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ENHANCEMENT OF SEISMIC SIGNAL BY HANNING FILTER — A CASE HISTORY

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Abstract

A case history regarding the recovery of shear waves is discussed to show that simple filtering sometimes becomes more important than that of optimum filtering. Shear wave singal received in the Lewisian Units Seismic Traverse is generally poor in quality, thus, the partial recovery could be made possible using Hanning band pass filtering, which appeared more effective than the other commonly used optimum filtering techniques.

Introduction

Deconvolution operators which are based on Wiener's approach (1949) employ a minimum mean-square-error criterion and are widely used on reflection data which is (treated) stationary and linear in properties, and may be viewed as the convolution of a source wavelet with a white random spike series of the earth's impulse response. If the process is non-stationary and non-random like that of refraction data, the Wiener's time-invariant filtering is generally impaired (Wang, 1969). Therefore, the refraction data which form the major tool of interpreting the earth's crust are attempted to be treated carefully for recovering the required signal.

The refraction seismogram shows different statistical properties for selected time windows down the trace, and gives distorted autocorrelation due to the noise spread on the trace. These factors effect seriously the performance of optimum filtering. The situation becomes even more difficult in case of shear waves, which being late arrivals on the refraction trace are generally weak, contaminated and immersed in P-signal generated noise (Assumpcao and Bamford, 1978). As these are produced in explosion seismology in a partitioning process of compressional energy impinging on an interface, the inefficient mode conversion may happen due to various factors like critical angle, physical properties and elastic velocities on both sides of the interface (White and Stephen, 1980).

Experiment and discussion

The Lewisian Unit Seismic Traverse is a 40 km long refraction line across the outcrop of different rock units (Hall and Ali,1985) and in this experiment P-and S-waves were recorded on 89 stations from different under-water shots. The shots are presented in Figure 1 to document an overall poor quality of shear waves. Although the seismic data of shot-1 (Figure 1-A) is relatively better than that of shot-2 (Figure 1-B), the shear waves in both cases are contaminated and/or strongly masked by noise. The sections with expanded time scale (Figures 1-C, 1-D) show this fact more clearly and also demonstrate very low signal-to-noise ratio. As far as the onsets of identifiable signal on some traces are concerned, they are completely lost in the noise existing on front.

For the recovery and detection of shear wave signal, the prediction error filter, cross-correlation, and spiking filtering were applied with the assumption that the prediction-error operator (Robinson and Treitel, 1980) designed with prediction distance equivalent to the initial cycle of the autocorrelation of a suitably chosen time-window (signal-bearing) of the recrod would amend the signal wavelet, the cross-correlation between continuously updated pilot message and the varied signal properties across the section may expose the occurence of signal (Warren, 1981) and the spiking filtering (Silvia & Robinson, 1979) would compress the signal energy into spike, above the background noise, at the onset position. But all these efforts proved least effective probably because of unlikely data.

Finally, the bandpassing approach was emphasised and a couple of filters were tried. But the output obtained with Hanning filter proved more effective.

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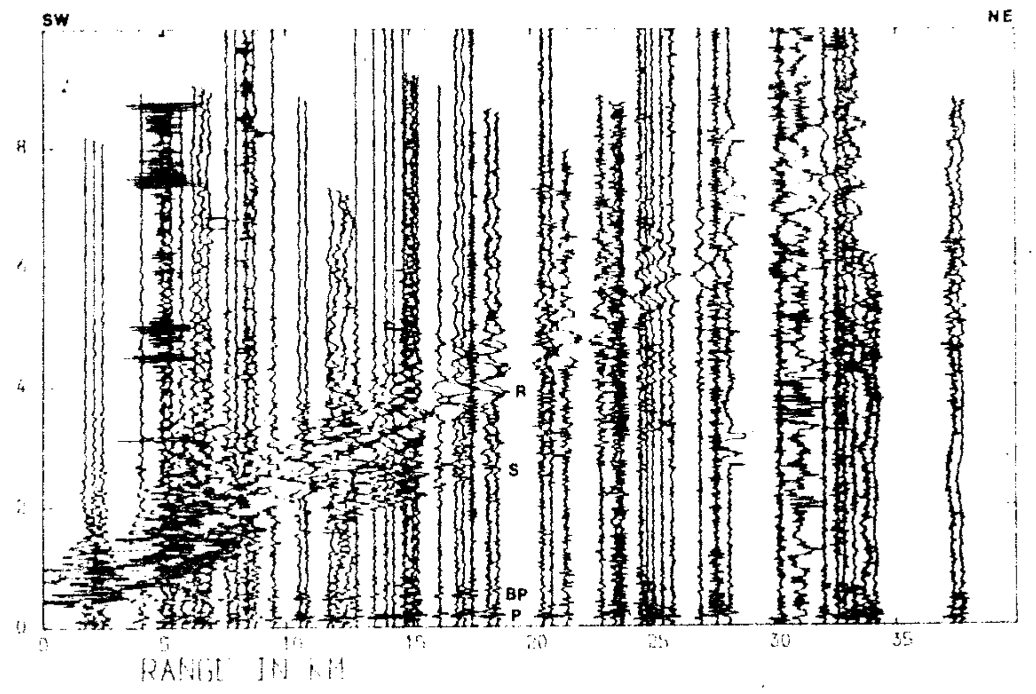
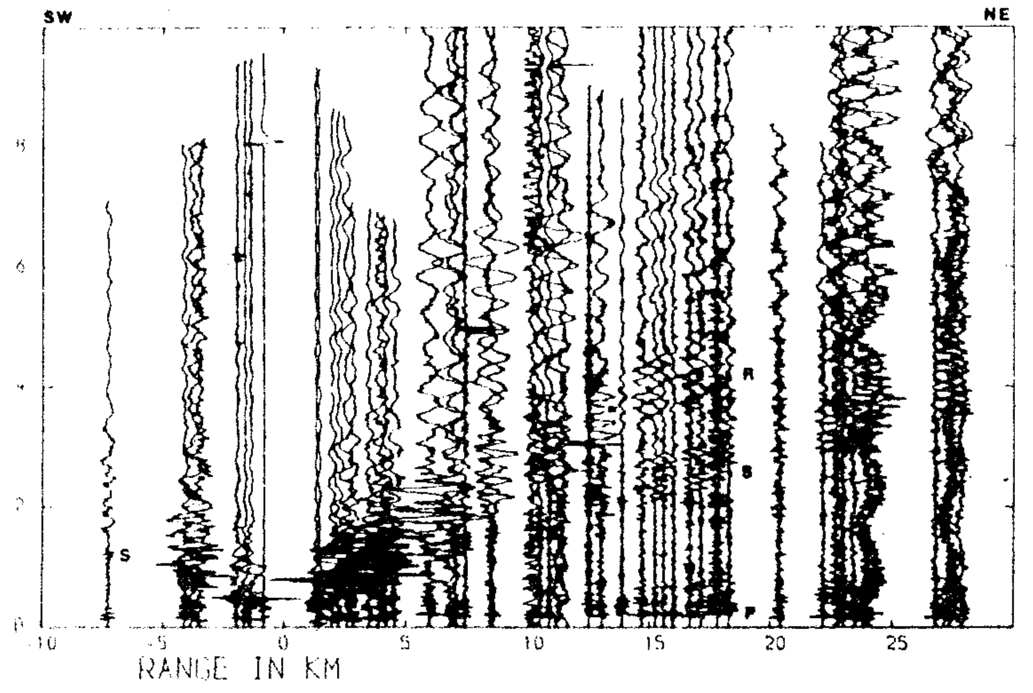
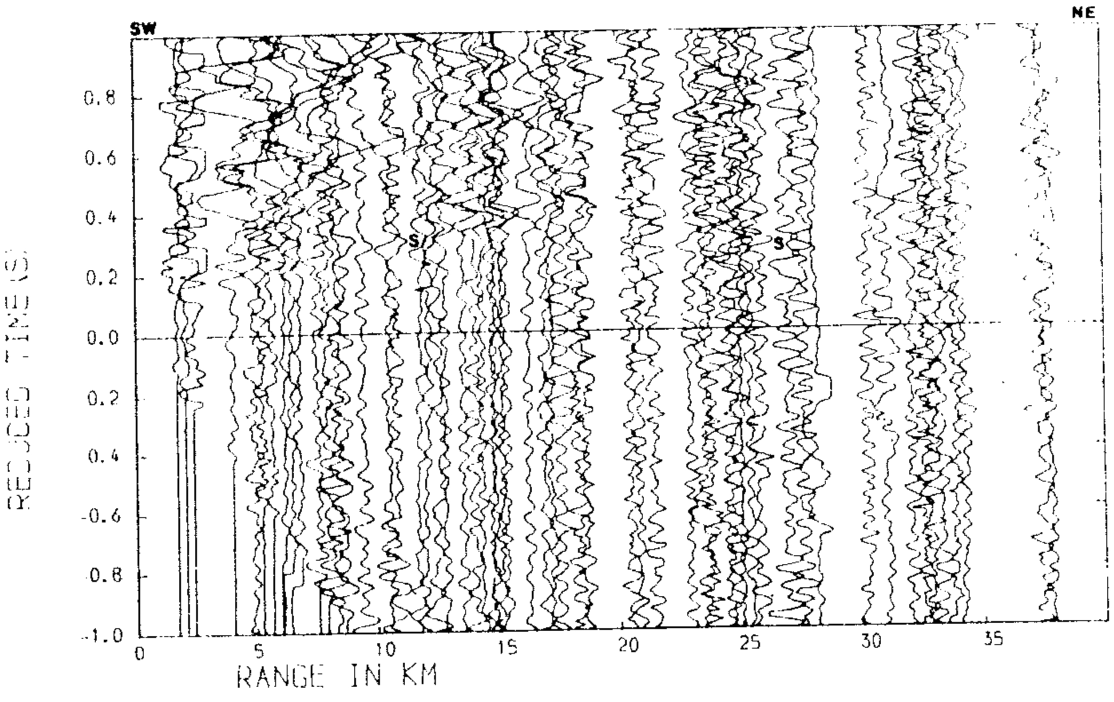
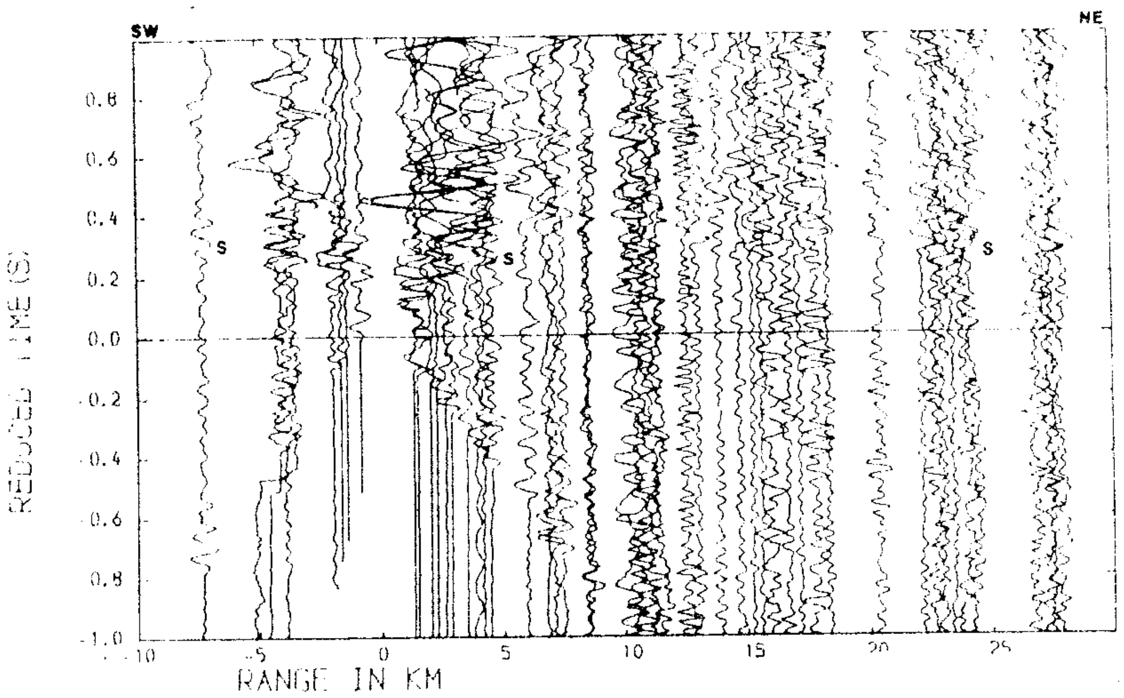


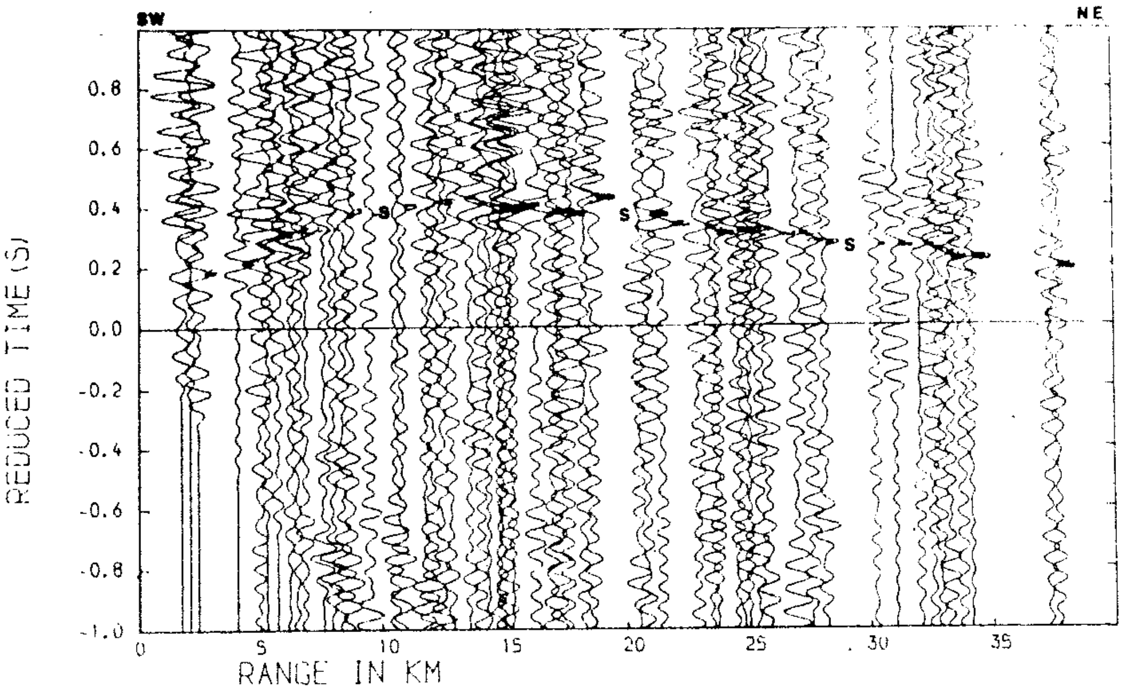


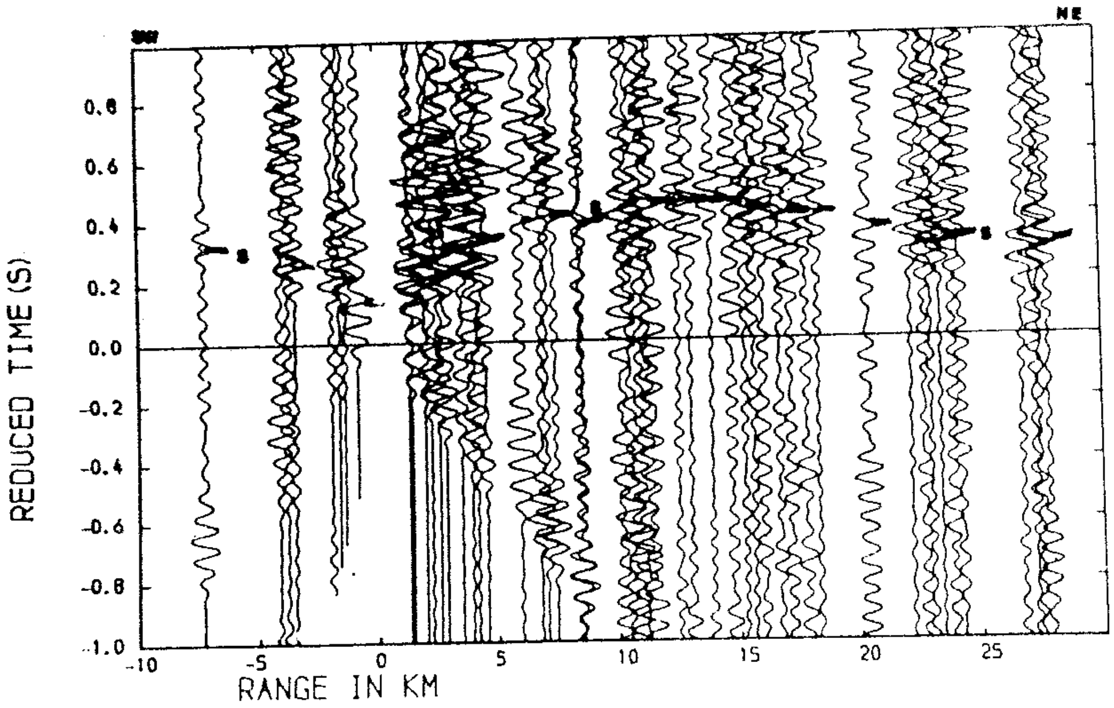
Figures 1A and 1B. Unfiltered sections of shots 1 and 2. P, BP, S, and R represent respectively the P-Waves, Bubble Pulse, Shear Waves and the Surface Waves.





Figures 1-C and 1-D Unfiltered sections with expanded time scale showing shear waves.





Figures 2-C and 2-D. Filtered sections showing effectiveness of Hanning band pass to enhance shear waves.

The Hanning filter described in the appendix (Warren, 1981) is a narrow bandpass filter which works appropriately over a defined frequency range symmetrical about the central frequency. Although the large and slowly decaying side lobes of the filter hide the onset by introducing undesirable ringy effect before and after the signal, the improvement in picking onsets can be achieved with special care using criteria such as timing of the reversed shots, visual phase fitting and the arrival patterns of other waves.

The frequency analysis of the shear waves of this experiment showed a dominant frequency range 8–20 Hz against 5–35 Hz bandwidth of the noise. The Hanning bandpass filter designed with compatible specifications centred at 14 Hz frequency, when convolved with zero-averaged, debubbled seismic data, gave a reasonable recovery of shear waves. Although prominently generated ringy effect has caused a difficulty in direct locating the onsets, however, the constraints of phase fitting, reversed timings, and the effect of filter on the synthetic spiky seismogram showed that the second strong cycle in the pulse train could be the best estimate of onset. As the filter consists of causal and non-causal coefficients, the output is shifted by half the length of the filter. Figure 2. shows an improved visual effect of the shear waves.

Conclusion

Tight filtering with Hanning band pass filter centred at the dominant frequency of the signal in a noisy trace may give promising results.

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Appendix

Hanning band pass filter differs from the ideal band pass filter in action of rolling off frequencies in the pass band region. It rolls off frequencies gradually on either side of the control frequency. The transfer function of the filter is the Hanning window defined as follows:

$$H(\omega) = \begin{cases} \frac{1}{2} + \frac{1}{2}\cos\left[\dfrac{\pi(2\omega+\omega_H+\omega_L)}{\omega_H-\omega_L}\right] & -\omega_H \leq \omega \leq -\omega_L \\ \frac{1}{2} + \frac{1}{2}\cos\dfrac{\pi(2\omega-\omega_H-\omega_L)}{\omega_H-\omega_L} & \omega_L \leq \omega \leq \omega_H \\ 0 & \text{elsewhere} \end{cases}$$

The corresponding impulse response consists of the following co-efficients like that of the ideal band pass filter:

$$H(\omega) = h_o + \sum_{n=1}^{\infty} h_n \cos\frac{n\pi\omega}{\omega_N}$$

$$\text{Where} \quad h_o = \frac{1}{\omega_N}\int_0^{\omega_N} H(\omega)\,d\omega = \frac{\omega_H - \omega_L}{2\omega_N}$$

$$h_n = \frac{1}{\omega_N}\int_{\omega_L}^{\omega_H} \cos\frac{n\pi\omega}{\omega_N}d\omega + \frac{1}{\omega_N}\int_{\omega_L}^{\omega_H} \cos\left\{\frac{\pi(2\omega-\omega_H-\omega_L)}{\omega_H-\omega_L}\right\}\cos\frac{n\pi\omega}{\omega_N}d\omega$$

$$= \frac{1}{n\pi}\left\{\sin\frac{n\pi\omega_H}{\omega_N} - \sin\frac{n\pi\omega_L}{\omega_N}\right\}\left[\frac{4\omega_N^2}{4_N^2 - n^2(\omega_H-\omega_L)^2}\right]$$

ω_N, ω_H and ω_L are Nyquist, high and low frequencies, respectively.

Let us put $a_o = h_o$ and $a_n = \frac{h_n}{2}$, $n = 1, 2, 3$ ----

Thus, $a(t) =$ --- a_2, a_1, a_o, a_1, a_2 ---

$\uparrow$ $t = 0$

As this two-sided filter consists of infinitely long series of causal and non-causal co-efficients, the truncation of the series causes Gibb's effect which could be reduced by multiplying the impulse response by a weighting function like that of Hanning window.

$$W_n = \begin{cases} 0.54 + 0.46 \text{ Cos } \frac{\pi n}{N}, & |n| \leq N \\ 0 & |n| > N \end{cases}$$

Hanning window results in gradual tapering of the co-efficients of the filter series such that the middle term is undisturbed and ends are reduced. The phase frequency behaviour of Hanning filter is linear one, produced as a result of shifting the axis of symmetry of zero-phase filter. The explanation can be provided by a Fourier transform of a real function with zero-phase characteristics.

$$H(\omega) = \frac{1}{\pi} \int_0^{\infty} h(t) e^{i\omega t} \, dt$$

If axis of symmetry is shifted by t_o, then

$$H(\omega) = \frac{1}{\pi} \int_0^{\infty} h(t-t_o) e^{i\omega t} \, dt$$

Let $k = t - t_o$, giving $dk = dt$ and

$$H'(\omega) = \frac{1}{\pi} \int_0^{\infty} h(k) e^{i\omega(k+t_o)} dk$$

$$= \frac{e^{i\omega t_o}}{\pi} \int_0^{\infty} h(k) e^{i\omega k} dk = e^{i\omega t_o} H(\omega)$$

or $|H'(\omega)| = |H(\omega)|$

and $\phi = \omega t_o$

This implies that shifting does not effect the amplitude characteristics but only causes phase effect which is a linear function of frequency.

The slope of which depends upon the amount of shift t_o. This is independent of frequency providing that linear phase is equivalent to a time delay equal to the gradient of phase *vs.* angular frequency line. In data processing linear phase is an acceptable operation because it does not affect the waveform except delaying it, and is easy to remove through simple data shift.