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Source time functions of North Korean nuclear tests

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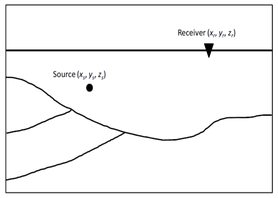
INTRODUCTION

A seismogram is the convolution of the source time function with the earth impulse response, or Green's function. For sources close together, as at the North Korean Test site, the path effects, or Green's functions, from the sources to a given seismometer are almost identical. The filter that converts the seismogram from a smaller event S to the seismogram of a bigger event B also converts the source time function of S to the source time function of B (Filson and Frasier,1978).

Using Blake's (1952) model of an explosion we calculate the best-fitting ratio filter by finding the following parameters: elastic radius of the small source a_s, scale factor of the radii $\alpha = a_B / a_S$, and Poisson's ratio of the rock ν. If the explosion depths are different, this introduces an amplitude factor $\beta > 1$ for the deeper source. We assume the P-wave velocity of the rock is 5,000 m/s. Density cancels.

METHOD



CONVOLUTIONAL MODEL

Velocity seismogram:

$v(t) = s(t) * g(t) + n(t)$

$s(t)$: reduced velocity potential at elastic radius a
$g(t)$: earth impulse response, or Green's function
$n(t)$: noise

RATIO FILTER FOR TWO SOURCES AT THE SAME SITE: ELIMINATE PATH EFFECTS

Velocity seismograms at a given receiver, neglecting noise:

$$\left.\begin{aligned} v_1(t) &= s_1(t) * g(t) \\ v_2(t) &= s_2(t) * g(t) \end{aligned}\right\} \text{ measurements}$$

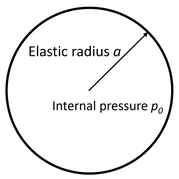
Find a filter $r(t)$ from the data to convert $v_1(t)$ to $v_2(t)$

$v_2(t) = v_1(t) * r(t)$. It follows that

$s_2(t) = s_1(t) * r(t)$

(Filson and Frasier, 1978).

BLAKE'S EXPLOSION MODEL (1952)



Cavity of radius a in a linear elastic whole space:

Density ρ
P-wave velocity v_p
Poisson's ratio ν

Blake derived the displacement potential:

$$\phi(r,t) = \frac{p_0 a^3 K}{\rho v_p^2 r}\left[-1 + \left(\frac{4K}{4K-1}\right)^{\frac{1}{2}} \exp(-\alpha_0 \tau)\cos(\omega_0 \tau - \tan^{-1}(4K-1)^{-\frac{1}{2}})\right]$$, where

$$K = \left(\frac{1}{2}\right)\frac{(1-\nu)}{(1-2\nu)}, \quad \omega_0 = \left(\frac{v_p}{2aK}\right)(4K-1)^{\frac{1}{2}}, \quad \alpha_0 = \left(\frac{v_p}{2aK}\right) \text{ and } \quad \tau = t - \frac{r-a}{v_p}.$$

The displacement is $\frac{\partial \phi}{\partial r}$; the reduced displacement potential is $f(t) = r\phi\big|_{r=a}$

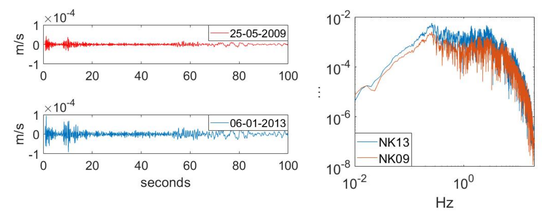
and reduced velocity potential is $f'(t)$.

MODEL-FITTING

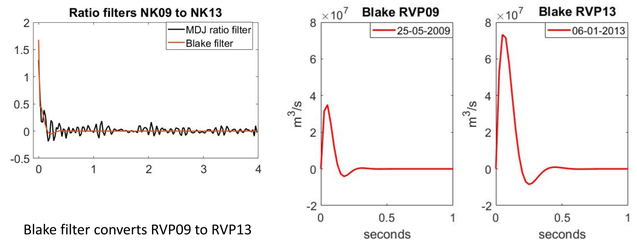
Two source time functions $s_{1B}(t)$ and $s_{2B}(t)$ are computed using Blake's model using the same elastic constants, different elastic radii a and αa and different internal pressures p_0 and βp_0. A ratio filter $r_B(t)$ is calculated to convert $s_{1B}(t)$ to $s_{2B}(t)$, as $s_{2B}(t) = s_{1B}(t) * r_B(t)$. The parameters are adjusted to minimise the error between $r_B(t)$ and $r_B(t)$

EXAMPLE

MDJ SEISMOGRAMS

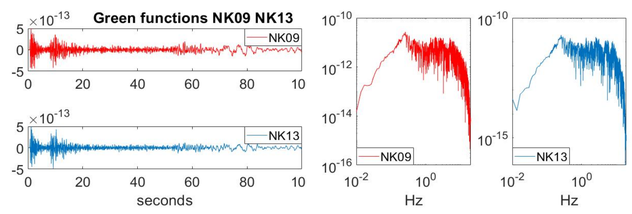


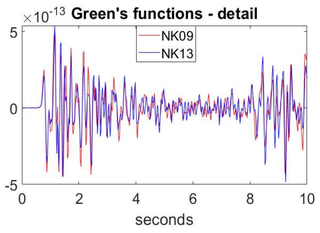
MODEL FITTING



Blake filter converts RVP09 to RVP13

GREEN'S FUNCTIONS OBTAINED BY DECONVOLVING SEISMOGRAMS FOR SOURCE TIME FUNCTIONS





EXTRACTED PARAMETERS

PARAMETER	NK09	NK13
Elastic radius (m)	200	290
Natural frequency (Hz)	3.7	2.6
Poisson's ratio	0.26	0.26

(P-wave velocity assumed 5,000 m/s)

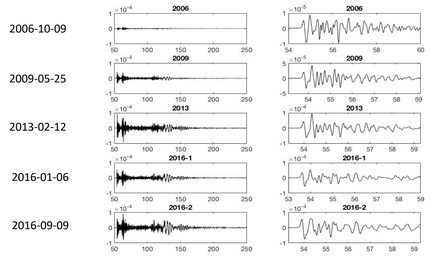
REFERENCES

Blake, F.G., 1952, Spherical wave propagation in solid media: *Journal of the Acoustical Society of America*, Vol **24**, No. 2, 211-215.

Filson, J. and C. W. Frasier, 1972, Multisite estimation of explosive source parameters: *Journal of Geophysical Research*, Vol. **77**, No. 11, 2045-2061.

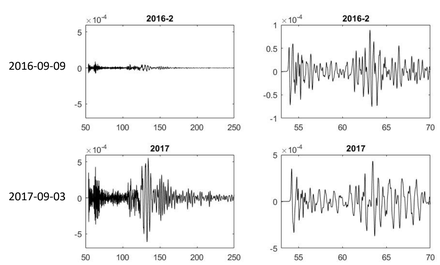
RESULTS

NK events seen at MDJ



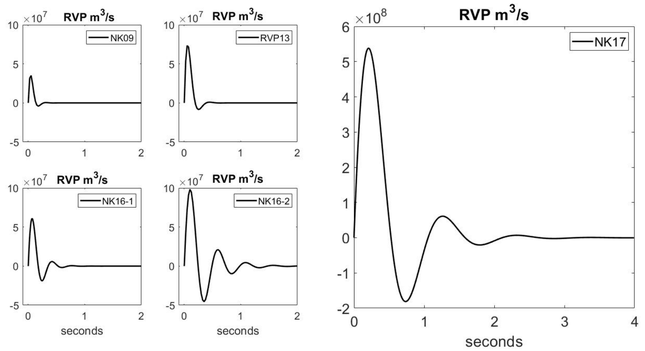
Amplitudes are m/s Time is s.

5th and 6th NK events seen at MDJ

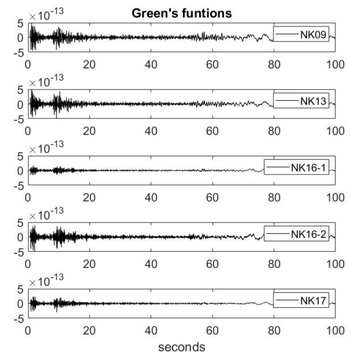


Amplitudes are m/s Time is s..

SOURCE TIME FUNCTIONS



GREEN'S FUNCTIONS



CONCLUSIONS

We have estimated the reduced velocity potential (RVP – m^3/s) of North Korean underground nuclear tests.

The method assumes the path effects from the NK test site to a distant seismometer are identical.

The ratio filter that converts the seismogram from one event to another is the filter that converts the first RVP to the second.

The RVPs are modelled using Blake's 1952 model and the parameters are adjusted to minimise the error between the synthetic and measured ratio filters.

The results are reasonable.

We expect the results to improve by averaging filters from different seismometers to increase the signal-to-noise ratio.

DISCUSSION

NK06 is different and ignored here.

The early source time functions show little oscillation and Poisson's ratio is about 0.3.

Later source time functions show increased oscillations and larger Poisson's ratios, sometimes > 0.4.

The results might improve with better signal-to-noise ratio.

Each nuclear explosion has huge impact on the site. The last one may have destroyed it.

ESTIMATED SOURCE PARAMETERS

Event	Elastic radius (m)	Natural frequency (Hz)	Yield (kt)
NK09	200	3.7	5*
NK13	290	2.6	15
NK16-1	260	2.8	11
NK16-2	300	2.5	17
NK17	800	0.9	320

- **Estimates are all scaled versions of this number. Scale factors are uncertain because of noise in the data.**