TIME-QUEFRENCY ANALYSIS FOR DETECTION OF INTERVALS BETWEEN PROXIMITY SIMILAR EVENTS

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1. INTRODUCTION

Analysis of similar earthquakes is a seismological tool to investigate Earth's subsurface structure [1]. Events with similar waveforms occur in the same or proximal fractures and share a similar source mechanism. Similar microseismic events can be observed during hydraulic injection in fracture reservoir systems, e.g. geothermal reservoirs [2]. Analyses of similar microseismic events are also used in reservoir engineering to elucidate fracture systems.

Analyses of similar earthquakes have provided highly precise relative locations for similar earthquakes. Two events are recorded in a single data file when an interval between events is much shorter than their data length. Two events mutually overlap and are recorded as one wavelet when the second event arrives before attenuation of the first event. Analysis of similar events of this type provides a more reliable relative hypocenter than the conventional analysis of similar events does. Such similar events with a short interval are called "Proximity AE doublets" in this paper. Temporal changes of media that seismic waves propagate in can be neglected in this analysis. It is nevertheless difficult to estimate the interval directly in its time domain analysis. Cepstrum of proximity AE doublets shows intervals between the events even though they mutually overlap. Two peaks are apparent in the cepstrum of proximity AE doublets when the propagation distance of P-wave differs from that of S-wave in proximity AE doublets. These two peaks can be identified by using a new analytical method in which data after the second S-wave are replaced with zeros in cepstrum analysis.

2. PROXIMITY AE DOUBLETS

This study uses microseismic data measured in the Soultz-sous-Forêts HDR field during hydraulic fracturing in 1993. About 10,000 events were located and 6,039 similar microseismic events were observed during this fracturing [2].

This study specifically examines a group of similar microseismic events. An example of this group are shown in Figure 1. Two events with similar waveforms are visible in the figure. Moreover, the interval between the two events is shorter than duration of an event [2]. The second event arrives in the attenuating process of the first event. They are proximity AE doublets.

A continuous signal including two similar events is observed when the following event arrives before complete attenuation of the previous event. One seismic event has both a P-wave and an S-wave. Therefore, two pairs of seismic waves are overlapped in the signal. The observed continuous signal $y\,(n)$ is

$$y(n) = x_P(n) + x_S(n) + \alpha x_P(n - \Delta T_P) + \alpha x_S(n - \Delta T_S), \tag{1}$$

where $x_P(n)$ and $x_S\,(n)$ are the P-wave and S-wave of the first event, ΔT_P and ΔT_S are intervals of the P-wave and S-wave between the similar events, and α represents a relative ratio of magnitude. The logarithm of a power spectrum of $y\,(n)$ has an additive periodic component because of the delayed event. Consequently, the Fourier inverse transform of the logarithm of the power spectrum exhibits two peaks at intervals of ΔT_P and ΔT_S. The Fourier inverse transform of the logarithm of the power spectrum is a cepstrum, which is a function of quefrency.

Relative location of a source of the second event from that of the first event is calculable in the similar microseismic event analysis [3]. Figure 2 presents a schematic diagram for estimation of relative location in measurement of the similar microseismic events.

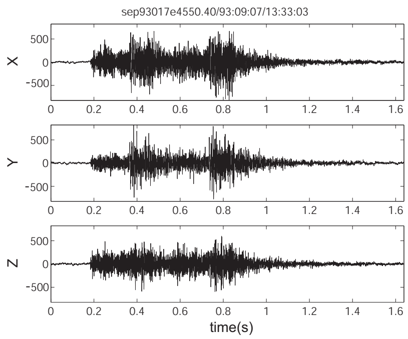

Fig. 1. Proximity AE doublets.

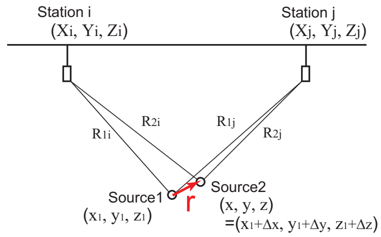

Fig. 2. Relative location between sources of proximity AE doublets.

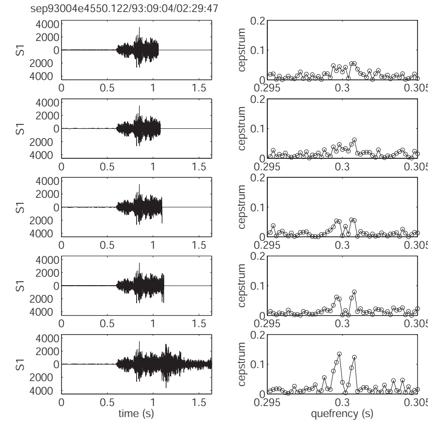

Fig. 3. Time-quefrency analysis for identification of a peak of P-wave in proximity AE doublets.

3. TIME-QUEFRENCY ANALYSIS

It is difficult to determine a peak of P-wave interval in the cepstrum of proximity AE doublets because there are two peaks in it. When the data after arrival of the second S-wave are replaced with zeros, ΔT_S in (1) disappears. Cepstra of the data including the replaced zeros after the arrival of the second S-wave show a decrease of the S-wave peak. We can discriminate the peak of the S-wave interval from that of the P-wave interval in the cepstrum using this zero-replacement method.

The beginning of the data that are replaced with zeros is shifted. in Figure 3. Some cepstra that have the shifted beginning of the zero-replacement are compared so that the peak of the S-wave interval can be discriminated from that of the P-wave interval. This method is designated as time-quefrency analysis. Original shapes of the peaks are depicted at the bottom of the figure in Figure 3. In Figure 3, the left peak loses its original shape more significantly than the right peak does as the beginning of the zero-replaced data is shifted forward. Therefore, the left peak signifies the S-wave interval.

4. CONCLUSION

The interval of P-wave in the proximity AE doublets is detectable using time-quefrency analysis in cases with two peaks, which show intervals of P-wave and S-wave, in their cepstrum. We can estimate a relative location based on the intervals that have been detected in the time-quefrency analysis. This relative location will be more reliable than that of the conventional AE doublets/multiplets analysis [2].

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6. REFERENCES

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