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Simultaneous and independent generation of P and S phases using rotational seismic source (ACROSS)

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1. Introduction

The time-lapse study in focal zone along the subducting plate boundary and volcanic area is extremely important in geophysics and P and S waves are very useful to trace the physical changes of the target zones. For this purpose, we propose use of seismic ACROSS which generates forces by rotation of eccentric mass controlled by GPS time base. The rotational speed varies according to the up-and-down sweep between minimum and maximum frequencies within a certain time window. The current seismic ACROSS changes the rotational direction at an interval of one hour. Most of the existing ACROSS units typically has vertical rotational axis which generates radial and transverse forces, and the most of energy travels as S wave. However, we like to generate P and S simultaneously, so that we consider to adopt the ACROSS source with horizontal rotational axis.

2. Calculation of transfer functions for vertical and horizontal forces

The arithmetic operation of the data observed for the normal and reverse rotation provides the synthetic observation of the single forces for two orthogonal directions.

The position of the center of gravity of the eccentric mass is represented as r(t)=[x,y,z]=[Rcos q(t),Rsin q(t),0], where z is the direction of the motor axis, x is downward, y is the horizontal direction orthogonal to the motor axis, R is the rotation radius of the mass, and q(t) is the time function of phase angle designed for the source operation.

The centrifugal force generated by the mass is $F(t)=-Md^2r(t)/dt^2$ whose Fourier transform is $F(w)=MRw^2[C(w),S(w),0]$. C(w) and S(w) denote the Fourier transform of cos q(t) and sin q(t), respectively. For the reverse rotation, the phase function becomes -q(t) and the force spectrum is $F^-(w)=MRw^2[C(w),-S(w),0]$. We write F for the normal rotation as F^+.

Assuming the linear system U(w)=H(w)F(w) whose input is the force at the source and output is ground motion at the receiver. U is the 3-component vector of displacement or velocity, and H is the second order tensor of the transfer function, which we are to determine. Decomposing the tensor H into three vectors Hx,Hy,Hz, the equation can be rewritten as U(w)=Hx(w)Fx(w)+Hy(w)Fy(w)+Hx(w)Fz(w).

According to this description, the spectra of the ground motion caused by the normal and reverse rotations are

$U^+(w)=H(w)F^+(w)=MRw^2\{Hx(w)C(w)+Hy(w)S(w)\}$,

$U^-(w)=H(w)F^-(w)=MRw^2\{Hx(w)C(w)-Hy(w)S(w)\}$.

Therefore, the transfer functions can be calculated by

$Hx(w)=\{U^+(w)+U^-(w)\}/\{MRw^2C(w)\}$, $Hy(w)=\{U^+(w)-U^-(w)\}/\{MRw^2S(w)\}$.

Note that Hz is unable to be measured by rotation-type ACROSS. The waveforms in time domain are calculated by inverse Fourier transform.

3. Field experiment and its results

In February and March, 2011, we carried out a field experiment of time lapse in Japan to prove the effectiveness of our time lapse method using a newly developed seismic ACROSS-H with the horizontal rotational axis. We used 32 surface and one 800m-borehole stations. Combining of observed records for normal and reverse rotations, we calculated transfer functions for vertical and horizontal forces, respectively. In the UD component at station #7, the P and S arrivals appears at 0.2 and ~0.6s, respectively. The source gather of transfer functions at the all stations are generated. For vertical force P waves are clearly identified, whereas S waves dominate for horizontal force. This result confirms that the transfer functions for vertical and horizontal forces are successfully calculated from the observation records of the normal and reverse rotations of the ACROSS.

4. Conclusions

P and S waves distinctively dominates for calculated vertical and horizontal forces, respectively, so that it is possible to investigate the temporal variations in the propagation manner of P and S waves separately.

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Keywords: P-wave, S-wave, Rotational Source, PS, Simultaneous generation, ACROSS