Body-wave interferometry using local earthquakes

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Other reports
CWP-777 & 778
\[ D(z, \omega) = \frac{u(z, \omega)}{u(1, \omega)} \]
Response to different earthquakes
Velocity vs. acceleration

Velocity (m/s)

Acceleration of observed records (m/s²)
Acknowledgments

ExxonMobil

- Michael Behm
- Filippo Broggini
- Joost van der Neut
### Observed records

<table>
<thead>
<tr>
<th>Trace number</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wz</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Wx</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

![Waveform graphs for Wz and Wx traces over time](image)
Observed records

\[
\sum_{j=EQs} W_z(a, \omega, j) \over W_z(5, \omega, j)
\]
After interferometry
Wavefield decomposition
Time windowing
Multi-D deconvolution (MDD)
Wavefield decomposition

Time windowing

Multi-D deconvolution (MDD)

reduces some crosstalk between P & S
Wavefield decomposition

Observed records

$W_x$

$W_z$

$U_p$

$U_s$

$D_s$

$D_p$
Wavefield decomposition

Observed records

W_x
W_z

U_p
U_s
D_s
D_p
Wavefield decomposition

\[ \sigma_{xz} = 0 \]
\[ \sigma_{zz} = 0 \]

Observed records

\[ W_x, W_z \]

\[ U_p, U_s, D_s, D_p \]
Wavefield decomposition

\[ \sigma_{xz} = 0 \]
\[ \sigma_{zz} = 0 \]

input + BC

output

\[ W_x \] Observed records
\[ W_z \]

\[ UP \ DS \]
\[ DPUS \]
\[ WX \]
\[ ZZ = 0 \]
\[ XZ = 0 \]
Wavefield decomposition

\[ \sigma_{xz} = 0 \]
\[ \sigma_{zz} = 0 \]

\[ W_x \] Observed records
\[ W_z \]

4 equations

4 unknowns

\[ U_p \]
\[ U_s \]
\[ D_s \]
\[ D_p \]
Observed records + BC

\[ W_z(x, t) \quad W_x(x, t) \quad \sigma_{zz} = 0 \quad \sigma_{xz} = 0 \]
Observed records + BC

\[ W_z (k, \omega) \quad \text{and} \quad W_x (k, \omega) \quad \& \quad \sigma_{zz} = 0 \quad \sigma_{xz} = 0 \]
After decomposition

\[ U_p(k, \omega) \quad U_s(k, \omega) \quad D_p(k, \omega) \quad D_s(k, \omega) \]
After decomposition

\[ U_p(x, t) \] 
\[ U_s(x, t) \] 
\[ D_p(x, t) \] 
\[ D_s(x, t) \]
After decomposition

Trace number

Time (s)

Up
Us
Dp
Ds
Wavefield decomposition

Time windowing

Multi-D deconvolution (MDD)

reduces crosstalk between direct waves
not good
T-by-T deconvolution
$T$-by-$T$ deconvolution

Offset (km)

Time (s)

PP

PS

SS
T-by-T deconvolution

\[ U_p^r(B) = G_{pp}(B, A)D_p(A) \]
\[ \frac{U^r_p(B)}{D_p(A)} = G_{pp}(B, A) \]
Crosstalk between P & S

\[
\frac{U_p^r(B)}{D_p(A)} = G_{pp}(B, A) + G_{sp}(B, A) \frac{D_s(A)}{D_p(A)}
\]
Crosstalk of receivers

\[
\frac{U^r_p(B)}{D_p(A_3)} = G_{pp}(B, A_3) + G_{pp}(B, A_1) \frac{D_p(A_1)}{D_p(A_3)} + G_{pp}(B, A_2) \frac{D_p(A_2)}{D_p(A_3)} + \cdots
\]
Wavefield decomposition

Time windowing

Multi-D deconvolution (MDD)

reduces crosstalk between P & S receivers
\[
\begin{pmatrix}
U_r^p(B_1) \\
U_r^p(B_2) \\
\vdots \\
U_s^r(B_1) \\
U_s^r(B_2) \\
\vdots
\end{pmatrix}
= 
\begin{pmatrix}
G_{pp} & G_{sp} \\
G_{ps} & G_{ss}
\end{pmatrix}
\begin{pmatrix}
D_p(A_1) \\
D_p(A_2) \\
\vdots \\
D_s(A_1) \\
D_s(A_2) \\
\vdots
\end{pmatrix}
\]

\[
G_{xy} = 
\begin{pmatrix}
G_{xy}(B_1, A_1) & G_{xy}(B_1, A_2) & \cdots \\
G_{xy}(B_2, A_1) & G_{xy}(B_2, A_2) \\
\vdots & \vdots & \ddots
\end{pmatrix}
\]
T-by-T deconvolution

Offset (km)

0 1 2

Time (s)

PP

PS

SS
Geology

Biryol et al., JGR (in press), 2013
Geology
Wavefield decomposition

Time windowing

Multi-D deconvolution