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SOURCE PULSE ENHANCEMENT BY DECONVOLUTION OF AN EMPIRICAL GREEN'S FUNCTION

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Abstract. Observations of the earthquake source-time function are enhanced if path, recording-site, and instrument complexities can be removed from seismograms. Assuming that a small earthquake has a simple source, its seismogram can be treated as an empirical Green's function and deconvolved from the seismogram of a larger and/or more complex earthquake by spectral division. When the deconvolution is well posed, the quotient spectrum represents the apparent source-time function of the larger event. This study shows that with high-quality locally recorded earthquake data it is feasible to Fourier transform the quotient and obtain a useful result in the time domain. In practice, the deconvolution can be stabilized by one of several simple techniques.

In this paper, the method is implemented and tested on high-quality digital recordings of aftershocks of the Jan. 9, 1982 Miramichi (New Brunswick) earthquake. In particular, seismograms from a Jan. 17 aftershock (017 13:33 GMT, local mag.=3.5) exhibit path or site effects which complicate the determination of source parameters. After deconvolution, the apparent far-field source of this event is a simple pulse in displacement with duration ≈ 0.07 second for both P and S.

Introduction

Small-earthquake seismograms were used as empirical Green's functions by Hartzell [1978] in synthesizing strong-motion records from a complex earthquake. For the purposes of Hartzell's study, several subsequent studies [e.g. Kanamori, 1979; Hadley and Helmberger, 1980; Irikura, 1983; Frankel and Kanamori, 1983] and this paper, a useful empirical Green's function is a seismogram written by a simple earthquake which includes the responses of path, recording site, and instrument:

$$G(t)=S(t) * P(t) * R(t) * I(t), \text{ where } S(t) \approx \delta(t).$$

I assume in what follows that instrumentation is constant or at least that differences are well known. Then, assuming that a small earthquake has a simple source-time function, the question of its usefulness as an empirical Green's function reduces to how well its seismogram captures the essential aspects of path and recording site relevant to the large/complex earthquake under study. Practically speaking, the answer to this question involves earthquake locations and focal mechanisms.

In modeling near-source high-frequency strong ground motion, it may be appropriate to use different Green's functions for different parts of a large fault [e.g. Hartzell, 1978; Irikura, 1983]. Modeling longer periods is less restrictive as it is only necessary that the Green's function correspond to an average path and recording site [e.g. Kanamori, 1979]. The above studies, as well as many forward-modeling studies using theoretical Green's functions [e.g. Heaton, 1982], all share the need to assume a space-time source behavior for the earthquake to be modeled. In contrast, the apparent source-time function is obtained directly using the method outlined in this paper.

It is conceptually straightforward to isolate the source-time spectrum of a large/complex event (considered as a point source) by dividing its spectrum by the spectrum of an empirical Green's function. Bakun et al. [1976] used this technique to examine the spectral amplitudes of small central California earthquakes. As the present study shows, with high-quality data the quotient spectrum can be transformed to the time domain, yielding the apparent far-field source-time function of the large/complex event. Time-domain observations have advantages over amplitude spectra alone in seismic source modeling. In either domain, meaning can be attached to the result by assuming linearity and assuming that the far-field source-time function of the small earthquake is a delta function in displacement. The spectral division serves to deconvolve path, recording-site, and instrument complexities. Then for frequencies less than the corner frequency of the Green's function (where the delta-function assumption holds) the result represents the source-time function of the large/complex earthquake in units of the seismic moment of the Green's function event. Equivalently, the result represents a scaled version of the displacement seismogram which the large/complex earthquake would have written in a homogeneous whole-space.

In earthquake seismology, deconvolution techniques have primarily been used in two areas of teleseismic-body-wave research. In one type of study, upper-mantle or crustal structure was determined using spectral division to deconvolve an independently determined source wavelet from teleseismic waveforms [e.g. Helmberger and Wiggins, 1971; Clayton and Wiggins, 1976]. In another type of study, source-time functions of large earthquakes were isolated using time-domain deconvolution of simple theoretical Green's functions [e.g. Boatwright, 1980; Kikuchi and Kanamori, 1982; Ruff and Kanamori, 1983]. Here I apply the spectral-division technique to relatively high-frequency local earthquake data; the main objective being the determination of the source function. Divisional deconvolution does not require any assumptions about the empirical Green's function as a time series [Clayton and Wiggins, 1976] and also provides a useful intermediate result, the quotient spectrum. Incorporation of the empirical Green's function also makes the method robust seismologically; if the Green's function is well chosen, no assumptions need to be

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