INTRODUCTION

Rotational seismology is an emerging field of study concerned with all aspects of rotational motions induced by earthquakes, explosions, and ambient vibrations. Two recent monographs (Teisseyre et al. 2006; Teisseyre et al. 2008) and a Bulletin of the Seismological Society of America special issue on Rotational Seismology and Engineering Applications (Lee, Celebi et al. 2009) are useful starting points. Rotational seismology is of interest to a wide range of disciplines, including various branches of seismology, earthquake engineering, and geodesy, as well as to physicists using Earth-based observatories for detecting gravitational waves generated by astronomical sources, as predicted by Einstein in 1916.

Traditionally, only translational ground motions are observed in seismology. However, we should also measure the three components of rotational motion and the six or more components of strain (Lee, Celebi et al. 2009). We will improve our understanding of the earthquake process (and the complex ground motions it generates) by developing new processing and inversion schemes including the new observables in rotations and strains. In this article we provide a summary of recent activities, some background information, and selected highlights of advances in rotational seismology and engineering applications.

INTERNATIONAL WORKING GROUP ON ROTATIONAL SEISMOLOGY

Following Hudnut (2005) on integrating real-time GPS with inertial sensors (including both translation and rotational), W. H. K. Lee (with K. W. Hudnut and J. R. Evans as coordinators) organized a mini-workshop on rotational seismology on February 16, 2006 (Evans et al. 2007). After the workshop, Evans and Lee contacted other groups active in rotational motions in several countries. An international working group on rotational seismology (IWGoRS) was then organized to promote investigations of rotational motions and their implications and to share experience, data, software, and results in an open Web-based environment (Todorovska et al. 2008).

Anyone can join IWGoRS at http://www.rotational-seismology.org, subscribe to the mailing list, and contribute to the content (publications, data, links, etc.).

The IWGoRS organized a special session on rotational motions in seismology, convened by H. Igel, W. H. K. Lee, and M. Todorovska during the 2006 AGU Fall Meeting (Lee, Igel et al. 2007). The goal was to discuss rotational sensors, observations, modeling, theoretical issues, and potential applications of rotational ground motions. It became apparent that there is a need for a workshop dedicated specifically to rotational seismology so investigators from different countries and different fields can discuss their many issues of mutual interest and draft a research plan.

FIRST INTERNATIONAL WORKSHOP

The First International Workshop on Rotational Seismology and Engineering Applications was hosted by the U.S. Geological Survey (USGS) in Menlo Park, California, on September 18–19, 2007. The technical program consisted of three sessions: plenary and oral presentations on the first day, posters on the second day, and discussions. A post-workshop session was held on September 20 in which scientists of the Laser Interferometer Gravitational-Wave Observatory (LIGO) presented their work on seismic isolation of their ultra-high-precision facility, which requires very accurate recording of translational and rotational components of ground motions (Lantz 2009).

In the plenary session, three lectures were presented for a general audience and the workshop participants. Five oral presentations were given in the afternoon on major areas of research on rotational seismology and engineering issues. The next morning’s session was devoted to 30 posters covering a wide range of topics, including large block rotations in geological-scale time; rotations of monuments after earthquakes; and theories, instruments, observations, and analyses of rotational motions. That afternoon participants divided into five panels for in-depth discussions on theory, far-field observations, near-field monitoring, engineering applications, and instrument design and testing. These discussions were followed by general discussion in which the panel chairs summarized the group discussions, listing key issues and future research directions. The assembled workshop concluded that collaborative work is essen-

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2. Ludwig Maximilian University Munich, Germany
3. University of Southern California, Los Angeles
Potential for nurturing this new field of inquiry. The panel reports and proposed future directions and research plans are described in detail by Lee, Celebi et al. (2007); the DVD in that report contains all presentation files and supporting materials.

**ROTATIONAL EFFECTS DUE TO EARTHQUAKES**

Rotational effects of earthquake waves together with rotations caused by soil-structure interaction have been observed for centuries (e.g., rotated chimneys, monuments, and tombstones relative to their supports). Figure 1(A) shows the rotation of the monument to George Inglis (erected in 1850 at Chatak, India) as observed by Oldham (1899) after the 1897 Great Shillong earthquake. This monument had the form of an obelisk rising over 60 feet high from a base 12 feet on each side. During the earthquake, the topmost six-foot section was broken off and fell to the south, and the next nine-foot section was thrown to the east. The remnant is about 20 feet high and is rotated ~15° relative to the base. Rotation angles are generally given in units of radians (1 rad = 57.3°). Since the instrumentally observed rotations are very small, the units are often given in milli-radians (mrad), or micro-radians (μrad).

A few early authors proposed rotational waves or at least some “vortical” motions. Many different terms were used for the rotational motion components at this early stage of the field’s development. For example, “rocking” is rotation around a horizontal axis, sometimes also referred to as tilt. Ferrari (2006) summarized two models of an electrical seismograph with sliding smoked paper, developed by P. Filippo Cecchi in 1876 to record three-component translation motions and also the torsion movements from earthquakes. Although these instruments operated for several years, no rotational motion could be recorded because of low transducer sensitivity. Mallet (1862) proposed that rotations of a body on the Earth’s surface are due to a sequence of different seismic phases emerging at different angles. Reid (1910, 43–47) studied rotational effects from the 1906 San Francisco earthquake and pointed out that the large observed angles of rotation could not be due to propagation of the rotational components of the seismic waves in the classical elasticity theory. A modern analysis of such rotational effects is presented in Todorovska and Trifunac (1990).

**ROTATIONS CAUSED BY RESPONSE OF STRUCTURES**

Man-made structures reach several tens to several hundreds of meters above the ground. Supported at their base, with their center of gravity near mid-height, structures undergo rocking motions when excited by earthquakes, strong winds, and man-made transient and steady excitations. Through the rocking compliance, the soil-structure interaction converts the incident wave energy into rotational motions of the foundation and the surrounding soil. In this way a building acts as a source of rotational waves. In densely populated metropolitan areas where separation of adjacent buildings is small, building-soil-building interactions occur. In such instances, and where long bridges have multiple supports resting on soil, detailed two- and three-dimensional analyses are required to describe the complex gen-

![Figure 1.](image-url)
eration of rotational response and of rotations in the ground (Trifunac 2008).

Full-scale experiments of soil-structure interaction have provided data to measure and to quantify the nature of the rotational motions at the interface between the soil and the building foundations, but in the absence of recorded rotational strong motion in the near field and in the buildings, engineering studies had to use numerical modeling to assess and estimate the contribution of the rotational motions to the response of structures. For example, Jalali and Trifunac (2009) have shown that the pseudo-relative velocity (PSV) spectral amplitudes for excitation by horizontal, vertical, and rocking ground motion can be represented by superposition of three mathematical terms. This new result emphasizes the significance of rotational ground excitation and why it is necessary to incorporate it into the response estimates in the design of very tall buildings (Zembaty 2009). In another numerical simulation study, Gičev and Trifunac (2009) showed how large seismic waves propagate through the structure and deform its members beyond the linear range of response, and how the creation of nonlinear response zones and their localization (plastic hinges) will give rise to the zones of large local rotations. By placing small-aperture arrays of rotational transducers on beams and columns, they showed how it will be possible to achieve the next level in the resolution of point deformations, because from closely spaced rotational sensors it will be possible to also record the point curvature (Trifunac 1990). Thus, future array measurements of rotational motions in important structures will make it possible to reliably monitor the state of structural health in real time.

TRANSLATIONAL AND ROTATIONAL MOTIONS

The general motion of the particles or a small volume in a solid body can be divided into three parts: translation (along the x, y, and z axes), rotation (about the x, y, and z axes), and strain. Figure 1(B) shows the axes in a Cartesian coordinate system for translational velocity measured by seismometers typically used in seismology, and Figure 1(C) shows the corresponding axes of rotation rate measured by rotational sensors. Figure 1(D) shows earthquake-induced rotation of an almost perfectly symmetrical structure that is difficult to explain without at least some local rotational acceleration.

Since the recurrence interval of a large earthquake at a given active fault can be ~100 to ~10,000 years, seismologists have been optimizing their observations for either 1) studying large earthquakes at great distances or 2) studying small local earthquakes nearby (Lee 2002). Consequently, traditional seismographs are designed to have high sensitivity at the expense of being able to record large motions on scale. Until recent decades, monitoring strong motion from damaging earthquakes has been left to earthquake engineers and their colleagues, generally using accelerometers (Trifunac 2009). In addition, observational seismology is based mainly on measuring translational motions because of a widespread belief that rotational motions are insignificant. For example, Richter (1958, 213, footnote) states that “theory indicates, and observation confirms, that such rotations are negligible.” Richter did not provide any references, and there were no instruments sensitive enough to measure rotation motions at the level of micro-radians (μrad) at that time.

EARLY ATTEMPTS TO STUDY ROTATIONAL MOTIONS

Rotational ground motions can be measured directly by gyroscopic sensors or inferred indirectly from an array of translational sensors. According to Cochard et al. (2006), displacement \( \mathbf{u} \) of a point \( \mathbf{x} \) is related to a neighboring point \( \mathbf{x} + \delta \mathbf{x} \) by

\[
\mathbf{u}(\mathbf{x} + \delta \mathbf{x}) = \mathbf{u}(\mathbf{x}) + \varepsilon \delta \mathbf{x} + \omega \times \delta \mathbf{x}
\]

(1)

where \( \varepsilon \) is the strain tensor and

\[
\omega = \frac{1}{2} \nabla \times \mathbf{u}(\mathbf{x})
\]

(2)

is a pseudo vector representing the infinitesimal angle of rigid rotation generated by the disturbance. The three components of rotation about the x axis, y axis, and z axis are given by the following equations for such infinitesimal motions:

\[
\omega_x = \frac{1}{2} \left( \frac{\partial u_y}{\partial z} - \frac{\partial u_z}{\partial y} \right),
\omega_y = \frac{1}{2} \left( \frac{\partial u_z}{\partial x} - \frac{\partial u_x}{\partial z} \right),
\omega_z = \frac{1}{2} \left( \frac{\partial u_x}{\partial y} - \frac{\partial u_y}{\partial x} \right)
\]

(3)

Therefore, rigid rotations can be observed: 1) indirectly by an array of translational seismometers for “cord” rotations (Equation 2) associated with long wavelengths by assuming that contamination of translational signals by rotational motions is small, and that classical elasticity theory is valid (e.g., Spudich and Fletcher 2008); or 2) by rotational sensors directly for “point” rotations (e.g., Lee, Huang et al. 2009).

Pioneers in several countries attempted to measure rotational motions induced by earthquakes. Nearly a century ago, Galitzin (1912) suggested using two identical pendulums installed on different sides of the same axis of rotation for separate measurement of rotational and translational motion. This was later implemented, for example, by Kharin and Simonov (1969) in an instrument designed to record strong ground motion. Using an azimuthal array of seismographs, Droste and Teisseire (1976) derived rotational seismograms for rock bursts in a nearby mine. Inspired by Walter Munk, Farrell (1969) constructed a gyroscopic seismometer and obtained a static displacement of < 1 cm and a tilt of < 0.5 μrad at La Jolla, California, during the Borrego Mountain earthquake of 9 April 1968 (magnitude 6.5) at an epicentral distance of 115 km.

Early efforts also included studies of explosions. For example, Graizer (1991) recorded tilts and translational motions in the near field of two nuclear explosions, using seismological observatory sensors to measure point rotations directly. Nigbor (1994) measured rotational and translational point ground motions directly with a commercial rotational MEMS sensor.
observes frequency splitting, thus a beat frequency. This beat rotating and the counter-rotating laser cavity differs, and one to inertial space, the effective cavity length between the co-squared closed evacuated cavities in which the light beams inter-

In the past decade, rotational motions—from small local earthquakes to large teleseisms—were successfully recorded by sensitive rotational sensors in several countries (e.g., Spudich and Fletcher 2008). The rotational components of ground motion have also been estimated theoretically, using kinematic source models (Bouchon and Aki 1982) and the linear elastodynamic theory of wave propagation in elastic solids (Lee and Trifunac 1985, 1987).

LARGE RING LASER GYROS

An unexpected advance in studying rotational ground motions came from a different field. Recent developments of highly sen-
sitive ring laser gyroscopes to monitor the Earth’s rotation also yield interesting data on rotational motions from large teleseismic events. The two most important properties that make a rotation sensor useful for seismology are its noise floor for rotational and strain fields can create rotations separate from those predicted by classical elastodynamic theory (e.g., Teisserre and Boratynski 2003). These rotations naturally generate rotational seismic waves and seismic spin and twist solitons (Majewski 2006).

THE G RING LASER AT WETTZELL

Since October 2001, The G ring laser has been operating at the Fundamentalstation Wettzell, in Bavaria, Germany (http://www.fs.wettzell.de/). A cross-section view of the site of the G ring laser is shown in Figure 2(A). The instrument is resting on a polished granite table (Figure 2B) being embedded in a 90-ton concrete monument. As shown in Figure 2(A), the monument is attached to a massive 2.7-m-diameter concrete pillar, which is founded on crystalline bedrock 10 m below. A system of concrete rings and isolation material shields the monument and pillar from lateral weathered-rock deformations and heat flow. The G ring laser is protected from external influences by a subsurface installation with passive thermal stability provided by a 2-m layer alternating between Styrofoam and wet clay, this beneath a 4-m soil mound. A lateral entrance tunnel with five isolating doors and a separate control room minimize thermal perturba-
tions during maintenance. After two years of thermal adapta-
tion, the average temperature reached 12.2°C with seasonal variations of less than 0.6°C. Figure 2(C) shows the schematic drawing of the instrument, and Figure 2(D) is a photo of the G ring laser with its designer, Ulli Schreiber, standing to the right.
Figure 2. G ring laser gyro at the Wettzell Superstation, Germany. (A) Cross-section view of the instrument site. (B) Instrument resting on a granite table. (C) Schematic drawing. (D) Photo of G ring laser gyro with its designer, Ulli Schreiber. See text for explanation.
Figure 3 shows a comparison of direct point measurements of ground rotations around a vertical axis (red lines) to transverse accelerations (black lines, converted to rotation rate for each time window) for the M 8.1 Tokachi-oki earthquake, 25 September 2003 (Igel et al. 2005). Figure 3(A) is a schematic view of the great-circle-path through the epicenter in Hokkaido, Japan, and the observatory in Wettzell, Germany. Figure 3(B–E) shows the superposition of the rotation rate derived from transverse translations (black) and measured directly (red) for different time windows: (B) for the complete signal, (C) for the latter part of the surface wave train, (D) for the direct S-wave arrival, and (E) for the initial part of the surface wave train.

**SMALL INERTIAL ANGULAR SENSORS**

In aerospace, automotive, and mechanical engineering, small rotational motion sensors are common and generically known as gyroscopic or inertial angular sensors. Nigbor (1994) used a micro-electro-mechanical-systems-based (MEMS-based) Coriolis sensor to measure the rotational components of strong ground motions of a large chemical explosion, as mentioned above. Similar sensors were used by Takeo (1998) to measure rotational motions from an earthquake swarm ~3 km away. However, such sensors do not have the sensitivity to record rotations from small (M ~ 4) local earthquakes at distances of tens of kilometers.

The eentec model R-1 rotational seismometer is the first modestly priced sensor capable of recording small M ~ 4 earthquakes at distances up to several tens of kilometers. It uses electrochemical technology in which the motion of an electrolytic fluid inside a torus is sensed electronically, yielding a voltage signal proportional to rotational velocity. Nigbor et al. (2009) carried out extensive tests of commercial rotational sensors and concluded that the R-1 sensor generally meets the specifications given by the manufacturer, but that clip level and frequency response vary from those specifications and between
individual channels enough that more detailed calibrations are warranted for each unit. A typical transfer function for the R-1 sensor can be found at the manufacturer’s website (http://www.eentec.com/). The instrument response is roughly “flat” from 0.1 to 20 Hz, and its self noise is <10 μrad/s rms over the same frequency band.

The R-1 rotational seismometers successfully recorded several hundred local earthquakes and two explosions in Taiwan (Lee, Huang et al. 2009). Figure 4(A) shows the instruments...
DISCUSSION

Many authors have already emphasized the benefits of studying rotational motions (e.g., Twiss et al. 1993; Spudich et al. 1995; Takeo and Ito 1997; Teisseyre et al. 2006; Trifunac 2006, forthcoming; Igel et al. 2007; and Fichtner et al. 2009). We will discuss briefly some basic issues.

Classical Elasticity versus Other Theories

Real materials of the Earth are heterogeneous, anisotropic, and nonlinear, especially in the damage zone surrounding faults and in poorly consolidated sediments and soil just beneath seismic instruments. In the presence of large nonlinearities, we are forced to consider the mechanics of chaos (Trifunac, forthcoming), and to interpret such complexities we must record the rotational components of strong motion in addition to the translational components.

Seismology is primarily based on the linear elasticity theory of simple homogeneous materials under infinitesimal strain. This theory was mostly developed in the early nineteenth century. Since then, linear elasticity theory has been embedded in seismology. “Cord” rotation is defined as the curl of the displacement field in Equation 2, and in linear elasticity theory, the rotational components of motion are contained in the $\bar{\delta}$ waves. Meanwhile, modern continuum mechanics in the past century has advanced far beyond the classical linear elastic theory. In particular, the elasticity theory of the Cosserat brothers (Cosserat and Cosserat 1909) incorporates 1) a local rotation of continuum particles as well as the translational motion assumed in classical theory, and 2) a couple stress (a torque per unit area) as well as the force stress (force per unit area). In the constitutive equation of classical elasticity theory there are two independent elastic constants; in Cosserat elastic theory there are six or more elastic constants. Pujol (2009) provides a tutorial on rotations in the theories of finite deformation and micropolar (Cosserat) elasticity. Twiss (2009) derives an objective asymmetric micropolar moment tensor from a discrete-block model for a deforming granular material. He also investigates seismogenic deformation associated with volumes of distributed seismicity in three different areas and finds support of the micropolar model for the effects of a granular substructure on the characteristics of seismic focal mechanisms.

Near-Field Seismology

Seismology has been very successful in the far field because large earthquakes occur every week somewhere on Earth and because classical elasticity theory works very well for interpreting the recorded translational motions at large distances. Because of this success and limited instrumentation options, most funding for earthquake monitoring historically has gone into global and regional seismic networks using only translational seismometers. However, to improve our understanding of damaging earthquakes we must also deploy appropriate instruments in the near field of active faults where large earthquakes ($M > 6.5$) occur infrequently. As is true for all strong-motion seismology and engineering, this is a risky business

BSSA SPECIAL ISSUE

In recognition of this emerging field of study, on 31 August 2007 the Seismological Society of America approved the publication of a special issue. More than 50 manuscripts were received after an open call for papers. The BSSA special issue (Lee, Celebi et al. 2009) contains an introduction, four reviews, 27 research articles, 11 short notes, six tutorials, and three supplements. The six tutorials and three supplements are intended to help readers who are not familiar with rotational seismology. For example, Grekova and Lee (2009) compiled suggested readings that may be useful in providing mathematical and physical bases for rotational seismology. They also included some suggested readings in earthquake seismology for scientists who are not seismologists. Because standard dictionaries may not include new technical terms, Lee (2009) compiled a list of glossary terms for rotational seismology from contributions of some of the authors of the special issue and also included some glossary terms on earthquakes. Readers are encouraged to read this BSSA special issue; its table of contents is highlighted in this issue of SRL on page 508.
because a large earthquake on any given fault may not take place for hundreds of years—many times longer than the carrier span of any scientist. Therefore, seismologists and earthquake engineers must accumulate data over centuries and must be willing to invest substantial resources in order to observe earthquakes in the near field.

Recording ground motions in the near field would require extensive seismic instrumentation along some well-chosen active faults—and luck. Several seismologists have been advocating such instrumentation. A current deployment in southwestern Taiwan by that nation’s Central Weather Bureau is designed to “capture” a repeat of the 1906 Meishan earthquake (M 7.1) with both translational and rotational instruments (Wu et al. 2009).

Processing collocated observations of Translations and Rotations
Processing collocated observations of rotation and translation is routinely performed in the inertial navigation units of aircraft and space vehicles. A similar analysis should be possible for various combinations of strain components, rotations, and translations. With the exception of velocity-strain combinations (e.g., Gomberg and Agnew 1996) this terrain is largely unexplored.

Phase velocities and propagation directions. A simple calculation for linear-elastic plane (not dispersed) waves with transverse polarization shows that the ratio of transverse acceleration to rotation rate is proportional to phase velocity. This implies that information on subsurface velocity structure (otherwise only accessible through seismic array measurements and combined analyses) is contained in a single point measurement. It has been shown that the ratio-derived phase velocities agree with the velocities predicted by calculation (Igel et al. 2005). In a recent theoretical study based on full ray theory for Love waves, using normal mode summation, it has been demonstrated that the Love wave dispersion relation can be obtained simply by taking the spectral ratio of transverse acceleration to rotation rate (vertical axis; Ferreira and Igel 2009). This result implies that seismic shear wave tomography can be possible without relating seismic observations from different stations, that is, without averaging over subarrays used to compute local mean phase velocities. Information on the direction of propagation also is contained in the azimuth-dependent phase fit between rotations and translations. This fit is optimal in the direction of propagation, from which back azimuths can be estimated to within a few degrees (Igel et al. 2007). Linking observational translations, strains, and rotations together can yield a snapshot of the wavefield where wave direction, slownesses, and radial/azimuthal amplitude gradients can be directly inferred from the data; Langston (2007) has also advocated this approach.

Toward a new kind of tomography. The possibility of deriving local dispersion relations from single stations leads to the question of which subsurface volume one actually “sees” and down to what depth velocity perturbations can be recovered. The method of choice to answer this type of question is the adjoint method, with which sensitivity kernels can be calculated to indicate the volume in which the observable (mostly travel times) is sensitive to structural perturbations. Fichtner and Igel (2009) introduced a new observable quantity—apparent shear wave velocity—which is a time-windowed ratio of the moduli of velocity and rotation angle. It turns out that the sensitivity near the source vanishes, leading to a new type of kernel that shows high sensitivity in the vicinity of the receiver only. This result implies that a tomographic inversion scheme for near-receiver structures based on rotations and translations is possible and further highlights the potential of rotation measurements. Preliminary synthetic tomographic inversions are given in Bernauer et al. (2008). Scattering properties of the crust: Partitioning of P and S waves. The partitioning of P and S energy and the stabilization of the ratio between the two is an important constraint on the scattering properties of a medium. It was a surprise to discover considerable rotational energy in a time window containing the P coda in the teleseismic seismometer records of Igel et al. (2007). Detailed analysis of the signals and modeling of wave propagation through three-dimensional random media demonstrated that the observed signals can be explained with P–SH scattering in the crust with scatterers of roughly 5-km correlation length (not well-constrained) and rms perturbation amplitude of 5% (well-constrained). This result further illustrates the efficacy of rotation measurements, for example, as a filter for SH-type motion. Similar processing steps will be possible for the horizontal components of rotation and the corresponding components of translation. It is conceivable that the combination of these various components might lead to tight constraints on near-receiver structure, results otherwise only available from array measurements.

CONCLUSION

Seismology and earthquake engineering are based primarily on the observation and modeling of three-component translational ground and structural motions. Although rotational effects from earthquakes have been observed for centuries, rotational ground motion has been ignored due to a widespread belief that rotation is insignificant, and because there were practical difficulties in measuring rotation. Seismology has been very successful in the far field using linear elasticity theory, where it is appropriate to assume infinitesimal stress and strain for interpreting the recorded translational motions. However, to improve our understanding of damaging earthquakes we must also deploy appropriate instruments in the near field of active faults where large earthquakes (M > 6.5) occur infrequently. Furthermore, by deploying both translational and rotational sensors, we can learn a lot more about earthquakes, as discussed in the previous section. Theoretical work in modern rotational seismology began in the 1970s, and attempts to deduce rotational motion from
accelerometer arrays began in the 1980s. However, modern direct measurements of rotational ground motions began only about a decade ago when affordable commercial angular inertial sensors became sensitive enough to detect microradian rotations while large ring laser gyrods (intended for studying the Earth’s rotation) became capable of detecting nanoradian rotations.

Ring laser observations at Wettzell, Germany, and Piñon Flat, California, demonstrated consistent measurements of rotational ground motions in the far field. So far this success can only be demonstrated with one component of rotation. The high cost of present high-precision ring laser gyrods makes widespread deployment unlikely. Less expensive and/or less sensitive alternatives are now being pursued by five academic groups (Cowsik et al. 2009; Dunn et al. 2009; Jedlička et al. 2009; Schreiber, Velikoseltsev et al. 2009; Takamori et al. 2009). At present, only Taiwan has a modest program to monitor both translational and rotational ground motions from local and regional earthquakes at several free-field sites, as well as two arrays equipped with both accelerometers and rotational seismometers in a building and a nearby site (Wu et al. 2009). The goal is to record both translational and rotational ground motions in the near field of damaging earthquakes.

Based on the developments described in the BSSA special issue, we believe that observation, analysis, and interpretations of both rotational and translational ground motions will soon play a significant role in seismology and earthquake engineering.

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