Characterization of earthquake ground motion and ambient-noise correlation using a rotational seismometer and an array-based rotational motion

1. Single-station 6C beamforming
2. 36C ambient noise correlation

Nori Nakata (MIT)
Oklahoma rotational data

M5.1, Fairview EQ
Feb 13, 2016
Oklahoma rotational data

M5.1, Fairview EQ
Feb 13, 2016

6C station
GS.OK038
GS.OKR1
(ATA sensor)
Geophone arrays

- Fairfield 5Hz, 3C
- 132 receivers
- 80-m spacing
- Total 2 months in 2017

M5.1, Fairview EQ
Feb 13, 2016
Example of observed data

Translation

Rotation

Time from earthquake origin (s)

Acknowledgment: Adam Ringler (USGS), Bob Pierson (ATA)
Example of observed data

Useful for Single station 6C beamforming

Acknowledgment: Adam Ringler (USGS), Bob Pierson (ATA)
Grid search
Measure distance of Rot and Tra
Measure distance of Rot and Tra
Probability analysis
Probability analysis
Probability analysis
Probability analysis

For all azimuths
Probability analysis

For all azimuths

Azimuth

Velocity

For all azimuths
Transform

Grid search
L2 norm between Rot & Tra

Probability-based approach (proposed approach)
Two waves arrive at same time (Synthetic data by adding two EQ data)

L2 norm between Rot & Tra

Probability-based approach
Two waves arrive at the same time (by adding two EQ data)

Probability-based approach
6C beamforming (back to OK data)

1.0-1.5 Hz

Time from earthquake origin (s)

130 km
6C beamforming

1.0-1.5 Hz

Time from earthquake origin (s)

Array beamforming (49 rec)

130 km
6C beamforming

1.0-1.5 Hz

Array beamforming (9 rec)

Array beamforming (49 rec)

130 km
Geophone arrays

- Fairfield 5Hz, 3C
- 132 receivers
- Total 2 months in 2017

M5.1, Fairview EQ
Feb 13, 2016
Ambient-noise correlation

Processing
Crosscorrelation & more
Ambient noise correlation

(Ambient noise correlation graph showing time, trace number, offset, and speed of 1 km/s and 0.5 km/s.)
Ambient noise correlation

- Source
- Receiver

- Offset
  - 1 km/s
  - 0.5 km/s
1C ambient-noise correlation

Source

Receiver

Z

Z
9C ambient-noise correlation

Source

<table>
<thead>
<tr>
<th>Z</th>
<th>R</th>
<th>T</th>
</tr>
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<tbody>
<tr>
<td>Z</td>
<td>X</td>
<td>X</td>
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<tr>
<td>R</td>
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<td>X</td>
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<tr>
<td>T</td>
<td>X</td>
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Receiver
9C ambient-noise correlation

Source

Z

R

T

Z

R

T

Rayleigh wave

Love wave
36C ambient-noise correlation

<table>
<thead>
<tr>
<th>Receiver</th>
<th>Source</th>
<th>Rayleigh wave</th>
<th>Love wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>Z</td>
<td>←→</td>
<td>×</td>
</tr>
<tr>
<td>R</td>
<td>←→</td>
<td>←→</td>
<td>←→</td>
</tr>
<tr>
<td>T</td>
<td>↑↓</td>
<td>↑↓</td>
<td>↑↓</td>
</tr>
<tr>
<td>rZ (Yaw)</td>
<td>←→ ×</td>
<td>←→ ×</td>
<td>←→ ×</td>
</tr>
<tr>
<td>rR (Roll)</td>
<td>←→</td>
<td>←→</td>
<td>←→</td>
</tr>
<tr>
<td>rT (Pitch)</td>
<td>←→ ✔</td>
<td>←→</td>
<td>←→</td>
</tr>
</tbody>
</table>
36C (two stations)
36C (two stations)
Rayleigh wave

Love wave

…with appropriate time derivative
Potential application: Reflected waves imaging

Nakata et al. (GRL, 2016)
Rayleigh wave

Love wave

...with appropriate time derivative
Ambient noise correlation

Source

Receiver

Rayleigh wave

Love wave

(Z) Z

(R) R

(T) T

(rZ) (Yaw)

(rR) (Roll)

(rT) (Pitch)

25

16

1 km/s

0.5 km/s

Offset

Time (s)

Trace number
Ambient noise correlation

Source

Rayleigh wave

Love wave

Receiver

Z

R

T

rZ (Yaw)

rR (Roll)

rT (Pitch)

Offset

Trace number

Time (s)
Ambient noise correlation

Source

Receiver

Rayleigh wave

Love wave

Z

R

T

rZ (Yaw)

rR (Roll)

rT (Pitch)

Offset

Trace number
Ambient noise correlation
Ambient noise correlation

Source

Receiver

Rayleigh wave

Love wave

Offset

Trace number

Time (s)
**Conclusion**

**Single-station 6C beamforming**

- Higher resolution
- Beamforming in shorter time window

**36C ambient noise correlation**

- Improve SNR
- Better stationary-phase approximation
- Etc.