high-quality results. Active sources (e.g. sledgehammers) generate higher frequency signals, providing insights into shallow layers. In contrast, passive sources (e.g. ambient noise) generate lower frequency waves, offering details about deep layers. Ideally, combining active and passive data can yield a comprehensive survey response. However, in practice, there are logistical difficulties working with passive sources. The so-called Passive Roadside is an alternative approach that uses vehicle traffic (active source) to induce intermediate-frequency signals. Using this approach, we conduct an MASW survey at a tailings dam in Brazil, employing a vehicle passing over a portable speed bump to generate seismic waves, which is uncommon in the mining industry. However, the approach delivered superior results compared to the active source (sledgehammer) data, which is the standard practice. Consequently, we conclude that the Passive Roadside approach in MASW surveys is advisable whenever possible.

KEYWORDS: MASW, Passive Roadside, S waves, Tailings Dam.

1 INTRODUCTION

The MASW (Multichannel Analysis of Surface Waves) method is based on the dispersive investigation of surface waves (Rayleigh and Love). It results in (1D) velocity profiles of shear waves (S waves), directly related to the modulus of rigidity and correlatable to SPT (Standard Penetration Test) tests (FATEHNIA; HAYDEN; LANDSCHOOT, 2015). One can integrate the profiles to generate sections (2D) or 3D models. This type of study began in seismology (EWING; JARDETZKY; PRESS, 1957) and, in engineering, applications gained importance with the SASW (Spectral Analysis of Surface Waves) method (NAZARIAN; STOKOE; HUDSON, 1983) that uses only a pair of sensors. With the introduction of a methodology for using multiple sensors, the method became known as MASW and achieved popularity through the work of Park, Miller and Xia (1999).

To generate seismic waves, we can use different types of sources, active and passive. Active sources are those over which we have control, in contrast to the passive ones. Examples of active sources are: sledgehammer, soil compactor, weight dropper, seismic gun, and vibroseis, among others. In general, active sources generate waves with higher frequencies, with information from the shallower subsurface. The primary examples of passive sources are ambient noise and earthquakes. Human activities are the predominant cause of seismic ambient noise, but the interaction between seas and continents is also an origin. Passive sources generate mainly lower-frequency waves, bringing information from the deeper subsurface. Ideally, the combined use of active and passive data helps to achieve better results (PARK et al., 2007; EIKMEIER; PRADO; TAIOLI, 2016). However, whatever the type of source MASW has the characteristic of being a shallow investigation method, working well for the first tens of meters of depth (FOTI et al., 2017).

The seismic array geometry needs to be chosen according to the source. Linear arrays are the correct choice for active sources, and two-dimensional arrays for passive sources (EIKMEIER, 2018) since it is necessary to calculate the wavefront direction. Several two-dimensional arrays have been proposed over the years. However, two-dimensional arrays cause logistical problems due to space limitations to install the sensors. In this sense, the ideal is an active source that generates low and high frequencies, which is the proposal of the so-called Passive Roadside strategy.

Passive Roadside (PARK; MILLER, 2008) is a data acquisition technique that uses vehicle traffic to generate seismic waves. Ideally, the vehicle must pass through some depression or elevation on the road to promote the generation of waves in a specific location. Thus, we have control of the source and its location concerning the seismic array, allowing the use of a linear array. Although Passive Roadside is an active source, its advantage over traditional active sources is that it generally generates lower-frequency waves, which is the reason for its name.

This work presents part of a seismic data acquisition survey to obtain S-wave velocity profiles in a tailings dam in Brazil. We used a sledgehammer and the Passive Roadside strategy as seismic sources. The objective is to evaluate the contribution of using Passive Roadside compared to the data obtained with the sledgehammer since Passive Roadside is not standard in the mining industry.

The results show that the Passive Roadside data streamlined the interpretation of the dispersion curves of the fundamental mode and first higher mode. Additionally, the strategy brought a slight increase in information in the low frequencies of both modes. Since Passive Roadside is not common in the mining industry, this work shows its potential to improve the results in conditions like this.

Below, we present some methodological aspects of the study, followed by the results and conclusions.

2 METHODS

The objective of the geophysical survey presented partially in this document was to obtain S-wave velocity profiles at different points of a tailings dam in Brazil. The data was processed using the MASW method. Figure 1 shows the study area of the dam, highlighting the geometry of the relevant data acquisition elements. As our focus is to present the potential use of the Passive Roadside technique, we show only the data from one of the MASW acquisition lines.

The acquisition array was composed of 4.5 Hz, with 5 m spacing. As an active seismic source, we used a sledgehammer. In addition, we used a vehicle passing over a portable speed bump (Passive Roadside) aligned with the array line as a seismic source.

The sledgehammer shots were carried out in 8 different positions: 5, 10, 12.5, and 15 m to the first geophone (direct shots), and the same to the last geophone (reverse shots). Direct and reverse shots are important to validate the application of the method in the study area (FOTI et al., 2017). When the interpretations of the dispersion curves for direct and reverse shots have significant differences, the subsurface may have a pronounced lateral heterogeneity, which is a premise violation for applying the method. On the other hand, different shooting positions on the same side of the array stand to evaluate possible near and far field effects (STROBBIA, 2003). In addition, different shooting positions can help the interpretation of the dispersion curves.

For the Passive Roadside, we chose two positions to place the portable speed bump. The first position was 23.2 m from the first geophone (direct shots), and the second 151.5 m from the last geophone (reverse shots). The asymmetry between the positions occurred due to logistical limitations of the study area. The dashed white lines (Figure 1) show where the vehicle could pass.

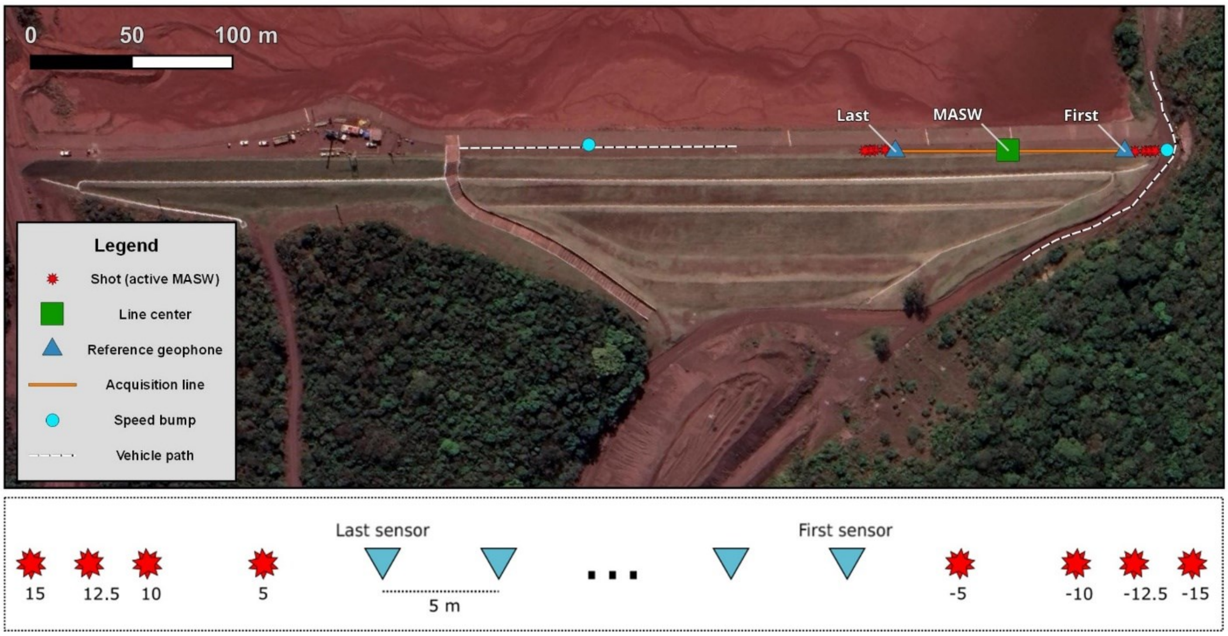

Figure 1. Study area (tailings dam) and seismic array.

Figure 2 presents three photos of the data acquisition. The photo on the left shows the acquisition line over the dam, the one in the center shows the use of the sledgehammer as an active source, and the photo on the right shows the vehicle and the portable speed bump used for the Passive Roadside.

The MASW data processing consists of two main steps. In the first, via a two-dimensional Fourier transform, we obtain the phase velocity spectrum, in which we interpret the dispersion curves based on the energy maxima. However, not all energy maxima are related to the dispersion curves, and several modes may be present. It makes the curve interpretation step one of the most sensitive in the method. The second and last step is the inversion of the interpreted curves to obtain the S-wave velocity profile. Before the inversion, it is necessary to set up a search space, also called parameter space (SAMBRIDGE, 1999; WATHELET, 2008). Based on prior information from the study area, we set a three-layer parameter space, as shown in Table 1.

Figure 2. Photo of the acquisition line, use of the sledgehammer as an active source and of the vehicle and the speed bumps used for the Passive Roadside acquisition strategy.

Table 1. Parameter space (search space) for the inversion process. V_P consists of the P wave (compressional wave) propagation velocity, and V_S of the S wave (shear wave) velocity.

Layer ID	Layer thickness (m)	V_P (m/s)	V_S (m/s)	density (kg/m^3)	Poisson
1	4 – 15	330 – 5000	200 – 1000	1200 – 2800	0.20 – 0.49
2	8 – 25	330 – 5000	200 – 1000	1200 – 2800	0.20 – 0.49
3	Half-space	490 – 5000	300 – 1500	1200 – 2800	0.20 – 0.49

3 RESULTS

Figure 3 presents the phase velocity spectra of the sledgehammer data. Each image shows the shot information and the dispersion curve interpretation. It is important to highlight that the interpretation of the curves was reached by analyzing all spectra together. For example, if we only had Figure 3c, the interpretation of the curve would be doubtful. It shows the importance of working with different shots, direct and reverse, at distinct positions.

The Passive Roadside data are shown in Figure 4. We notice that the dispersion curve of the fundamental mode (lower curve) is more easily interpreted in the spectra of images (a), (b), and (c) compared to any of the spectra in Figure 3 related to the sledgehammer. The same occurs for the first higher mode (upper curve). In Figure 4 (d) and (e) it is identified more clearly than in any spectrum from Figure 3.

Bringing together all the interpreted curves in the same graph (Figure 5a), we see that the interpretations are consistent considering the interpretation error. The blue curves are related to the sledgehammer source, and the red ones to Passive Roadside. The solid curves are the fundamental mode, and the dashed are the first higher mode of the dispersion curve. The regions highlighted by black ellipses show how the Passive Roadside data introduced a slight increase of information in the low frequency. Although, in this case, there was only a small contribution from the Passive Roadside data at low frequencies, the contribution may be higher in other cases. Considering all the curves related to their modes, the next step was to reach the mean curves, shown in Figure 5b.

The last processing step was to perform the joint inversion of the mean curves. We ran 100 independent inversions to ensure the robustness of the result, starting from different initial models in the parameter space. One way of presenting the results is to display all 100 results together on the same graph with the misfit values. However, as this is not the focus here, we chose to present only the best fit among the 100.

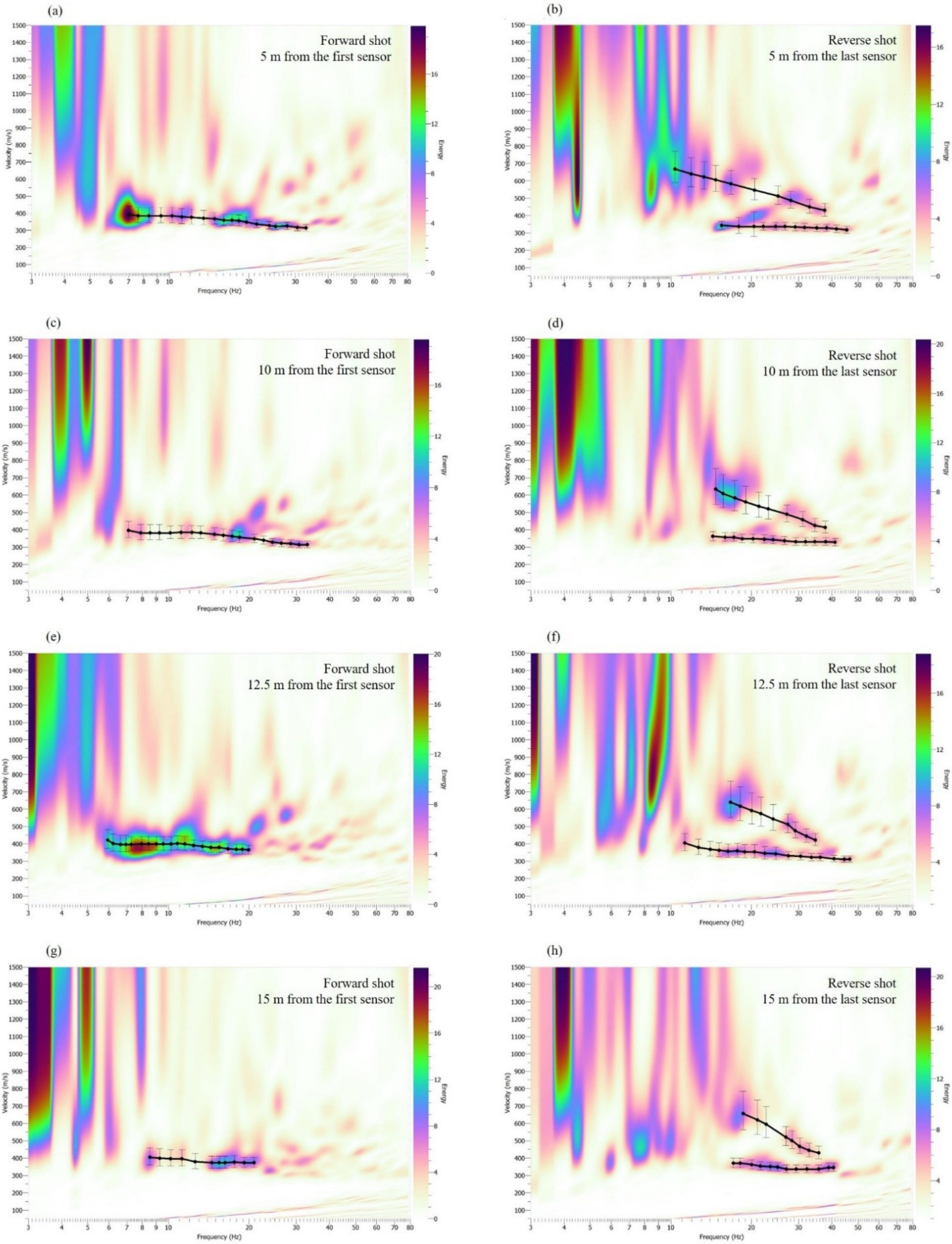

Figure 3. Active source phase velocity spectra. Each image shows the interpretation of the dispersion curves and the shot position.

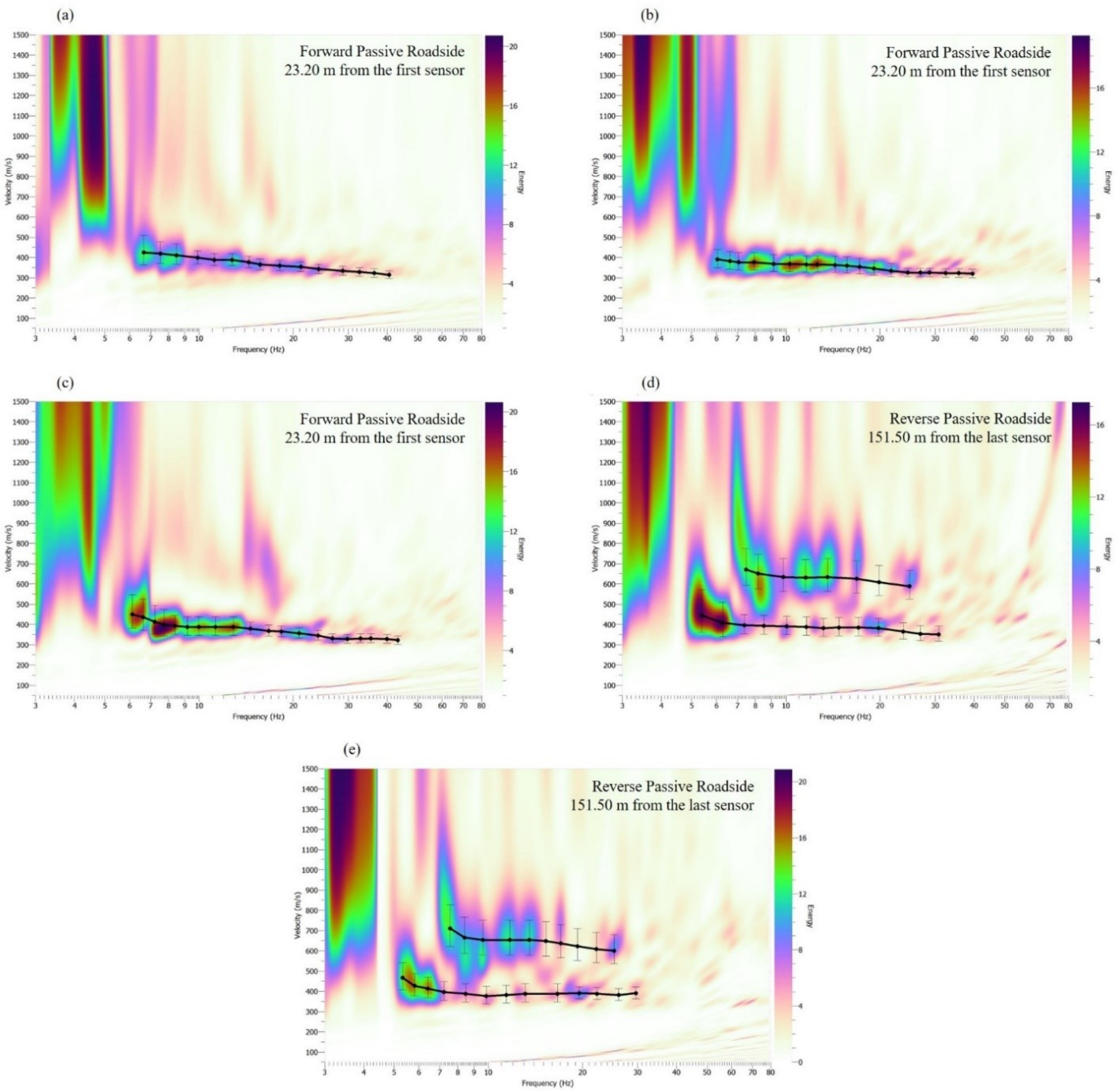

Figure 4. Passive Roadside phase velocity spectra. Each image shows the interpretation of the dispersion curves and the shot position.

Figure 6 (a) and (b) show in black the dispersion curves interpretation, respectively the fundamental and first higher mode, and in green, the inverted curves. We can see that the inverted curves are within the interpretative error. In (c) is shown the S wave velocity profile.

Regarding the Passive Roadside, there are two main conclusions: (i) the phase velocity spectra made the interpretation of the dispersion curves easier for both modes of the curves; (ii) there was a little increase of information in the low frequencies of the curves. We cannot generalize the result presented here by itself. However, other works corroborate such conclusions (PARK; MILLER, 2008). Therefore, we conclude that the Passive Roadside acquisition technique can be useful and should be used whenever field logistics allow it.

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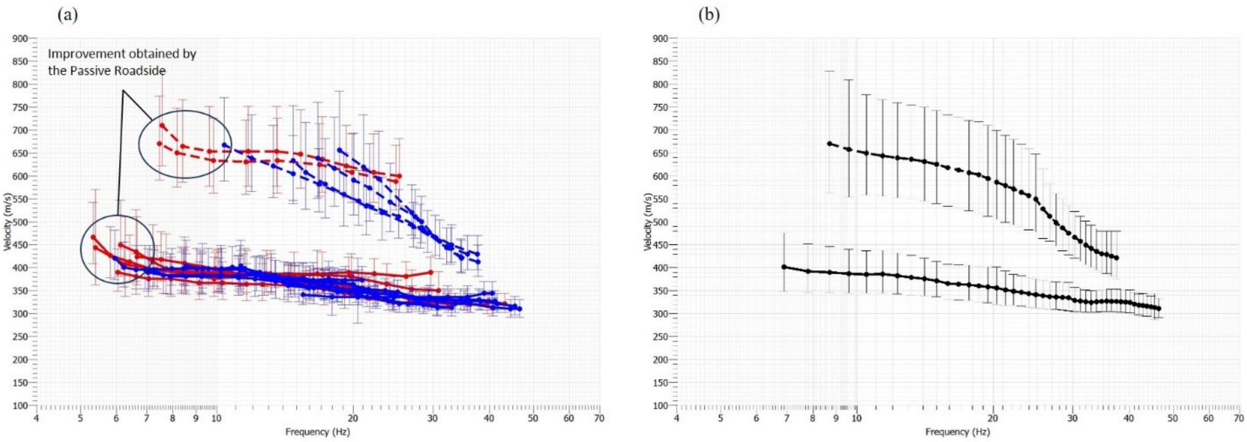

Figure 5. Interpreted dispersion curves. (a) in blue are the curves obtained by the active source, and in red by the Passive Roadside. The solid curves stand for the fundamental mode, and the dashed ones for the first higher mode. (b) the solid curve is the average of the fundamental mode, and the dashed curve is the average of the first higher mode.

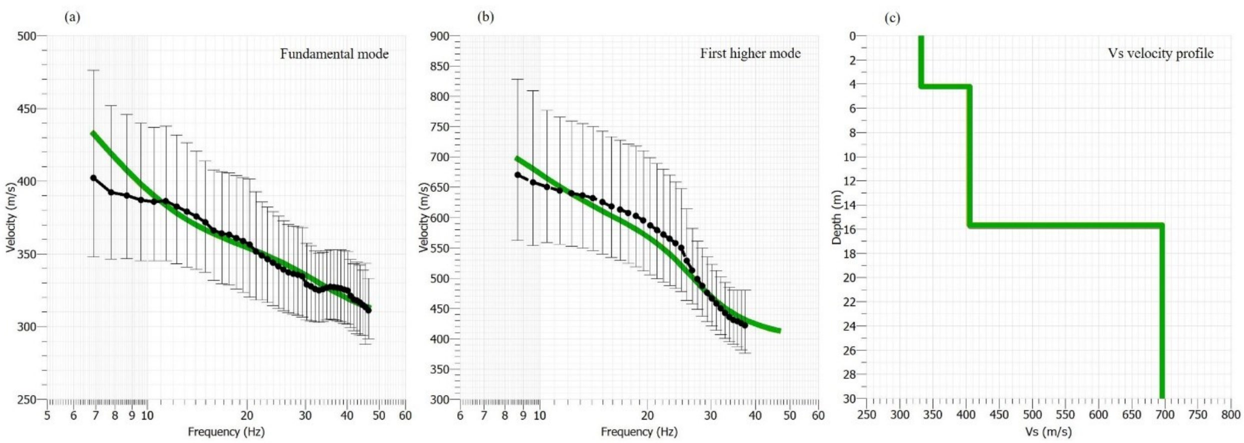

Figure 6. Results. In black the interpreted dispersion curves, and in green the best result (best fit) of 100 independent inversions.

4 CONCLUSIONS

This work presented part of a seismic data acquisition survey to obtain S-wave velocity profiles in a tailings dam in Brazil. We acquired the data with a linear seismic array and two seismic sources: a sledgehammer and vehicle traffic over a portable speed bump (Passive Roadside). The Passive Roadside strategy is uncommon in the mining industry, and therefore the objective of this work was to present how Passive Roadside data can provide benefits to the traditionally sledgehammer data. We showed that the frequency-phase velocity spectra of the Passive Roadside allowed a clearer interpretation of the fundamental and the first higher mode of the dispersion curves. Furthermore, there was a little increase in information in the low frequencies of the curves. Therefore, based on this study and other works, we conclude that the Passive Roadside strategy should be considered whenever possible as a complement to the standard acquisitions carried out with active sources, such as a sledgehammer.

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