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Influence of Some Data Processing Operations on the Phase of Seismic Waves

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Abstract. Application of different processing techniques, based on different mathematical hypothesis, affects the amplitude and the shape of seismic wavelet. The phase changes resulting from the processing is discussed. Alignment of downgoing events in a vertical seismic profile, the velocity filter, the predictive deconvolution and the waveshaping through appropriate windows, are studied.

Investigation of the unaligned wavelet and downgoing alignment showed minimum phase changes. The predictive deconvolution (PDN) shift the phase response of the measured seismic wavelet by 13 18 degrees.

Keywords : Phase deviations. Seismic processing

Introduction

Most of the processing systems for seismic waves are applied in the frequency domain. Hence, the frequency response of the applied system can lead to a destruction of low-frequency details in a signal. Signal amplification might be of weak effect on phase changes but may be responsible for a loss of information at high frequencies. A combination of these effects can diminish the quality of a signal to a discernible degree. Observed changes in waveform between a source and a detector can be attributed to the effect of signal processing in the geophysical measurement system.

By definition seismic signal can be described as a measurable variation in some geophysical quantity such as particle displacement, phases, energy of motion, and many others can construct measurable variations. This variation normally contains information, which may be very simple (free noise case) or it may be considerably complicated in case of coherent noise.

The processed output signal will be different in shape from the source input because a stage of signal processing has occurred between input and output. The signal processing is generally performed for signal enhancement analysis and interpretation.

The shape of the propagated seismic pulse inside the earth has been investigated by many authors [1-5]. The vertical seismic profiles (vsp) was first studied by [6].

The statistical characteristics of the seismic data are manipulated to extract the wavelet and to attenuate undesired signals [7]. Deconvolution, as one of the statistical approaches to data processing, has allowed some progress in overcoming unwanted multiples [8]. Predictive deconvolution was employed to attenuate multiples produced by the water surface [9]. Ziolkowski [10; 11] tested an air gun experiment in which it was shown the source signature could be recovered from near-field measurements even when the synchronization error of the air guns was as much as 100 ms. The phase distortion due to absorption was addressed by McDonal, *et al.* [1]. The above described effects demonstrate the necessity of utilizing different processing procedures and techniques for the seismic data. Investigation of their influence on the delineated seismic signals is important for exploration or simulation targets. Consequently, it is meaningful and significant to examine the effect of these applied processing operations on the phase of the seismic signals. That is the main purpose of this study.

Basic Concepts

If we have a reasonably function y(t) of period T, then the function can be illustrated by Fourier as:

$$y(t) = \int_{-\infty}^{+\infty} Y(f)\ \exp(+i2\pi ft)\ df \tag{1}$$

with

$$Y(f) = \int_{-\infty}^{+\infty} y(t)\ \exp(-i2\pi ft)\ dt \tag{2}$$

The function Y(f) is the Fourier transform of y(t). The Fourier transform of the recorded wavelet y(t), which $y(t) = 0$ for $t < 0$, may be expressed as :

$$Y(f) = \int_{0}^{+\infty} y(t)\ e^{(-i2\pi ft)}\ dt \tag{3}$$

Usually, Y(f) is complex and could be represented as follows:

$$Y(f) = A(f)\ \exp(i\phi(f)) \tag{4}$$

where A(f) and ϕ (f) are real and A(f) is positive. A(f) is the amplitude spectrum and ϕ(f) is the phase spectrum of the function y(t). Denoting the real part by R(Y) and the imaginary part by I(Y), we have for the amplitude spectrum the succeeding term:

$$|Y(f)| = \left([R(Y)]^2 + [I(Y)]^2\right)^{0.5} \tag{5}$$

and for the phase spectrum:

$$\phi(f) = \tan^{-1}(I(Y) / R(Y)) \tag{6}$$

In a typical system, free of distortion, the phase-frequency response is linear over the frequency extent and passing through the zero phase point, or integral multiples of 2π on the phase axis [7]. Fig. 1(A), exposes a comparison between two synthetic wavelets — one is a nonzero phase and the other is nonzero phase with time shift. In Fig. 1(B), the spectrum of the nonzero phase is linear and passing through the zero point, but it is altered for the nonzero with time shift case and it may be nonlinear as shown from the linear fitting line. The seismic signal is distorted in the recording system and also during its transition through the earth's layers. Phase spectrum can be depicted as a sum of many terms and may be expressed as:

$$\phi(f) = K(f) + \phi_s(f) + \phi_I(f) \tag{7}$$

where K(f) is the wave number, $\Phi_s(f)$ is the source phase shift, and $\Phi_I(f)$ is the instrumental phase shift. The phase shifts due to the source and the instruments for studied events are supposed to be constant, thus we ignore it.

Material and Techniques

In vertical seismic profiles (vsp), a source on or near the surface close to the well is detected by a geophone that is clamped to the vertical wall of the well, as shown in Fig. 2. The recorded pulses on an vsp delineate the subsurface layering. For these pulses, it is reasonable to employ the data-processing steps that should be supportive in acquiring the full information from it, as displayed in Fig. 3. One of the influential operations for a vsp is the shift of the individual traces by a time that corresponds to the first arrival time.

This is carried out in two separate operations, designed to accomplish diverse targets. The principal one is to arrange the first arrivals at a constant, near-zero time. upgoing travelling waves have expanded their times. The second target is to align the upgoing waves by increasing the arrival times out of the zero-time line. The processing of the vsp data is necessary to eliminate the downgoing pulses and that requires deconvolution or spiking deconvolution filter [12].

The present study is interested in a vsp profile measured in Abu Gharadig Basin (well BED2-1) in the Western Desert of Egypt, as shown in Fig. 4. The applied source for the investigated wavelets is an air gun, of volume 200 cubic inches and of ring pressure of 140 bars. The gun depth was 3 meters and its offset was 83 meters from the well opening. The handled events are recorded at depth equal to 365.6 meters within the upper part of Dabaa Formation (shales). The depths are measured from the earth's surface. There are different patterns of the available vsp-data. From these vsp-data, there are the unaligned arrangements of the traces after band pass filtering between 5 and 50 hertz. Figure 5.A1, shows the extracted direct event which unaligned and band-pass filtered. Figure 5.A2, describes the first recorded aligned upgoing reflected event.

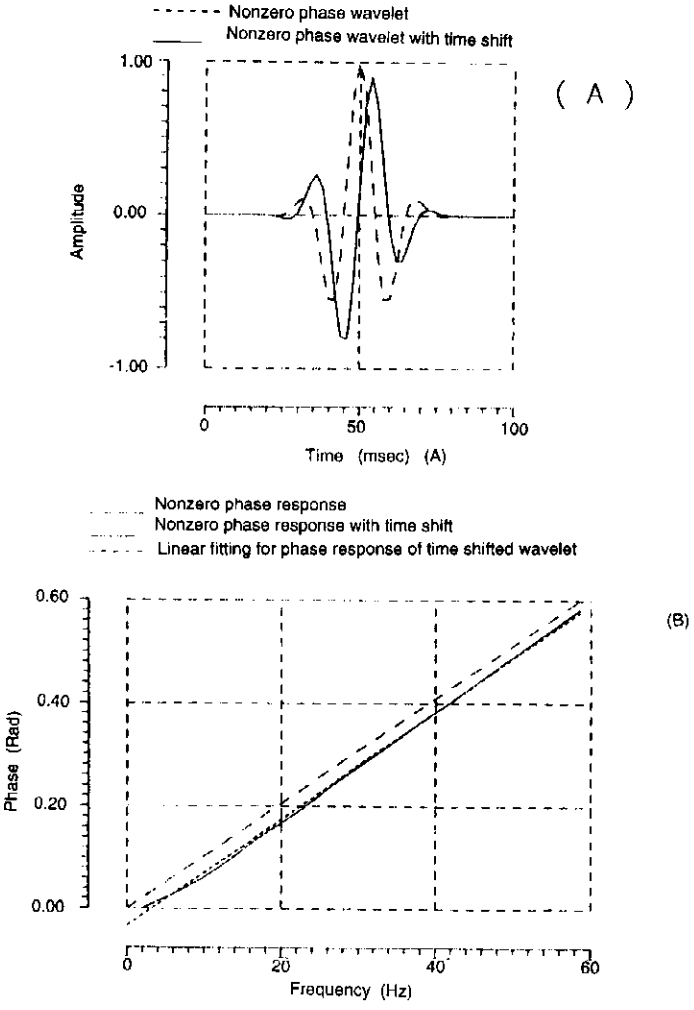


Fig. 1. **(A)** Nonzero- and nonzero- phase with time shift synthetic wavelets.

(B) Phase responses of the presented wavelets in (A) and the linear fitting of the nonzero phase wavelet with time shift.

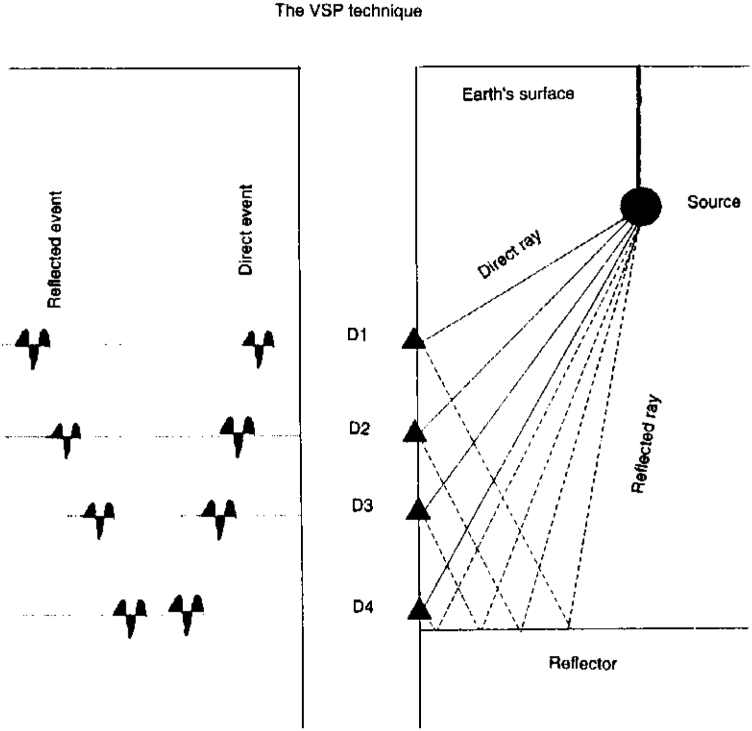


Fig. 2. Right side of the figure displays a schematic representation for the vertical seismic profile (vsp) principle. Energy originating at the source generates downward travelling wavefronts directly, and upward (reflected) travelling wavefronts via the reflector, which are recorded at detector locations D1 to D4. The left side of the figure shows the recorded signals on the traces well.

Another processing routine was carried out to resolve the downgoing event and aligning it. The alignment originated at an arbitrary time of 500 msec. The outcome of this processing step is characterized by the displayed wavelet in Fig. 5.A3. To clean the downgoing events from other adjuncted disliked events or incoherent noise, seven velocity levels are used to specify an appropriate velocity filter. The wavelet in Fig 5.A4 shows the application of the velocity filter. Multiple reflections sometimes are considered as noisy signals particularly when they interfere with the desired event. In the present evaluation a predictive deconvolution filter was applied to gain downgoings without other multiples, as inspected in Fig 5.A5. For this predictive deconvolution, a one second operator length was manipulated, and the prediction distance is assigned to 50 msec.

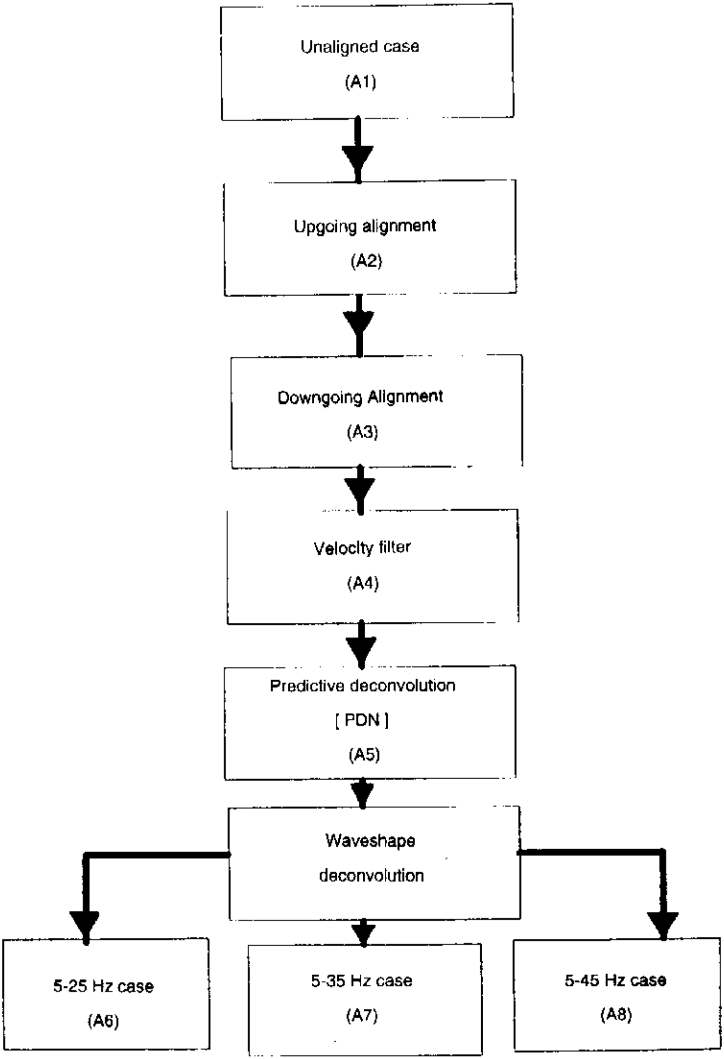


Fig. 3. Flowchart illustrates the processing steps on the considered available seismic data.

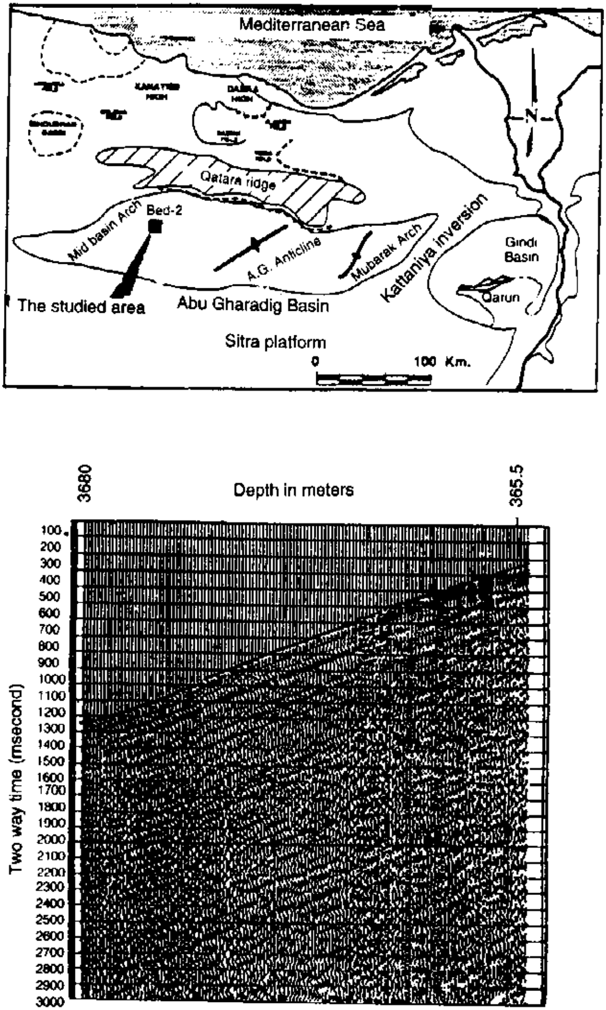


Fig. 4. Location map of the Well BED 2-1 and the measured VSP time section in Abu Gharadig field.

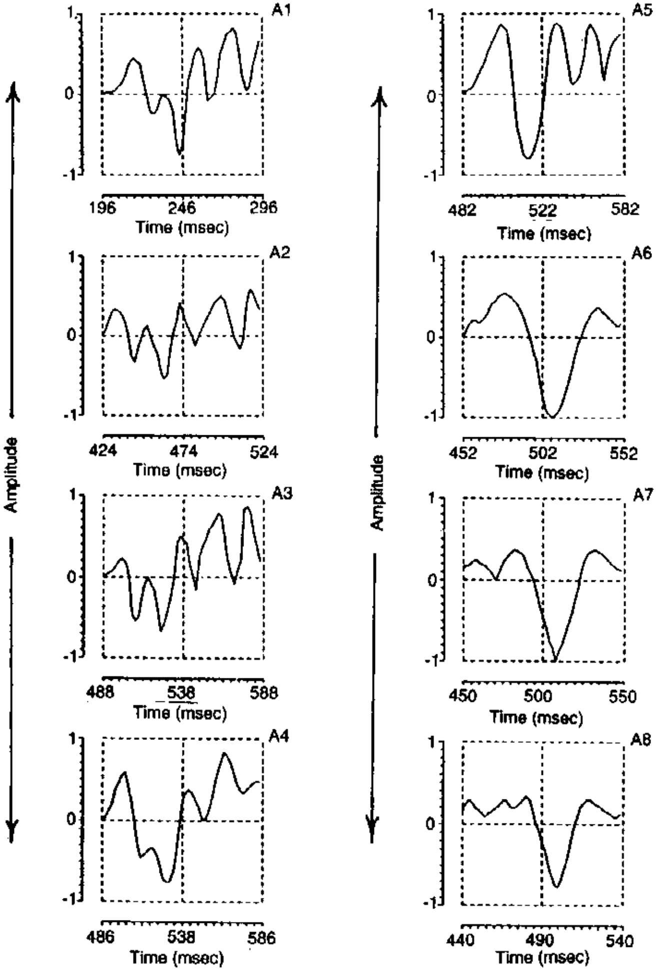


Fig. 5. The extracted seismic event at different processing stages: al-unaligned; a2-aligned upgoing events; a3-aligned downgoing events; a4-after applying velocity filter; a5-PDN filtering stage; a6-wave shaping for 5-25 Hz; a7-shaping for 5-35 Hz; and a8-shaping for 5-45 Hz.

A wave shape deconvolution was applied extraordinary for the upgoing events. The operator length for this waveshaping was 0.8 second. Three different zero-phase wavelets are examined at different frequency ranges. The lower cut frequency for the three frequency ranges is equal to 5 Hertz. The upper cut frequency is limited at 25, 35 and 45 Hertz, as shown in Figs 5.A6, 5.A7, and 5.A8, respectively.

Discussion and Results

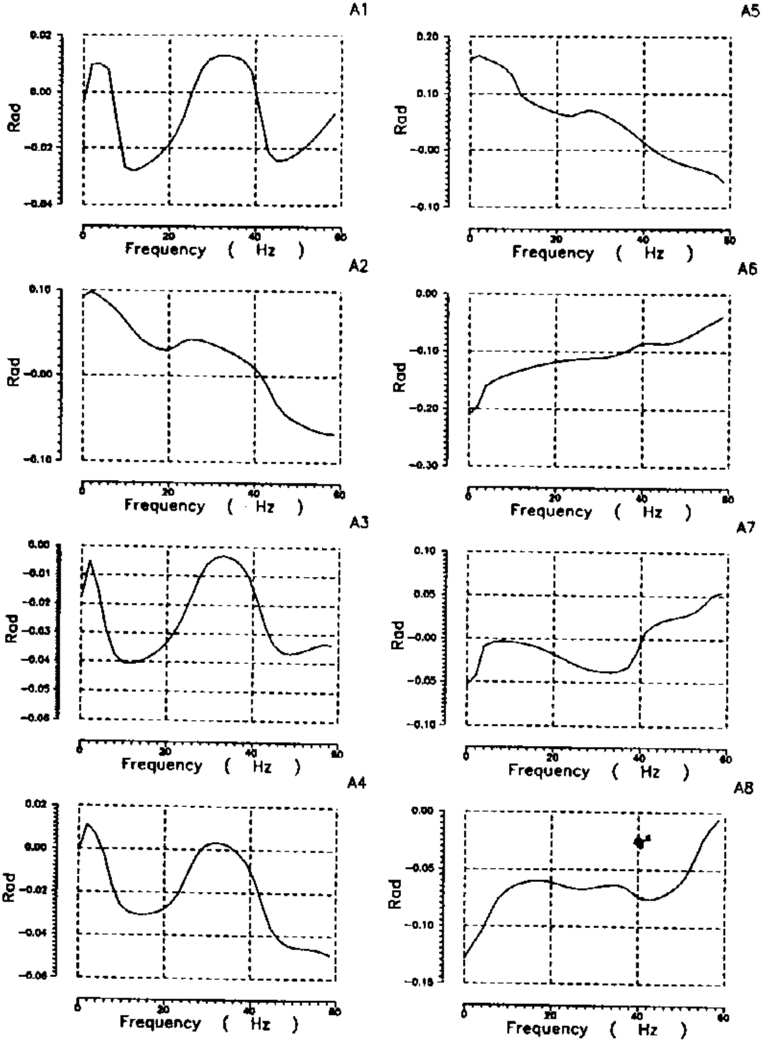
There are distinct influences upon the phase response of the seismic wavelet according to the different approaches of the processing techniques, as shown in Table 1.

Table 1. The estimated phase deviation for the extracted event at different processing cases

No.	Case	Phase deviation (In Deg.)
1	unaligned alignment	2.29
2	upgoing alignment	9.73
3	downgoing alignment	2.29
4	downgoing after velocity filter	3.43
5	after predictive deconvolution (PDN)	13.18
6	after waveshaping for 5-25 Hz	9.74
7	after waveshaping for 5-35 Hz	5.72
8	after waveshaping for 5-45 Hz	6.88

The measured phase distortion in the unaligned wavelet Fig. 6.A1 ranged between −1.72 rad and + 0.57 rad which is equivalent to 2.29 degrees, and of wavy nature as function of frequency. The alignment for the upgoing events, as revealed in Fig. 6.A2, elucidates increase of the phase distortion with increasing frequency, and it varies from −0.07 rad to +0.10 rad. This value of distortion is identical to 9.73 degrees of phase shift. It should be declared that at this step, there is a time shift of about 30 mseconds. The phase distortion of the aligned downgoing wavelet, Fig. 6.A3 is equal to 0.04 rad which equals 2.29 degrees. It is of variable nature as function of frequency.

The phase distortion range changed between −0.05 rad and +0.01 rad by applying the velocity filter. This value is equivalent to phase shift of 3.43 degrees, as shown in Fig. 6.A4. Furthermore, the last figure shows the decrease of the phase response as frequency increases. Introduction of the predictive deconvolution (PDN) in the processing steps smoothed the phase response as function of frequency and contribute a phase distortion ranged from -0.06 rad to +0.17 rad which this range in degrees may be expressed as 13.18 degrees, as in Fig. 6.A5. It is obvious to distinguish at this processing step that the PDN deforms the phase of the extracted wavelet, and this distortion decreases by increasing the frequency.



ig. 6. The phase deviation of the extracted wavelet at the same processing stages as described in caption of Fig. 5.

The three subsequent forms of the processed wavelet after applying the waveshaping is demonstrated in Figs. 6.A6, 6.A7 and 6.A8. At this status, the phase distortion may be due to the introduction of the arbitrary time shift. In the case of wavelet shaping from 5 to 25 Hertz, the range of the phase distortion is between -0.21 rad and -0.04 rad which equals to a phase shift of 9.74 degrees. The condition of 5-35 Hertz wavelet shaping contributes a phase distortion changed from -0.05 rad to +0.95 rad and its phase shift equals 5.72 degrees. The last case of 5-45 Hertz shows a phase distortion range varies between -0.13 rad and -0.01 rad which is equivalent to 6.88 degrees. From the above mentioned results, it is obvious that the predictive convolution (PDN) operation affects the extracted wavelet in a recognizable manner.

A close up view for all the phase response deviations are shown in Fig. 7. According

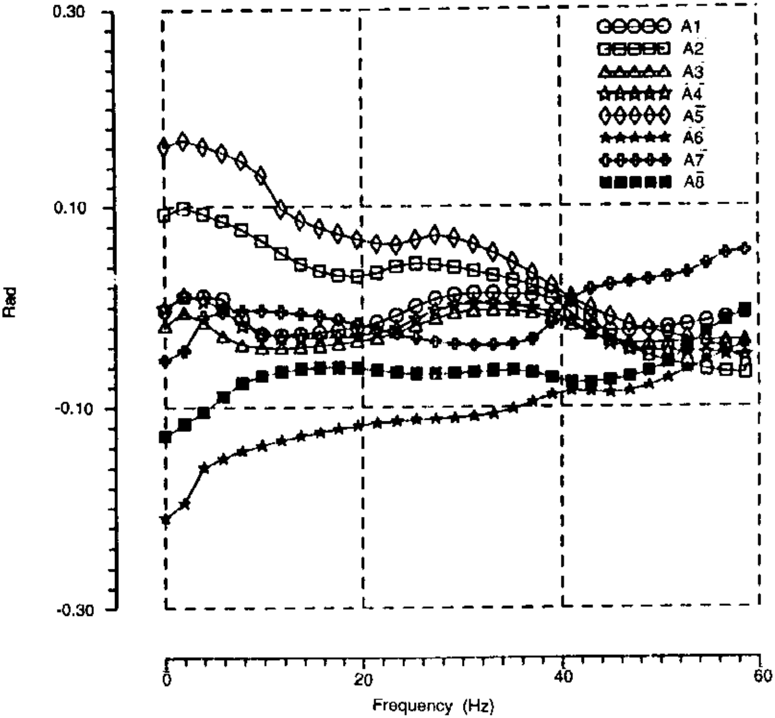


Fig. 7. A close up view of the different stages of the applied processing operations for the phase deviation.

to the overhead mentioned processing operations, it is apparent that the phase response of the measured wavelets is distorted. This distortion may guide to an erroneous interpretation and specifically for the attenuation measurements, using the distortion techniques as that used by [1]. Hence, the affect of the velocity filter on a wavelet must be previously known before the inference of the Q-values or other attenuation parameters can be made. The unaligned band pass filtered, and true amplitude recovered wavelets show a small phase distortion. That seems reasonable because the different processing operations were not applied at that early stage of data processing.

It is concluded that many processing operations may attack the phase response stability of seismic wavelet. Correspondingly, the measured seismic events will be affected, while existing in processing handling. The influenced phases guide to a mistaken termination or incorrect geologic structure resolution.

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تأثير بعض عمليات معالجة المعلومات على طور الموجة السيزمية

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(سُلِّم في ٢٨ رجب ١٤١٤هـ؛ وقُبل للنشر في ١٨ جمادى الأخرة ١٤١٦هـ)

ملخص البحث. إنّ تطبيق تقنيات المعالجة المختلفة والمعتمدة على افتراضات رياضية مختلفة تؤثر على سعة الذبذبة (Amplitude) وشكل الموجة السيزمية. نوقش في هذا البحث انحراف الطور عن المثالية بسبب عمليات المعالجة. تمّت دراسة بعض من هذه العمليات وهي: الموجات السيزمية الهابطة المرتبة في القطاع السيزمي الرأسي ومرشح السرعة والفصل المتوقع (PDN) وتشكيل الموجة من خلال نوافذ مناسبة.

لقد أظهر البحث أن الموجة الهابطة قبل الترتيب أقل تغييرًا في الطور. في حالة استعمال الفصل المتوقع (PDN) فإنه يشوّه بلا شك الاستجابة الطورية في الموجة السيزمية المقاسة وذلك بإزاحة الطور مقدار ١٣,١٨ درجة.