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# A new method to estimate the true vibroseis source wavelet

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**A new method to estimate the true vibroseis source wavelet**

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## Introduction

In vibroseis data acquisition, the source wavelet is typically assumed to be the autocorrelation of the pilot sweep. However, significant discrepancies can exist between the pilot sweep of the vibrator and the signal transmitted into the formation, due to factors such as the mechanical system of the vibrator, the coupling of the baseplate with the ground, and the near-surface structure.The autocorrelation results of the pilot sweep do not accurately represent the true source wavelet.

In pursuit of a more accurate vibroseis source wavelet, numerous scholars have undertaken relevant research and proposed a variety of methods and perspectives. Building on these previous studies, the present paper introduces a new method for estimating the transmitted signal from the near-vibrator geophone. It suggests using this signal as a substitute for the pilot sweep in correlation analyses, with the aim of obtaining a more precise representation of the true vibroseis source wavelet. This approach can significantly enhance the quality of seismic data.

## Near-field Signal

Miller and Pursey demonstrated in 1954 that, in the case of an isotropic-homogeneous-elastic half-space, there is a proportional relationship between the far-field particle displacement and the surface stress, provided the latter is uniformly applied across a small disc. This correlation between force and far-field particle displacement underpins the theoretical foundation of the vibroseis method. The statement suggests that the force exerted by the vibrator on the ground is directly proportional to the displacement of particles in the far field, provided the ground is an isotropic-homogeneous-elastic body and the size of the vibrator baseplate is significantly smaller than the wavelengths of interest.

Wei and Phillips (2012) introduced a sophisticated model that incorporates the coupling of the baseplate with the ground, in addition to a representation of the earth underlying the vibrator baseplate, as illustrated in Figure 1. This model adeptly simulates the flexural vibration of the baseplate, concurrently accounting for its coupling with the ground. Based on Wei's (2015) research, the application of a mass-spring-damper model is viable not only for the vibrator but also for its corresponding ground model.

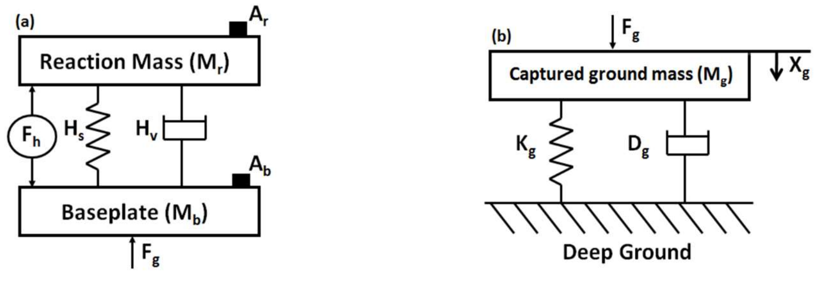


***Figure 1*** *The vibrator mechanical model (a) and the 'captured' or coupled ground model (b), after Wei (2012). In this diagram, Mr and Mb represent the mass of the reaction mass and the mass of the baseplate respectively. Mg is the ground mass seen by the baseplate when the baseplate is coupled with the earth surface. Ar and Ab are the accelerations of the reaction mass and the baseplate respectively. Fg is the vibrator ground force. Kg and Dg are the ground stiffness and damper.*

Based on Miller and Pursey's theory and the previously mentioned model by Wei, the velocity of the ground $V_g(s)$ at a certain position S near the vibrator can be inferred, as shown in equation 1:

$$V_g(s) = \left(\frac{s}{M_g s^2 + D_g s + K_g}\right) F_g \quad (1)$$

Equation 1 states that the velocity of the ground near the vibrator is caused by the vibrator ground force filtered by the associated ground mass system. It is proportional to the true ground force which is transmitted down into the ground.

In that case the signal recorded by the velocity-type near-field geophone must also be proportional to the force transmitted down into the ground. However, the near-field signal also includes other components, such as noise, harmonics, etc. (see Figure 2).

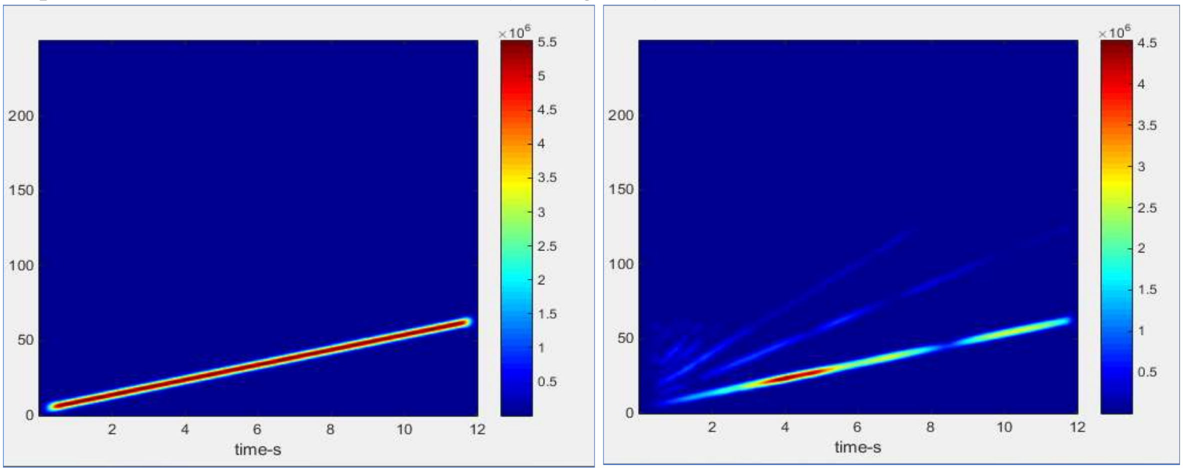


***Figure 2:*** *The time-frequency spectrum of the pilot sweep (left) and the time-frequency spectrum of the near-field signal recorded by a velocity-type geophone (right).*

The ground force signal is the result of the mechanical and hydraulic system of the vibrator and the pilot sweep. It has the same frequency content as the pilot sweep. Therefore, using the frequency characteristics of the pilot sweep as a constraint, the force transmitted downwards can be extracted from the signal recorded by a geophone nearby the vibrator (the near-field geophone). By using the result for the correlation, a more accurate estimate of the wavelet propagating through the formation can be obtained.

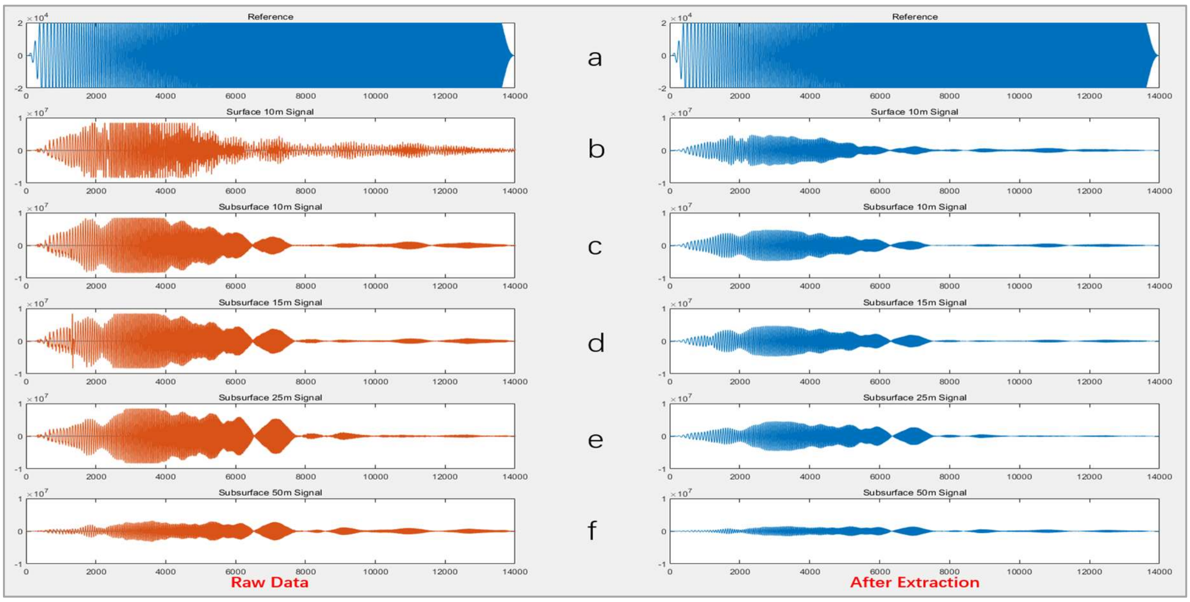


***Figure 3:*** *Pilot sweep (a) and signals recorded: at the surface (b); at 10m depth (c); at 15m depth (d); at 25m depth (e); and at 50m depth (f). The signals on the left are raw data, and the signals on the right are extracted from raw data constrained by the time-frequency spectrum of the pilot sweep.*

Tests were conducted to verify the reliability of this new method. A conventional velocity-type geophone was buried at 20 cm depth at a distance of 10 m from the vibrator. In addition, 3C geophones were deployed at depths of 10, 15, 25 and 50 m in a well at 1 meter distance from the vibrator. Figure 3 shows the pilot sweep, as well as the vertical components of the signal recorded by surface and underground geophones after constraining them with the pilot sweep.

Figure 3 shows a high similarity between signals obtained at the surface and at 10, 15, 25 and 50 m depth. This shows that it is possible to obtain more accurate signals transmitted down into the earth from a near-vibrator geophone then from conventional methods.

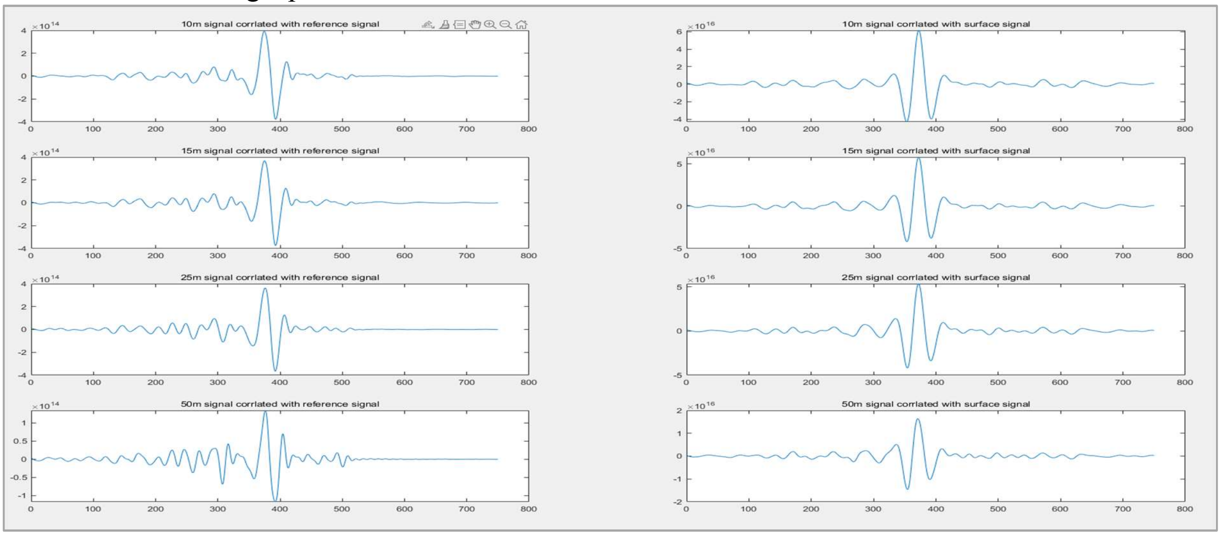


***Figure 4:*** *Wavelets obtained by correlating signals recorded at different depths with the pilot sweep (left) and the signal extracted from surface recorded signal (right).*

The wavelets in Figure 4 indicate that the wavelet obtained by correlating with the pilot sweep is inferior to that obtained by correlating with the signal extracted from near-field surface recorded signal.

**Experimental tests and data examples**

In order to further verify the application of this method to seismic data, a comparison was made between a correlation using the pilot sweep and the result obtained by this new method.

Figure 6 compares shot-gathers obtained by correlation with the pilot sweep and shot-gathers obtained by correlation with the signal obtained using the new method. We can see that the surface wave is weaker with the new method and the reflected signal is clearer and more continuous. The resolution is better, while the frequency band of single-shot data is broader.

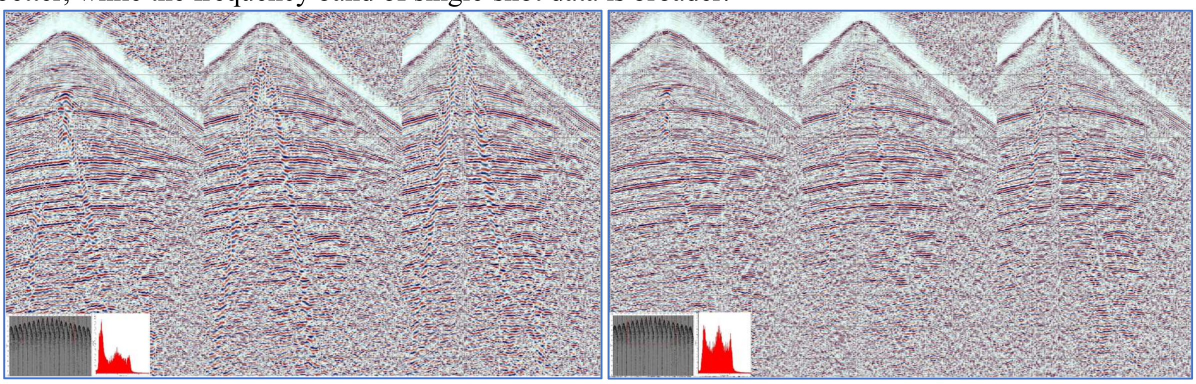

***Figure 5*** *Shot gathers for which measurements were correlated with the pilot sweep (left) and shot gathers for which measurements were correlated using the new method (right).*

Figure 6 compares a seismic section obtained through correlation with the pilot sweep with the same section obtained using the new method. With the new method the resolution has improved and the geological structure is clearer. The stratigraphic pinchout (shown in the red ellipse) has become much clearer.

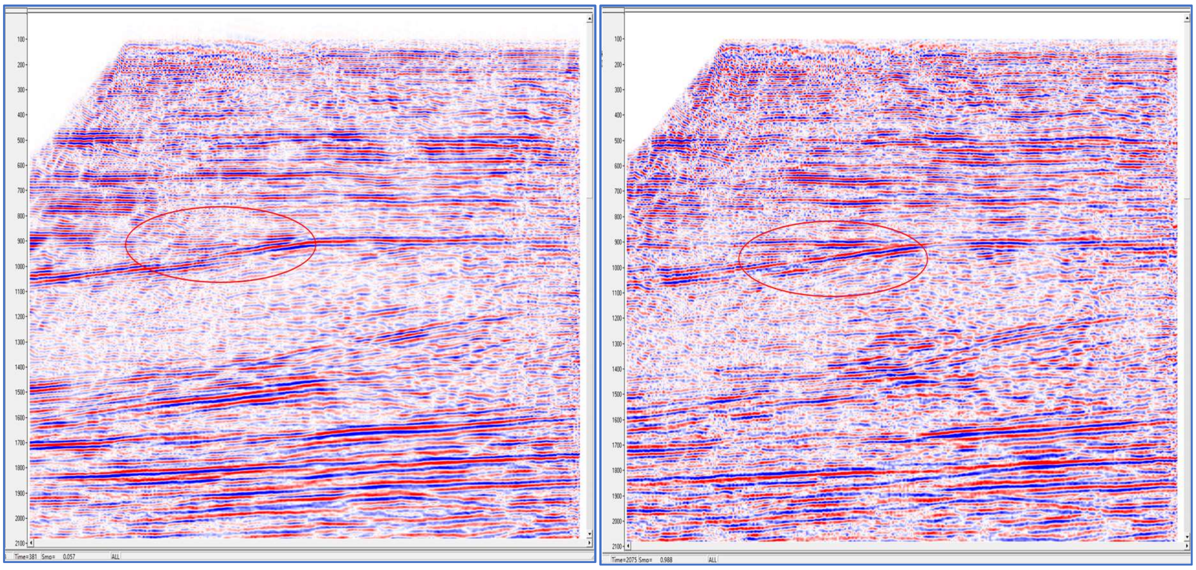

***Figure 6*** *Brute stack, after correlation with the pilot sweep (left), and after correlation using the signal derived by using the new method (right).*

**Conclusions**

By using the pilot sweep for correlation of vibroseis recordings, it is implicitly assumed that the pilot sweep is an accurate representation of the effective ground force transmitted into the earth by the vibrator. There may in practice be significant differences however, due to factors such as the vibrator mechanism, the coupling between the baseplate and the ground, and the near surface geology. Retrieving and using a more accurate measurement of the signal transmitted into the earth should be expected to deliver better data quality.

This paper shows how downgoing waves can be more accurately recovered using a near-field geophone (nearby the vibrator), and how using this signal for correlation instead of the pilot sweep improves the quality of the seismic data.

**References**


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