Broadband Observations of Rotational Ground Motions: Observations and Modelling

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• Array-derived vs. directly measured rotations
• Broadband observations of rotations vs. transverse accelerations
  • Peak rotation rates
  • Waveform comparison with translations
  • Horizontal phase velocities
  • Love wave dispersion
  • P-coda signals

• Conclusions and future
Rotation is the **curl** of the wavefield

... it separates P- and S-wave in isotropic media

\[
\begin{align*}
\omega_x &= \frac{1}{2} \nabla \times \mathbf{v} = \frac{1}{2} \left( \begin{array}{c}
\partial_y v_z - \partial_z v_y \\
\partial_z v_x - \partial_x v_z \\
\partial_x v_y - \partial_y v_x
\end{array} \right)
\end{align*}
\]

**Ground velocity**

**Seismometer**

**Rotation sensor**
Rotation from seismic arrays?
... by finite differencing ...

\[ \omega_z \approx \partial_x v_y - \partial_y v_x \]

Rotational motion estimated from seismometer recordings
Initial Questions

• How do direct observations compare with array-derived rotations?

• Are the direct observations consistent with broadband translations?

• Can we extract any useful information from collocated recordings of translations and rotations?
Array Experiment
Dec 2003-Mar 2004

\[ \omega_z \approx \partial_x v_y - \partial_y v_x \]
First comparison of array-derived rotations (black) and direct ring laser measurements (red)

From Suryanto et al (2006, BSSA, in print)
Theoretical relation
rotation rate and transverse acceleration
plane-wave propagation

Plane transversely polarized wave propagating in $x$-direction with phase velocity

$$u_y(x,t) = f(kx - \omega t) \quad c = \omega / k$$

Acceleration

$$a_y(x,t) = \ddot{u}_y(x,t) = \omega^2 f''(kx - \omega t)$$

Rotation rate

$$\Omega(x,t) = \frac{1}{2} \nabla \times [0, \dot{u}_y, 0] = \left[ 0, 0, -\frac{1}{2} k \omega f''(kx - \omega t) \right]$$

Rotation rate and acceleration should be in phase and the amplitudes scaled by two times the horizontal phase velocity

$$a(x,t) / \Omega(x,t) = -2c$$
Rotational data base

events with varying distance

transverse acceleration - rotation rate

From Igel et al., GJI, 2007
Compatibility with MS
(surface wave magnitude)
$T=30s, c=4300m/s$

\[
M_S = \log_{10} \frac{A}{T} + 1.66 \log_{10} D + 3.3
\]

\[
\Omega_z = 2 \frac{\pi^2}{cT^2} A(M_S, D) = 2 \frac{\pi^2}{cT} 10^{M_S - 1.66 \log_{10} D - 9.3}
\]
$M_w = 8.3$ Tokachi-oki 25.09.2003

transverse acceleration - rotation rate

From Igel et al., GRL, 2005
Max. cross-corr. coefficient in sliding time window
transverse acceleration - rotation rate

Small tele-seismic event

P-onset

S-wave

Love waves

Aftershock
M8.3 Tokachi-oki, 25 September 2003
phase velocities (+ observations, o theory)

Horizontal phase velocity in sliding time window

From Igel et al. (GRL, 2005)
Stacked spectral ratios ...

**Synthetic example**

Four spectral ratios averaged - theoretical dispersion for ak135

![Graph showing phase velocity vs period for fundamental mode Love wave](image)

**Fundamental mode Love wave**
Stacked spectral ratios …
observations – nine teleseismic events

Fundamental mode Love wave
Rotational signals in the P-coda???
Increase in **correlation** (rotation rate vs. transverse acceleration) at P-onset ... observable for all events!

The main cause of this phenomenon must be P-SH scattering.
Rotations - why bother?

- Standard seismological observations are polluted by rotations
- Tiltmeters (rotation around horizontal axes) are polluted by translations
- 6C sensor may allow integration to displacements
- Rotations may contribute to co-seismic structural damage
- Rotational measurements may provide additional wavefield information (phase velocities, etc)
- ... and may allow further constraints on rupture processes ...
Summary
seismic ground rotations

- We do have a new observable for broadband seismology, that is consistent in phase and amplitude with collocated recordings of translations.
- The joint observations allow seismic array-type (but array-free!) processing steps.
- A prototype sensor designed for seismology has been installed at Piñon Flat Observatory, CA.

Open questions:
- Love-wave dispersion, how accurate? -> Tomography? -> What volume does it represent?
- Understanding observations in data base in terms of structure, anisotropy, scattering, source, etc.
- How to improve S/N ratio of ring laser records?
- What technology is best for strong motions?
- Would observations of rotations allow tighter constraints on finite source parameters?
Welcome to the IWGoRS Home page!

The purpose of the International Working Group on Rotational Seismology (IWGoRS) is to promote investigations of all aspects of rotational motions in seismology and their implications to other related fields such as, earthquake engineering, geodesy, strong-motion seismology, tectonics, etc., and to share experience, data, software, and results in an open Web-based environment. In addition, to disseminate information on all matters pertaining to rotational seismology through publications and by holding meetings and workshops, and to interact with professional bodies in engineering and science. A provisional Charter containing the goals, structure, and task groups of IWGoRS is available.

Why and how to join a mailing list? If you are interested in receiving information on any issues happening in the task groups or the working group as a whole you can click on the specific mailing lists and join directly.

If you want to become an active member (providing information on projects, events, news, etc) you can request a login for immediate access.

by Homer Igel — last modified 2006-12-06 11:16
International Working Group on Rotational Seismology aims at

- promoting investigations of all aspects of rotational motions in seismology and their implications for "related fields" such as, earthquake engineering, geodesy, strong-motion seismology, tectonics, etc.

- sharing experience, data, software, and results in an open Web-based environment.

- disseminating information on all matters pertaining to rotational motions through publications and by holding meetings and workshops.

- interacting with professional bodies in engineering and science.

- seeking funding for research projects.
Provisional Sub-Groups

- Processing of rotational motions
- Strong motion
- Theory
- Sensors
- Broadband observations
Sub-Group:  
Processing of rotational motions

Chair: Joachim Wassermann, LMU Munich.

Goals: Development and provision of processing and modelling tools for rotational motions

Current project:
• Developing a new Web-based methodology to archive and process multi-component data with six-degree-of-freedom (6DOF) data (specifically, but not exclusively, included).
• 3-year project, funded by German Research Foundation, Project scientist: Robert Barsch
Sub-Group: Strong Motions

Chair: Misha Trifunac and Maria Todorovska, USC, Los Angeles.

Goals:
- Guidelines and recommendations for how and where to record rotational strong motions.
- Promoting establishment of several full-scale laboratories for measurement of rotational strong motions in buildings and on bridges, dams, and lifelines, as well as in the free field (near and far).
- Developing data processing methods for processing 6DOF strong-motion records.
- Developing software for synthetic generation of realistic rotational accelerograms, to facilitate engineering studies of the associated structural response.
Sub-Group: Theory

Chairs: Alain Cochard, Strasbourg, and Eugeneiusz “Eugene” Majewski, Poland.

Goals:
• The relevance of rotational motions for source inversion.
• Rotational motions in various rheologies (anisotropic, viscoelastic, viscoplastic).
• Understanding the difference between direct rotation and acceleration-derived rotation.
• Physics of rotations in rock-forming minerals: dislocations and disclinations.
• Generation, propagation, and attenuation of seismic rotational waves.
• Dispersion of seismic rotational waves.
• Solitary rotational waves as a fracture mechanism.
Sub-Group: Sensors

This task group will be divided into strong and weak motion sensors.

Chairs: Robert Nigbor, UCLA, John R. Evans, USGS, and Robert Hutt, USGS.

**Strong-motion rotational sensors**

Test sensitivity, linearity, 6DOF cross-axis sensitivity, and self noise of various strong-motion rotational sensors. Work with the USGS Albuquerque Seismological Laboratory to procure and validate improved testing apparatus and to perform precision tests of at least strong-motion rotational sensors.

Chairs: Ulrich Schreiber, Wettzell, and B. Hurst, Christchurch.

**Weak-motion rotational sensors**

Improving the performance of large ring lasers for seismic studies
Verification of rotational sensor data by collocation of alternative techniques
Improve existing detection concepts
Explore and evaluate alternative sensor concepts (FOG, IMU, Superfluid helium, electro-chemical) for telesismic and strong motion application
Develop a full highly sensitive 6-degrees of freedom sensor to be tested at Pinon Flat Observatory and verify the performance (investigate implications of alignment errors)
Develop and evaluate sensor concepts to monitor rotations in civil eng. structures
Enhance productivity by interacting with other development groups
Sub-Group: Broadband Observations

Chairs: Heiner Igel, Munich, and Frank Vernon, SCRIPPS.

Goals:

• Develop infrastructure for data transfer and availability of high-resolution broadband sensors (Wettzell, Germany; Christchurch, New Zealand; Pinon Flat Observatory, California).

• Defining formats for storage and transfer of multi-component ground motion data (e.g., translations, rotations, tilt, strain, etc.).

• Data analysis, interpretation and modeling of observations.

Current projects:

Array-derived rotations and tilt (PhD project Wiwit Suryanto, finished in a few weeks).

Analysis of broadband data (N.D. Pham, PhD project, currently working on P-coda).

2 year postdoctoral position in broadband rotational motions (open and advertised)
The web-interface

Get login for active membership

Join mailing lists (global or subgroup)
Inauguration Lunch

The Garden Terrace Restaurant on the Second Floor of the San Francisco Marriott Hotel, 55 Fourth Street

Today 12:30