3Pb2-1

Frequency and azimuth characteristics of active fault vibration by singular value decomposition method
特異値分解法による活断層振動の周波数とその方位性

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1 Abstract
This paper describes the dynamic vibration characteristics of active fault. Deformation of an active fault due to an earthquake is represented by a beach ball, but the deformation is static. The beach ball has a weak relationship with the dynamic seismic waves generated by the rapid deformation of the active fault. Therefore, the dynamic vibration form of the active fault is obtained by signal processing the seismic waves. The result shows a new radiation form including static form. Moreover, the relation between the radiation form and the oscillation in an active fault boundary is clarified.

2. Singular value decomposition method
The singular value decomposition method[1] is used to decompose an orbit matrix consisting of a partial time series of the original observed signal. Singular value decomposition is a means for decomposing using an orthonormal matrix, $\mathbf{U}(m\times r)$, $\mathbf{V}(n\times r)$ that satisfies $\mathbf{U}^T\mathbf{U}=\mathbf{V}^T\mathbf{V}=\mathbf{E}$ ($\mathbf{E}$: identity matrix) when given an arbitrary $m\times n$ matrix X.
The following relationship holds.

$$\mathbf{X}=\mathbf{UWV}^T \quad (1)$$

where, $\mathbf{W}(r\times r)$ is a diagonal matrix that is 0 except for the diagonal elements. The diagonal component $\lambda_1>\lambda_2>\ldots>\lambda_r$ are called the singular value. Putting $\mathbf{U}$ and $\mathbf{V}$ as follows,

$$\mathbf{U}=(u_1,u_2,\cdots,u_r),\quad \mathbf{V}=(v_1,v_2,\cdots,v_r) \quad (2)$$

$\mathbf{X}$ is rewritten as follows,

$$\mathbf{X}=\lambda_1 u_1 v_1^T+\lambda_2 u_2 v_2^T+\cdots+\lambda_r u_r v_r^T \quad (3)$$

This is called the spectral decomposition of the matrix.

3. Azimuth distribution
The beach ball is one of the structural analyzes of active faults. It is constructed from the polarities of the most extreme part of an observed seismic wave. The fault plane is obtained from the nodal plane that the polarity changes. Since the initial polarity is closely related to the fault structure in this way, it is presumed that it is largely dependent on the wave structure after the initial motion. Therefore, we try to estimate the fault structure from the wave structure. The wave structure includes wave shape, level, and vibration period. Next, consider the seismic wave level.

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3.1 Amplitude level
Similar waveforms are often observed when seismic waves are observed. One example is the logarithmic function type. The characteristics of this waveform are the peak level and the vibration frequency. Here, the peak level is used as an index. We examined the M4.9 earthquake that occurred near Mt. Fuji on January 28, 2012. The peak level of the received wave (P wave) obtained at the observation station is displayed with respect to the azimuth angle. The results show in **Fig.1**.The level is an arbitrary logarithmic scale. As is clear from the figure, it is a bipolar distribution consisting of the west where the level changes rapidly with respect to the azimuth and the east where the fluctuation is gentle. The vibration frequency, which is the second factor, is described in the next section.

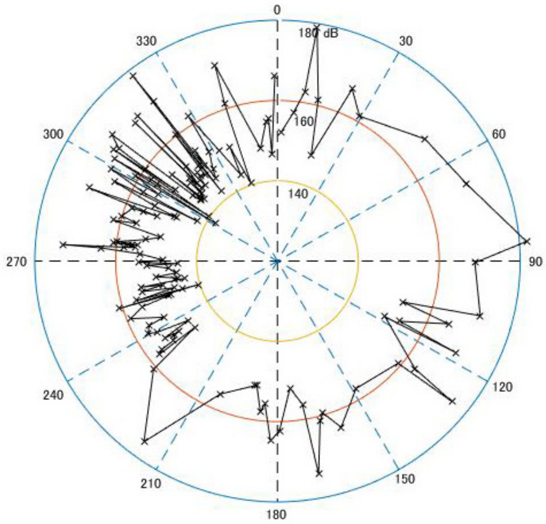

Fig.1 Maximum amplitude level for azimuth.
Target: M4.9 earthquake occurred near Mt. Fuji on January 28, 2012

3.2 Principal frequency
First, the matrix consisting of *n* points with a time interval *dt* is created from the received wave at an observation station. The second matrix is created by delaying the matrix by *dt*. The third matrix is with further *dt* delay. Repeating the process *m* times to get $m\times n$ matrix X. The matrix is called the trajectory matrix. The matrix X is applied to Eq.(1) to obtain W. Further, the singular value $\lambda_1>\lambda_2>\ldots>\lambda_r$ are obtained by applying the Eq.(3). The largest term λ_1 is the main

component and its frequency is the Principal frequency. **Fig.2** shows the azimuth distribution of the principal frequencies obtained for the earthquake shown in Fig.1. In the azimuth range of 220° to 30°, the Principal frequency fluctuates drastically between 1 and 13 Hz with azimuth changes. In the azimuth range of 30° to 220°, the principal frequency is a gradual change of about 5 Hz on average, except for around 200° with respect to changes in azimuth. Compared with Fig.1, the bipolar distribution is more clearly shown.

3.3 Propagation environment correction

The azimuth angle of 200° in Fig.2 is the area with a large topographic change toward Izu Peninsula. The seismic waves used for the calculation in Fig.2 are the wave itself received at each station. However, since the observation station is installed as a fixed point, the observation distance from an epicenter to an observation station changes depending on earthquakes. The observation distances for the earthquakes targeted here are widely dispersed from the shortest Yamakita (7.5 km) to the longest Nagakute (178.6 km). The seismograph installation depth is distributed from 1270 ｍ (Sudama) to -1006 m (Hamamatsu) above sea level. Therefore, changes in the waveform due to changes in the propagation environment cannot be ignored. Therefore, the time reversal method is applied to correct the propagation environment. That is, a received signal is subjected to time reversal processing, and the reversal signal is radiated from the observation depth toward the epicenter in the simulation environment. A parabolic equation method is used for the simulation. That is, the wave replaced in the vicinity of the epicenter is calculated in the same manner as a beach ball. Like the previous section, the singular value decomposition method is applied to the calculated waves to find their principal frequencies. **Figure 3** shows the azimuth distribution of the obtained results. Compared with Fig.2, the fluctuation of the principal frequency with respect to the azimuth angle in Fig.3 became slower and the bipolar became more remarkable. The so-called nodal surface, which changes the initial polar region, plays an important role in the beach ball. The nodal surface of this earthquake is 31° as observed by Japan Meteorological Agency. In Fig.3, the line from 10° or 30° to 210° seems to correspond to the nodal plane. In the theory of the beach ball, the main axis exists in the 45° direction of the nodal surface. However, it is difficult to discuss from the observation results of the beach ball. Therefore, the wave structure in the main axis direction was analyzed using the signals for the same earthquake as in Fig.1. See the literature[2] for processed results.

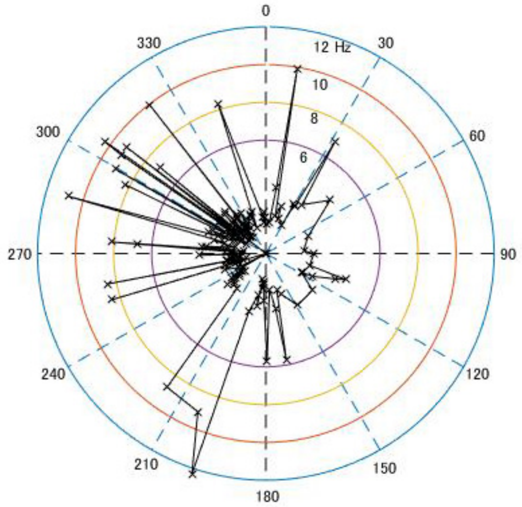

Fig.2 Principal frequency distribution with respect to azimuth for the same earthquake as in Fig.1.

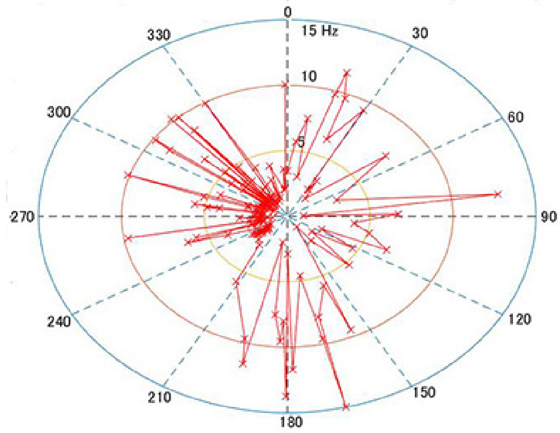

Fig.3 Principal frequency distribution modified by the time reversal method.

Summary

The deformation of the active fault associated with an earthquake is represented by a beach ball. However, although this method represents static crustal movements, its relationship with the seismic waves generated by the vibration of the active faults is weak. Therefore, in order to clarify the dynamic vibration structure of the active fault, we investigated the dynamic vibration structure of the active fault using signal analysis. As a result, it was found that the radiated wave from the dynamic vibration has a bipolar characteristic. In addition, the axis of active fault vibration was obtained from the frequency analysis of the radiated wave. This axial vibration greatly contributes to bipolar formation.

Acknowledgment

Here, we used the data from Hi-net of NIED.

1. M. Masugi, “*Signal analysis*” Morikita Pub.
2. T.Kikuchi et al., ASJ Meeting. 2020.9, 3-7-2