Analysis of multicomponent seismic data recorded with a new hydraulic thumper source

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ABSTRACT

This paper examines the performance of the new multicomponent weight drop source built by CREWES. The source was tested on the University of Calgary campus to generate P-waves and S-waves, and to provide a detailed velocity structure of the near-surface. The source generates SH-waves by orienting the source mast ±45 degrees from the vertical and subtracting records generated with opposite source polarities. This cancels P-waves and constructively adds SH waves.

The data collected show that the uppermost layer of the shallow subsurface has a P-wave velocity of 840 m/s and a SH-velocity of 215 m/s, yielding Vp/Vs of 3.90.

INTRODUCTION

The idea of generating seismic waves using a weight drop source is not particularly new. However, as technology advances and higher resolution and repeatability are demanded, most equipment needs to perform better than once before. Shallow seismic surveys using refraction methods were conducted in the Foothills Hospital area on the west side of the University of Calgary campus. The survey was carried out by placing two lines of receivers. The first line was composed of three component receivers and had a length of 390m with 5m spacing between the receivers. The second line was used for new fiber optics receivers that were acquired by the university. This paper will analyze the performance of the source thumper for the generation of P and S-waves using the 3 component receivers. In this particular survey we used 3 different weight drop forces, 300psi, 600 psi and 900psi. This paper analyzes only the 900 psi data because higher force sources show P and S wave propagation more clearly.

Survey Set-up

The survey consisted of 3 different shot locations. The beginning of the line was indicated with the flag number 101, also known as the zero mark. The thumper performed 3 sets of 10 hits for each location. After each set of hits, the recorder automatically generated a stack file for the previous 10 hits. On the first set the thumper was perpendicular with respect to the surface. This helped with the creation of the P-waves. For the second set the thumper was set to 45 degrees and was oriented in a transversal orientation with respect to the line. The third set was similar to the second set arrangement: the angle was also 45 degrees and the direction was also transversely with respect to the line, but in the opposite direction. Since the set for shots 2 and 3 were exactly opposite to each other, the plus and minus technique could be used.

Plus and Minus Technique

The plus and minus technique is used for the S-wave analysis. This technique allows for the elimination of P-waves from the S-waves recorders and for the enhancement of the S-waves. This is very useful when interpreting the S-wave, since these waves have a much lower velocity than P-waves. Depending of the source used, it could be very difficult to interpret the velocities for S-waves without this technique. In our survey, our S-waves were generated with the source oriented to the west and the east direction. Subtracting the two sets of shear wave data produces an addition of waves since the two sets of S-waves have opposite polarity and subtraction of data with different polarities results in an addition. On the contrary, the P-waves have the same direction and the same polarity, and results in subtraction.

Data Processing

In order to apply the plus and minus technique, a series of processes were conducted. First, an exponential gain of 1.5 was applied to our data. Due to attenuation losses from earth responses into the signals, some corrections needed to be made to process the data in an effective way. Another process that was applied to our data was the application of an automatic gain control (AGC). For this process, a small window of 200ms was used. The depth of investigation on this paper was limited to the first second of recorded data, and with the application of the AGC, the amplitudes in our investigation were all balanced; this helped with the interpretation of the data and the subtraction process.

Shot Gathers

Due to some source static inconsistencies during the collection of the data, only the files that showed the best signal to noise ratios were considered for the analysis.

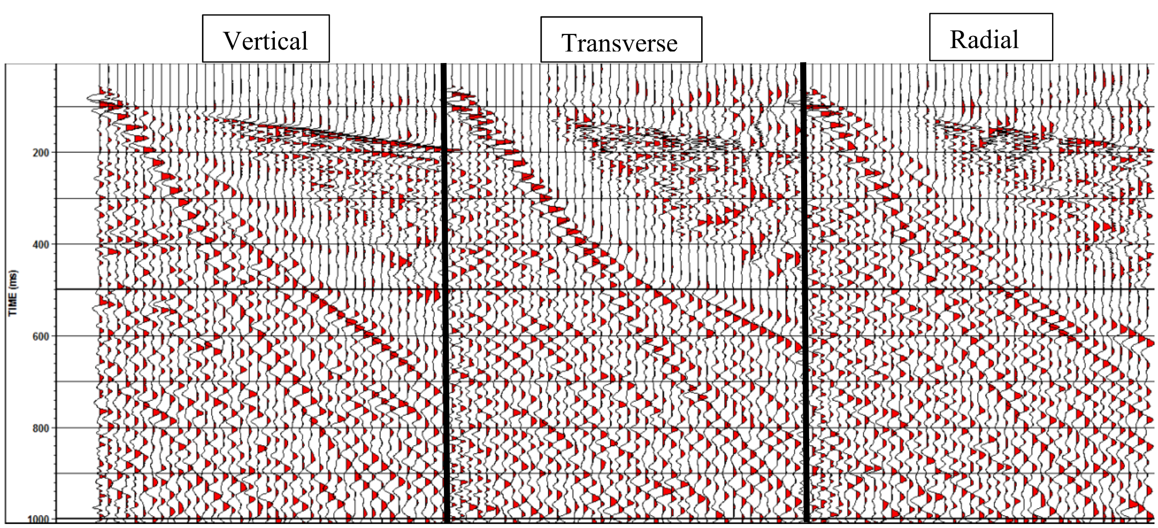

FIG. 1. Shot gather at location 101.

Figure 1 shows data taken at shot location 101. As noted, the seismic gathers are divided into 3 areas. Three component geophones provide the data in the following order, the P-wave component in the first section and the S-wave data is shown in the transverse and the radial component in sections 2 and 3 respectively. This particular result shows very clearly both types of waves. The velocities were estimated by calculating the slopes of the refraction events. For the first layer, the S-wave velocity was 200 m/s and for layer 2 and 3 the velocities were 350 and 550m/s respectively. The thumper source appears to acquire consistent data for shallow layers.

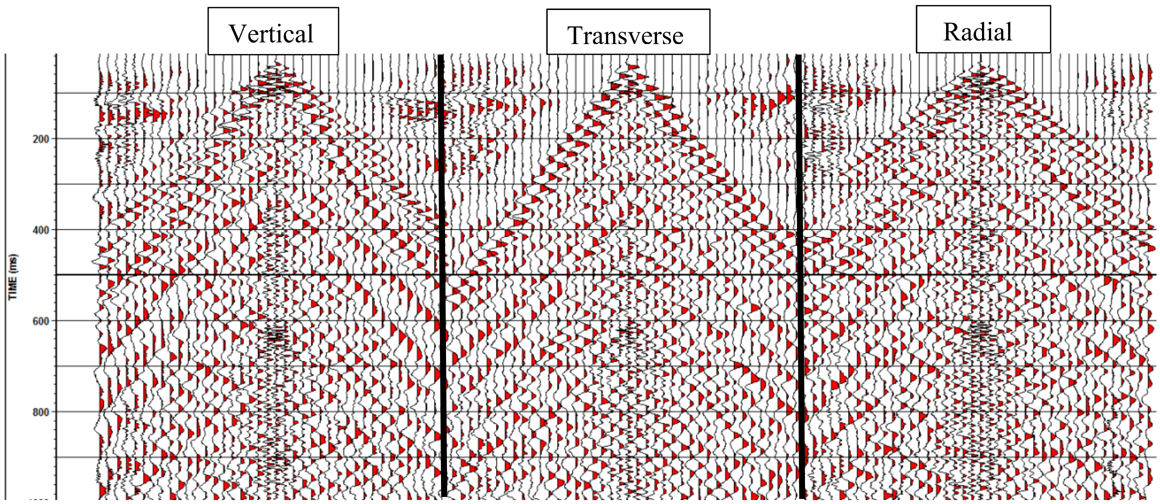

FIG. 2. Shot gather at location 121.

Figure 2 shows the shot gather at the location 121. As in the previous figure, this gather clearly identifies P and S-wave refracted arrivals. As shown, there is only a limited number of traces for each component. For each component there are only 40 traces. Therefore, only the shallowest layers for this particular area could be estimated. In this particular location the S-wave velocity was 195 m/s.

In Figure 3, the slopes are a little less steep than at the other two locations. Therefore, the interpretation resulted in higher velocities at this particular area. Three distinct reflectors were observed. The S-waves velocities were 200, 350 and 750 m/s for layer 1, 2 and 3, respectively. The trigger and recorder were perfectly synchronized.

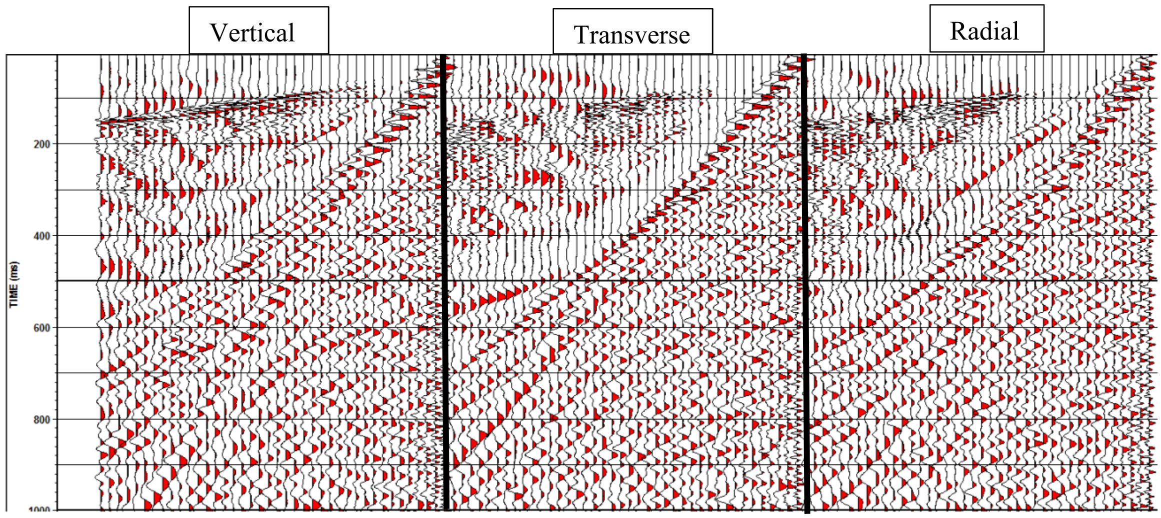

FIG. 3. Shot gather at location 140.

In order to accurately interpret a velocity model, both P-waves and S-waves have to be computed. P-waves play a very important role in these models, and P-waves will have much higher velocities than S-waves in shallow layers.

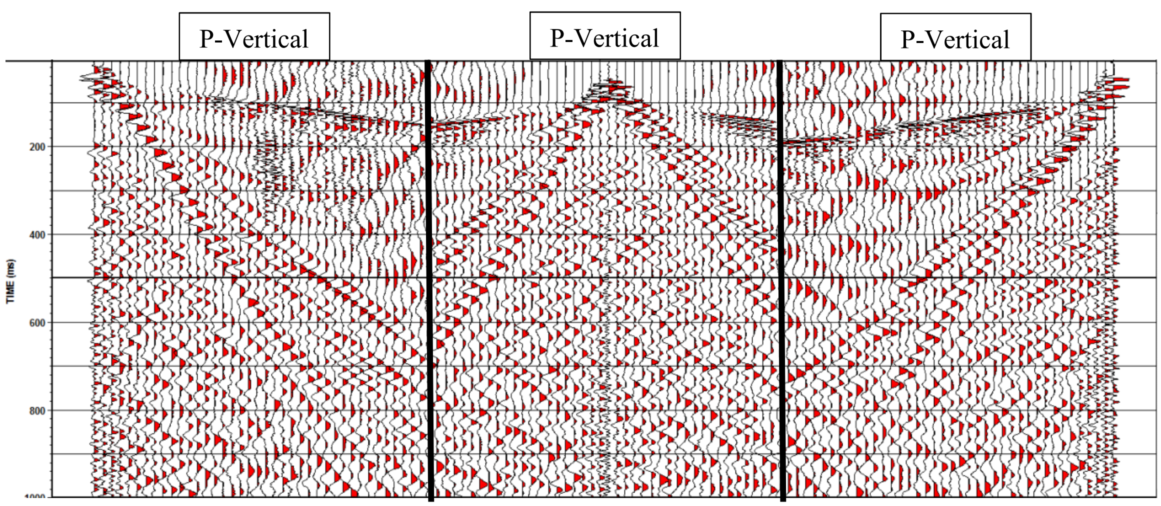

FIG. 4. Vertical-component gathers at locations 101, 121 and 140.

Figure 4 shows vertical-component data at the 3 shot locations. Only the P-wave components are present in this figure. Despite the low signal to noise ratio in these gathers, an interpretation for the velocities was still possible. At location 101, only two layers were distinguished, with velocities of 770 m/s and 1810 m/s for both layer 1 and 2. At location 121, the noise was considerably more noticeable, allowing only one refractor to be interpreted, resulting in a velocity of 790m/s. On the last location two layer velocities were computed. The first layer velocity was 950 m/s and the second layer velocity was 1900 m/s.

Following the refraction velocity analysis, the thicknesses of the near-surface layers was determined from the intercept times or cross-over distances. Two layers were determined from the P-wave data and 3 from the S-wave data. The velocity and depth structure and Vp/Vs values were determined, and these are shown in Figure 5.

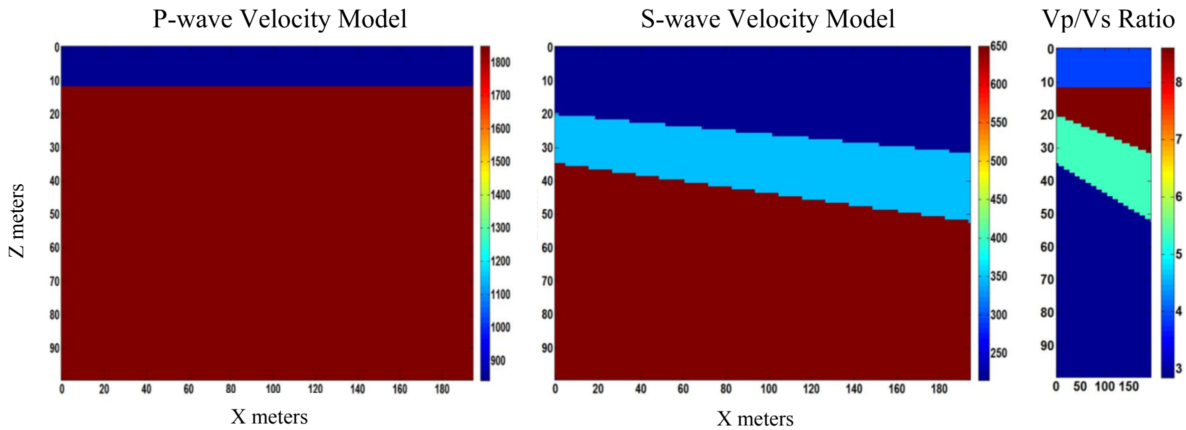

FIG. 5. Velocity models and Vp/Vs ratio.

Figure 5 shows velocity models for both P-waves and S-waves and the deduced Vp/Vs values with depth. The average velocities analyzed at the 3 shot locations were input into this model. The averages velocities for the P velocity model were 840m/s for layer 1 and 1850m/s for the second layer. As for the S model, average velocities were 215, 350 and 650m/s for layers 1, 2 and 3 respectively. Vp/Vs appear consistent with the numbers we were expecting: higher around the shallow surfaces and decreasing with depth. The data acquired with this thumper seem reasonable for what is expected of shallow beds in terms of velocities and Vp/Vs.

Shot Gathers with the plus and minus

The following figures demonstrate the gathers difference before and after the application of the plus-minus technique. In theory, the amplitude of the S-waves should increase after this technique is applied, and P-wave energy on the horizontal component gathers should be suppressed.

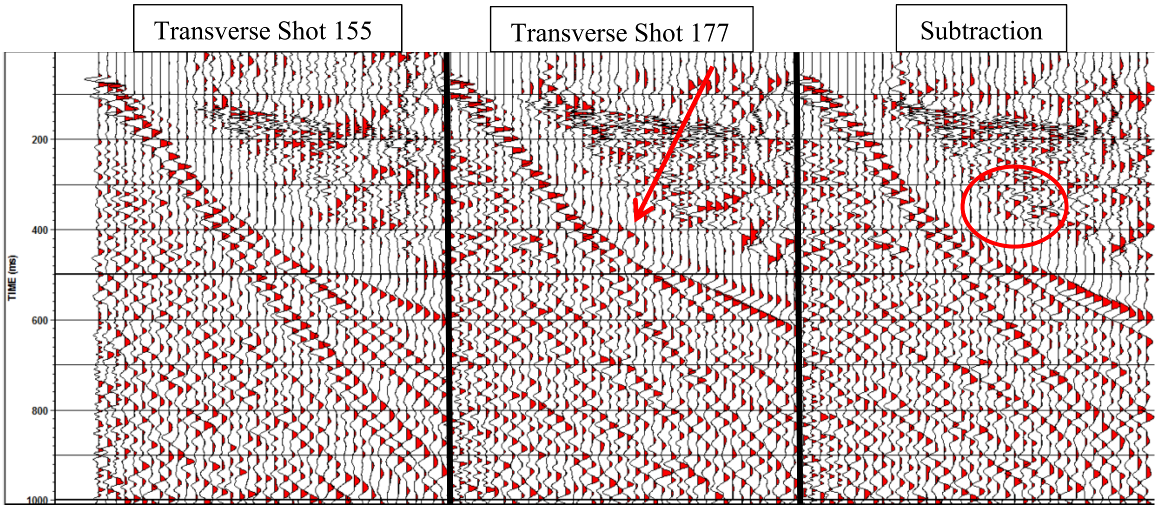

FIG. 6. Shot gathers at 101 and subtraction result.

Figure 6 shows the transverse components of data for shots at 155 and 177. The section on the right shows the subtraction of these two records. The events of the refractor are better defined after this subtraction. This technique works well when using larger offsets, but a small improvement was still observed in this particular dataset.

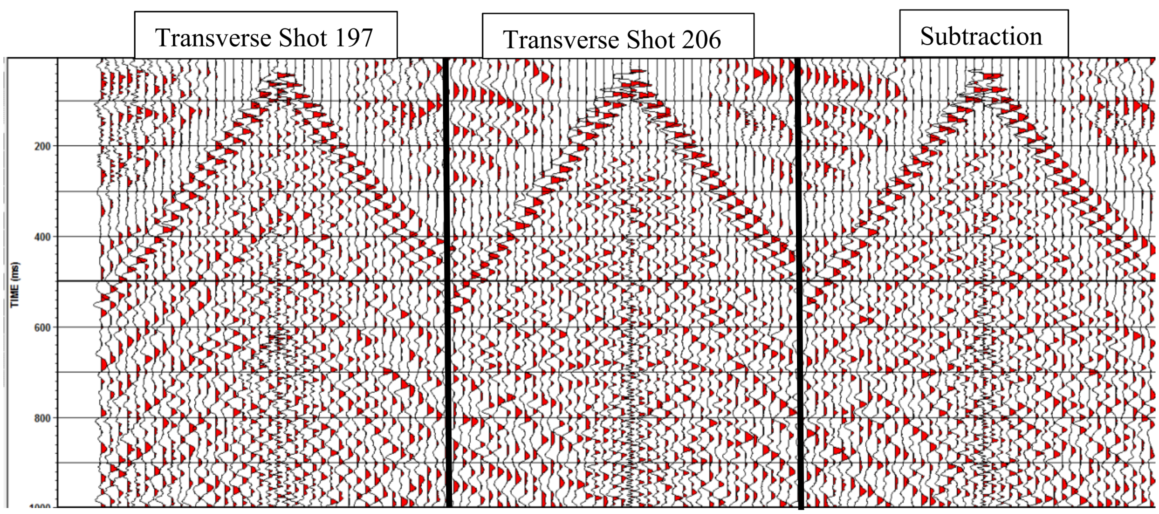

FIG. 7. Shot gathers at 121 and subtraction result.

In Figure 7, the data resolution is good and the subtraction process again enhances the S-wave energy. It is interesting to note that there is almost no leakage of P-wave energy onto the horizontal components.

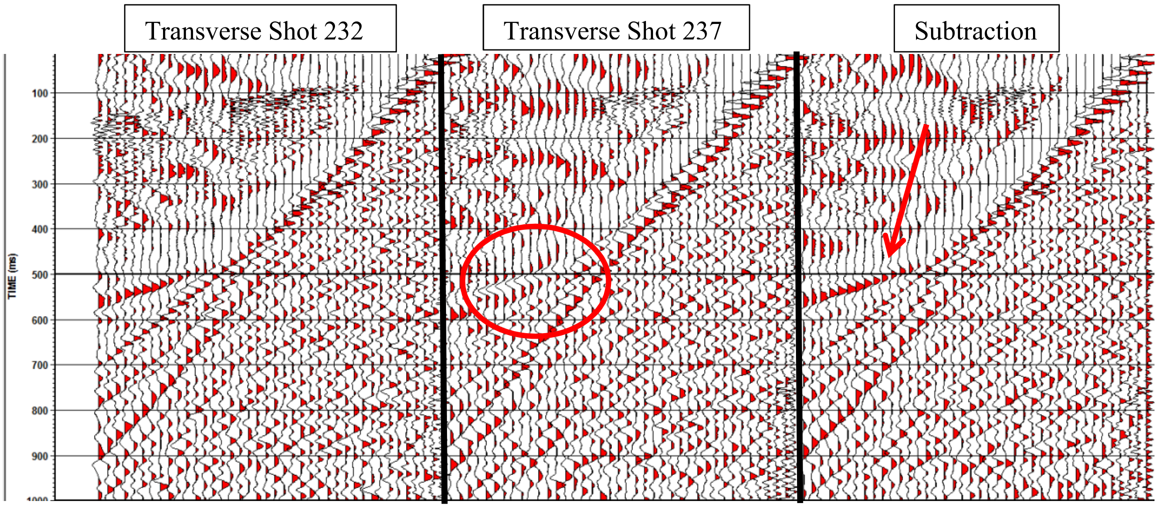

FIG. 8. Shot gathers at 140 and subtraction result

Figure 8 shows some of the improvements from using the plus and minus method. The refractor becomes more visible at the 140 location.

DISCUSSION

The performance of this new source thumper provided very clear gathers despite the noise encountered. The development of an accurately controllable weight drop source with very high impact energy has led to recording seismic data which is of better quality than traditional dynamite, for example, and considerably cheaper. The flexibility of the source means that source locations and source intensity can be changed dynamically, leading to better custom seismic solutions to local problems.

There is still more work that needs to be done in terms of accurately determining the repeatability factor of the weight intensity when it hits the ground, in order to have a measurement of the consistency of the equipment.

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