Dynamics of the Hammer Blow

Thomas Forbriger, Schiltach

Introduction

Shallow seismic record sections are not just the impulse-response of the subsurface. Filters in the recorder, the geophone response, also influence the waveforms and, in particular, the unknown force time-function of the hammer blow. By fitting a trial function to the data, I show that half a period of a sine-function of finite duration may serve well as force time-function in modeling recorded data by synthetic seismograms.

Modeling Shallow Seismic Record Sections

The data quality we can obtain with simple hammer blows in shallow seismics is often underestimated. Fig. 1 shows two field examples. The seismograms are recorded in an offset range of a few decameters and are displayed on a reduced time-scale. The large amplitude signal in the center of each plot is the dispersed Rayleigh wavetrain with multiple modes contributing to the signal. Clearly these waveforms contain valuable information about subsurface structure.

In recent years we learned how to deal with these multimode datasets (Forbriger, 2001) and how to infer subsurface properties by modeling the field data in the frequency and phase-slowness domain using the reflectivity method (Fuchs & Müller, 1971). The resulting models can be used to model full seismograms quantitatively, although no waveform modeling took place in the inversion.

Synthetic seismograms for both datasets are shown in Figs. 2a and 2b. They are calculated for the subsurface models obtained from the frequency and phase slowness wavefield-coefficients. In the plot they are compared to the recorded seismograms. The amplitudes are scaled by an offset-dependent factor. The synthetics fit the data already quite well. There are, however, still residuals. In particular in Fig. 2b (BERKHEIM) dissipation in the model is still too weak for high frequencies.

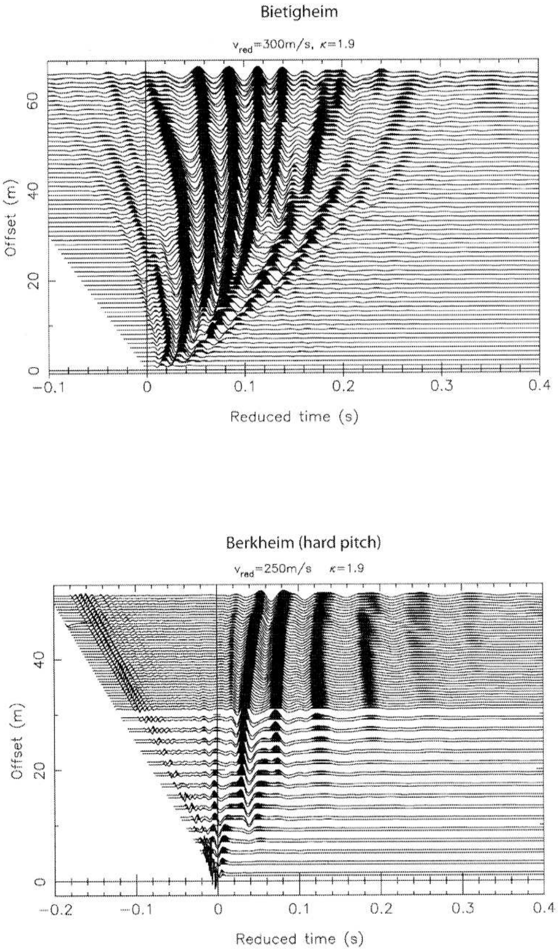


Figure 1: Two examples of shallow seismic field data. The seismograms are excited by a hammer blow and are recorded by vertical geophones. In both cases multiple modes are interfering in the Rayleigh wavetrain.

Preliminary results show, that we can obtain significant constraints on the Q-model by a subsequent inversion of full seismograms. The waveform fit is clearly improved at large offsets in Fig. 2c and the amplitudes at near offsets now almost equal the data.

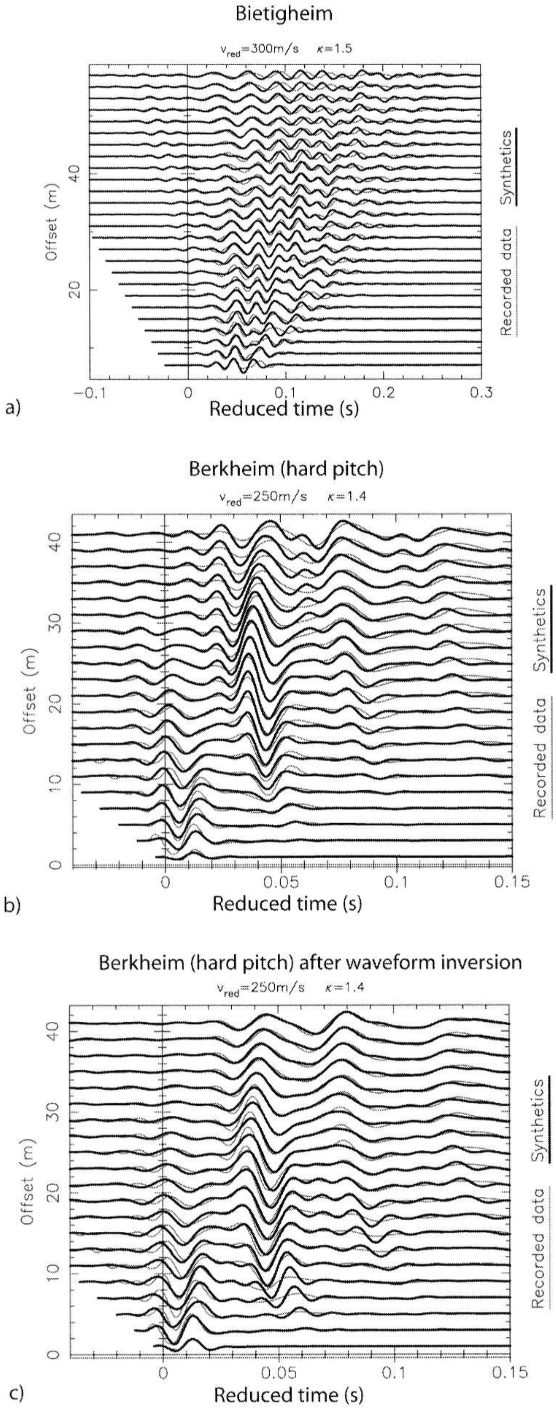


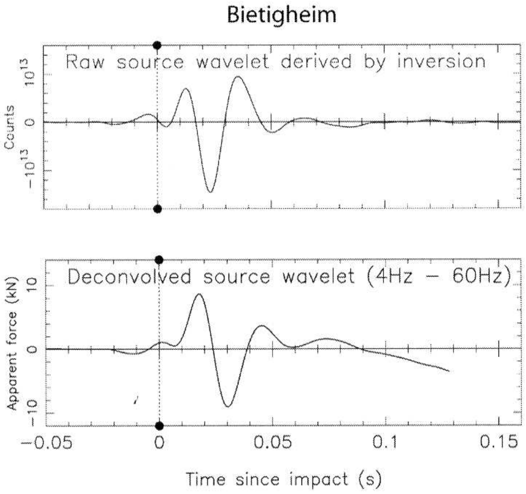
Figure 2: (a) and (b): Synthetic seismograms (thick lines) are compared with recorded waveforms (thin gray lines). Traces are scaled by an offset dependent factor. Absolute amplitudes are compared. The seismograms already fit quite well although no waveform fitting was involved in deriving the underlying subsurface models. In (b) dissipation is still too weak at high frequencies. (c) shows synthetics for an improved subsurface model obtained from subsequent waveform inversion.

Waveform inversion introduces extra complications. The recorded waveform is not only the impulse response of the subsurface but also contains the response of all field instruments. While the filters in the recording system and the geophone response are known, we do not know the force time-function of the hammer blow. The latter has a time constant within the recorded period range and strongly influences the waveform. Thus, we have to account for this in waveform inversion by using an appropriate source wavelet.

Our synthetic seismograms are the elastic response of the ground to an idealized point force. In the experiment, however, the hammer's target plate is of finite extent and the ground definitely undergoes plastic deformation below it. For the moment it is unclear whether our idealized model is physically appropriate to explain the observed excitation. But, since the same force time function of the source is contained in each seismogram, we can at least derive an optimal source wavelet to fit the data.

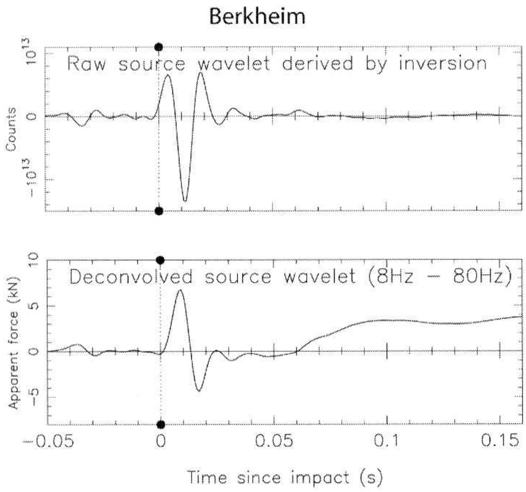
Source Wavelets

Figs. 3a and 3b (top panels) show the source wavelets that were used to calculate the synthetic seismograms in Figs. 2a and 2b, respectively. They are derived from the data by linear regression independently for each Fourier component (Forbriger, 2003). As they should, they are compact in time and shortly follow the hammer impact. These are properties we expect for reasonable estimates. Now, can we derive the true force time-function from them? The wavelets still contain all filter responses of the recording system, in particular the geophone response to ground velocity rather than displacement. By deconvolution we can remove some of these effects and widen the bandwidth of the signal. But we cannot restore components at low frequencies that got lost due to the filters. In particular the DC-component will remain missing.



HP 4 Hz, 2 poles	geophones (after deconvolution)
HP 4 Hz, 2poles	data recorder
LP 60 Hz, 4 poles	signal processing
LP 250 Hz, 4 poles	data recorder (anti–aliasing)

a)



HP 4 Hz, 2 poles	geophones (after deconvolution)
HP 8 Hz, 2poles	data recorder
LP 80 Hz, 4 poles	signal processing
LP 500 Hz, 4 poles	data recorder (anti–aliasing)

b)

Figure 3: The top panels show source wavelets used for the synthetic seismograms for cases BIETIGHEIM (a) and BERKHEIM (b). The wavelets still contain the full geophone response and filters of the recording system. A deconvolved version of each wavelet is given in the bottom panels. The remaining filter responses are specified in the table beneath each graph. All have a Butterworth characteristic.

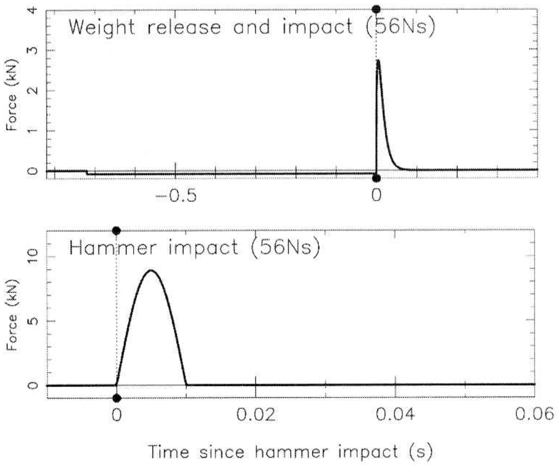


Figure 4: The top panel shows a hypothetical force time function containing a release phase during the acceleration of the hammer. The bottom panel gives the force exerted by an elastically reflected mass.

In the bottom panels of Figs. 3a and 3b the deconvolved wavelets are given already in units of apparent force. The tables beneath the graphs list the remaining filter effects. The signal is positive for a force directed downwards into the ground. The hammer impact only transfers momentum in one direction. We would therefore expect an entirely positive force function. The deconvolved wavelets are, however, definitely two-sided. The remaining high-pass filters remove the average of the input signal, but they have time constants of 125 ms and 250 ms respectively, much longer than the extent of the wavelets. Do these wavelets indicate an inappropriate physical concept for modeling the excitation of the observed wavefield? At this point, Gerhard gave the advice to answer this question in a scientific way, rather than discussing arbitrary philosophical arguments. He proposed to model the wavelets by a hypothetical force time-function.

In several studies he proved interest in source dynamics during his career. In Fig. 4 (top) I show a function that he once used to model seismograms excited by a world-wide recorded rock burst near Völkershausen (Müller, 1989) and which he proposed for modeling a landslide in the Veltlin (Baumann, 1991). This function could also resemble a shallow seismic hammer source. It contains a release phase during the acceleration of the hammer preceding the actual impact. It is mean free because the hammer first collects exactly the momentum that it transfers to the ground during the impact. Thus the negative and the positive area cancel each other. But in the case of a hammer the release force is small in comparison to the short impact and a high-pass filter will leave only a small wiggle some hundred milliseconds prior to the main onset.

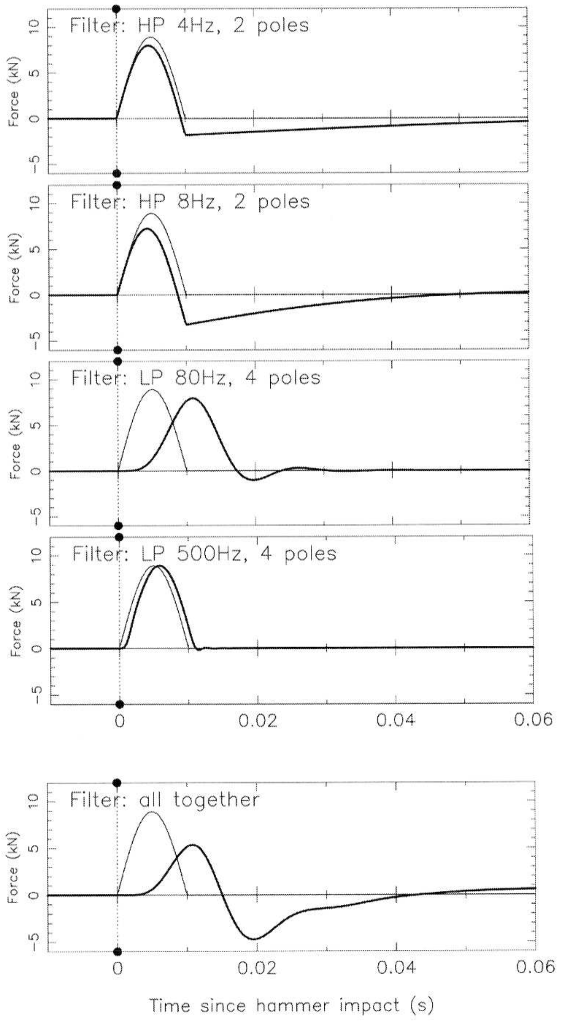


Figure 5: Filtered versions (thick lines) of the hypothetical force time-function (thin line). All filter stages together produce a two-sided wavelet from a purely positive trial function.

Therefore we do not expect to observe the release. We rather concentrate on the impact. The bottom curve in Fig. 4 is the force exerted by an elastically reflected mass. It is actually half a period of a sine function.
Now, how do the remaining filters distort this curve? None of the filter stages alone may explain the wavelet that we obtained from the data. But all of them together produce approximately the two-sided impulse we want to reproduce, as can be seen in Fig. 5.

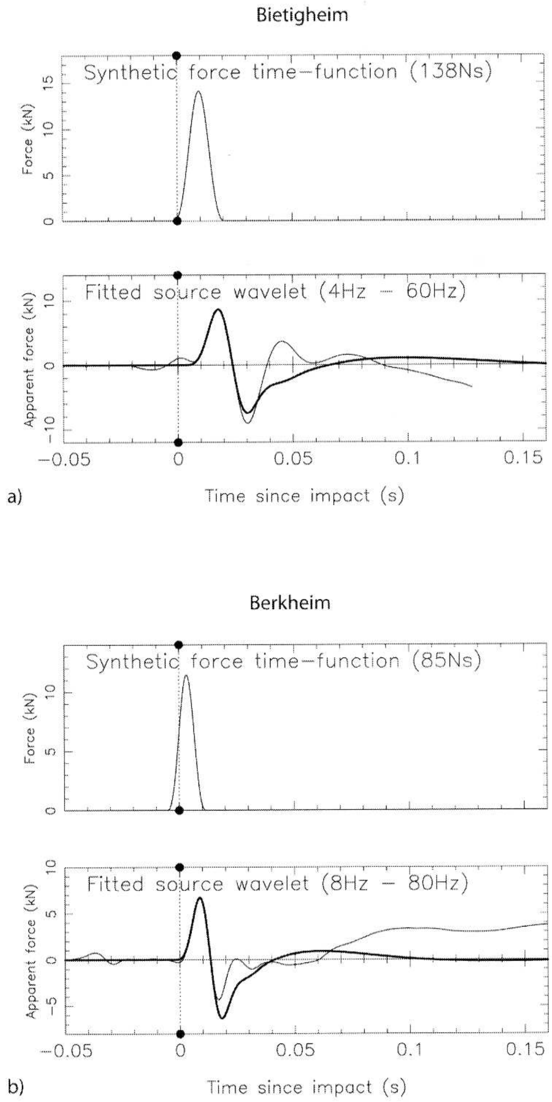


Figure 6: Fitting the source wavelets: The top panels show the trial functions that fit the source wavelets in the case of BIETIGHEIM (a) and BERKHEIM (b). The bottom panels show the fit to the deconvolved source wavelets (thin line) obtained for filtered versions of the trial function (thick line).

The Force Time-Function of a Hammer Blow

A filtered version of the trial function now can be used to fit the deconvolved wavelets obtained from the data. The trial functions and the fit are shown in Figs. 6a and 6b for both datasets. The result is quite satisfactory.

Although the DC component is not present in the data, we can estimate it when assuming the half-period sine function for the exerted force. We then derive a transferred momentum of 85 Ns in the case of BERKHEIM and of 138 Ns in the case of BIETIGHEIM. Both are larger than 56 Ns, which is the momentum of an 8 kg weight being dropped from 2.5 m height. This is reasonable, because the hammer was accelerated manually in addition to gravity and in some cases was weakly reflected by the ground.

Similar results can be obtained from other datasets. However, a large scatter of the derived momentum for the same hammer blow (in the case of BERKHEIM from 84 Ns to 154 Ns) depending on the subsurface model and the actual fit criterion reminds us, that we should not put too much emphasis on these numbers. But from this study we have clearly learned, that a force time-function defined by three parameters only — which are amplitude, onset time, and duration — can be successful in waveform fitting. This will be a great aid in the task of inverting full shallow seismic seismograms.

Acknowledgements

I am deeply indebted to Gerhard Müller for all good advice and friendship he gave to me. The time I could share with him was too short.

I am grateful to Wolfgang Friederich who contributed remarkably efficient code for the calculation of partial derivatives of full seismograms. Without such code waveform inversion would not be feasible.

I thank Walter Zürn for helpful comments on the manuscript.

Further I thank Ingrid Hörnchen for touching up the figures and typesetting the manuscript with a Wordprocessor I'm too ignorant to use.

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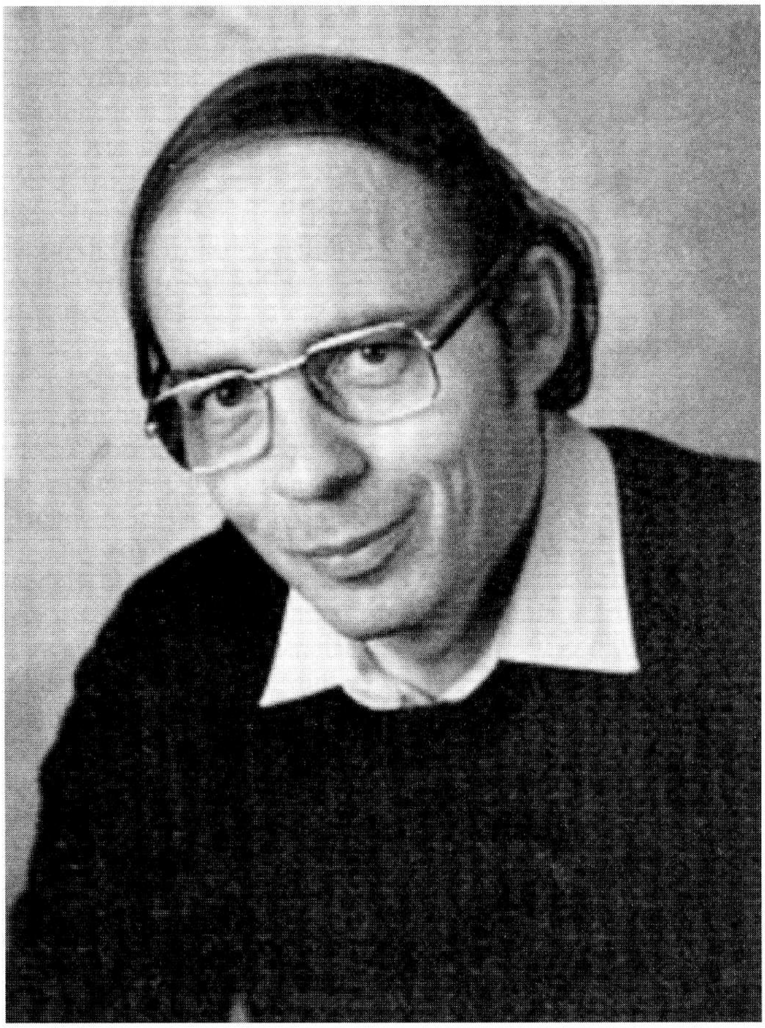

Professor Gerhard Müller
(1940 – 2002)

Editorial

On 16 – 17 January 2003, a symposium was held in memoriam of the late Professor Gerhard Müller in Neustadt an der Weinstraße, Germany. This symposium was organized by the Institute for Meteorology and Geophysics of the Johann Wolfgang Goethe-University in Frankfurt am Main where Gerhard Müller had worked and lectured for more than 20 years. It was supported by the Deutsche Geophysikalische Gesellschaft (DGG).

The first day of the symposium was dedicated to scientific results of Gerhard Müller and his group, and the second day allowed for presentations of newer research results, often in many ways influenced by Gerhard Müller.

Obituaries of Gerhard Müller by Brian L. N. Kennett and Walter Zürn have been published elsewhere (Kennett, 2002; Zürn, 2002) and Harro Schmeling has published a German language summary report on the symposium (Schmeling, 2002). This volume now contains in English manuscripts or extended abstracts of all contributions given during the symposium. It therefore gives a much more detailed view of the methods used by Gerhard Müller and also of the continuing scientific relevance of his work. It is hoped that it reaches a broad international audience.

The order of contributions in this volume follows the program of the symposium. In addition, a bibliography of Gerhard Müller's publications as author or co-author is included. This bibliography was compiled by Ingrid H. Hörnchen and Walter Zürn and has been homogenized and completed by the editor. Since many items in the bibliography have been cited many times by the different authors, all citations of publications included in the bibliography were removed from the individual contributions.

May this collection help to remember Gerhard Müller as he was: an internationally respected, excellent scientist, an exceptional teacher in Geophysics at the Universities of Karlsruhe and Frankfurt, and a good friend to many of us.

NORSAR, 29 October 2003

Johannes Schweitzer

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Thomas Forbriger

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