Data Stacking for Downhole Seismic Testing

For Downhole Seisic Testing (DST) data stacking refers to generating multiple seismic traces at a specific depth and source location, which are then averaged. The motivation for doing this is the desire to minimize additive measurement error and to increase the Signal-to-Noise Ratio (SNR). However, data stacking will only increase the SNR if the additive noise is a random process as is illustrated below.

The seismic source wave is represented by a Berlage Wave as shown in Figure 1. Very low correlated Gauss-Markov measurement noise (variance: 0.4; time constant: 0.000001 ms) is then added 12 different times to the source wave, which creates Figure 2 where all 12 resulting traces are shown. Figure 3 again shows all these traces, but now after a bandpass filter of 30Hz to 130Hz was applied. As is shown in Figure 4, the peaks align very well, which means that a simple bandpass filter is sufficient to remove the minimally correlated Gauss-Markov noise. Figure 5 illustrates the outcome of stacking the 12 traces, and while the SNR of the stacked trace is better than that of each unfiltered trace, the SNRs of the filtered traces shown in Figure 2 are significantly higher.

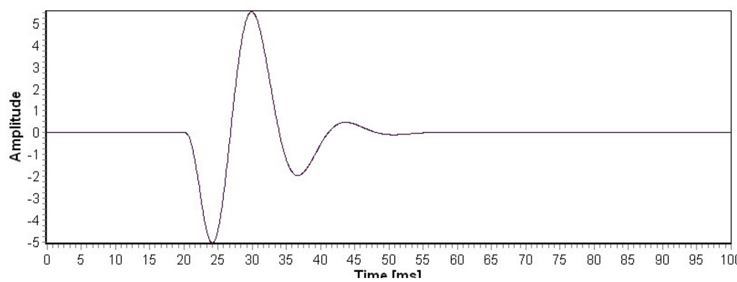

Figure 1. Berlage Source Wave (frequency: 70 Hz; phase: 100^{o}; attenuation: 300)

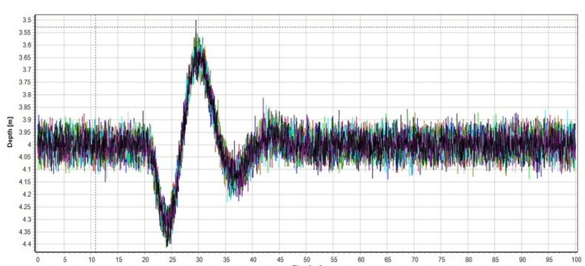

Figure 2. Illustration of 12 seismic traces with very low correlated Gauss-Marov measurement noise

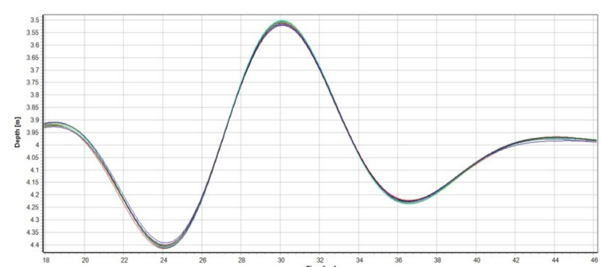

Figure 3. Twelve seismograms illustrated in Fig. 2 with a bandpass filter of 30 Hz to 130 Hz applied

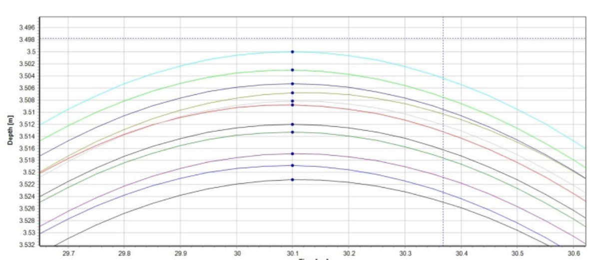

Figure 4. Alignment of peaks of filtered traces illustrated in Fig. 3.

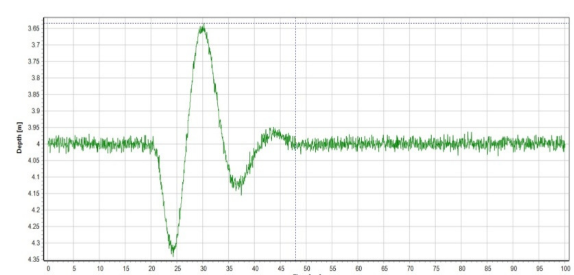

Figure 5. The resulting trace when stacking the 12 traces illustrated in Fig. 2

In reality measurement noise is seldom as minimally correlated as implied in this first example. To demonstrate this Gauss-Markov correlated measurement noise (variance: 10; time constant: 1.6 ms) is added 10 times to the same Berlage source wave. The resulting traces are shown together in Figure 6 and again in Figure 7 after applying the same bandpass filter as before (30 Hz to 130 Hz). It is important to note that the dominant troughs and peaks align within a time window of approximately 0.3 ms. In Figure 8 three different stacked traces are shown: one for all ten traces in Figure 7 (blue line), another for the first four traces (red line), and a third for traces 2 and 8 (black line). It is clear that the resulting trace depends on which the individual traces are included in the stack, but what is more interesting is the outcome after applying a bandpass filter of 30 Hz to 130 Hz to these three stacked traces: despite all the efforts to gather multiple traces so they can be stacked, the dominant troughs and peaks still align within a time window of approximately 0.3 ms, just as when single traces are used for the analysis.

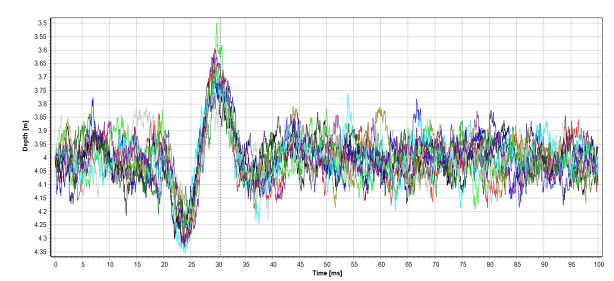

Figure 6. Illustration of 10 seismic traces with correlated Gauss-Markov measurement noise

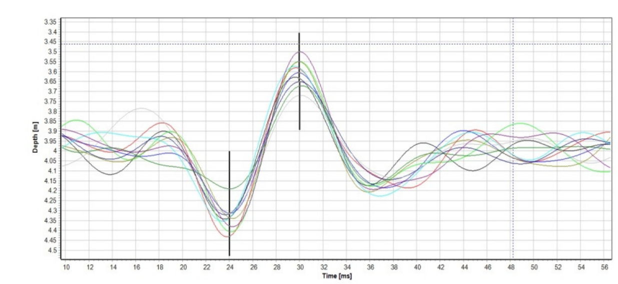

Figure 7. Ten seismograms illustrated in Fig. 6 with a bandpass filter of 30 Hz to 130 Hz applied

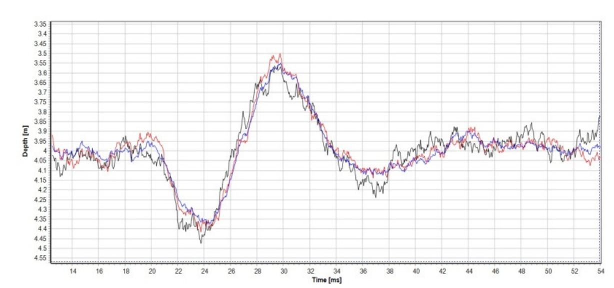

Figure 8. Stacked trace for all ten traces (blue trace) of Fig. 7, first four traces of Fig. 7 (red trace), and traces 2 and 8 of Fig. 7 (black trace).

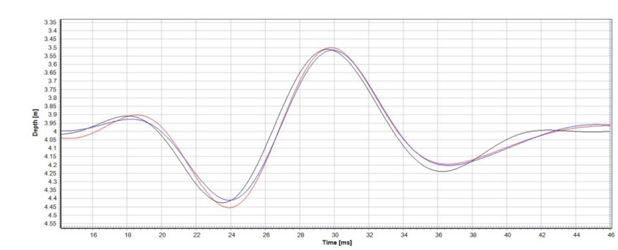

Figure 9. Stack traces of Fig. 8 after application of a 30 Hz to 130 Hz bandpass filter.

The previous two test bed simulations clearly demonstrate that the advantages of data stacking to improve upon the SNR of DST seismic traces with additive random measurement noise is questionable at best compared to simple filtering the seismic traces.

This conclusion becomes even more evident in case of non random measurement noise (due to say near-field waves or reflections). In Figure 10 the same Berlage Source Wave used for Figure 1 is shown with an arrival time of 20 ms, a first cross-over of approximately 26.7 ms and second cross-over of approximately 33.3 ms. A realistic reflections series is illustrated in Figure 11 with a direct wave at 20 ms and reflections at 25 ms and 29 ms. Combining the source wave with the reflection series gives the seismogram illlustrated in Figure 12. As is illustrated in Fig. 12 the first cross-over has been shifted to 29.8 ms (for a 3 ms time shift) and the second cross-over has been time shifted to 39.3 ms (for a 6 ms time shift).

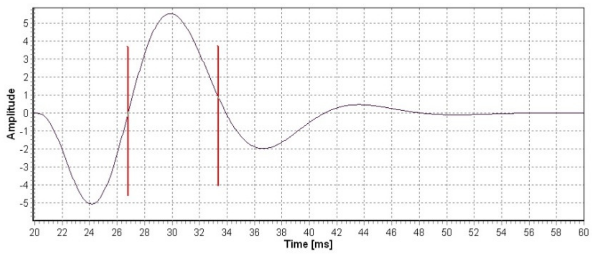

Figure 10. Berlage source wave of Fig. 1 with the first cross-over and the second cross-over marked

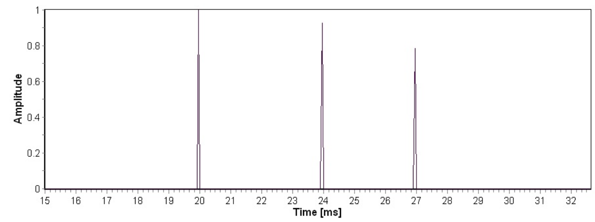

Figure 11. Reflection series illustrating direct wave at 20ms and reflections at 24ms and 27ms.

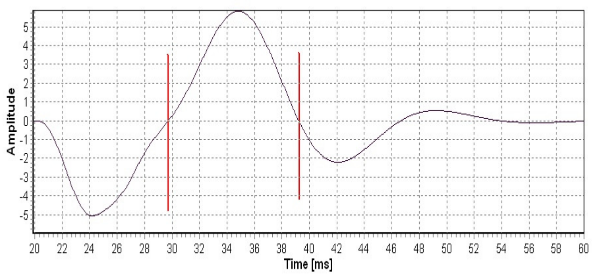

Figure 12. Seismogram obtained by combining the Berlage source wave of Fig. 10 with the reflections series illustrated in Fig. 11, and with the first and second cross-over marked

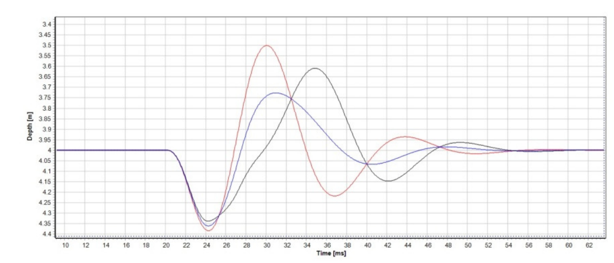

Figure 13. Berlage source wave of Fig. 1 (red trace). Seismogram of Fig 12 (black trace), and the a trace generated by stacking these two traces (blue trace).

But more importantly Figure 13, where the Berlage source wave is combined with a data trace affected by reflections, shows that data stacking can be very disadvantagesous when stacking an errant source wave when there is non-random measurement noise.

In conclusion data stacking is a time consuming effort, that will only improve the SNR of traces with random measurement noise, which can as easily be achieved by frequency filtering. To address non-random additive measurement errors (such as due to the superposition of near-field waves and reflections) data stacking offers minimal, if any benefit.

Erick Baziw
Gerald Verbeek

BCE's mission is to provide our clients around the world with state-of-the-art seismic data acquisition and analysis systems, which allow for better and faster diagnostics of the sub-surface. Please visit our website (www.bcengineers.com) or contact our offices for additional information:

e-mail: info@bcengineers.com

phone: Canada: (604) 733 4995 – USA: (903) 216 5372