UNIVERSITY OF CALIFORNIA, SAN DIEGO

Seismogeodesy and Rapid Earthquake and Tsunami Source Assessment

A dissertation submitted in partial satisfaction of the
requirements for the degree
Doctor of Philosophy

in

Earth Science

by

Diego Melgar Moctezuma

Committee in charge:

    Yehuda Bock, Chair
    T. Guy Masters
    David T. Sandwell
    Peter M. Shearer
    Jose I. Restrepo

2014

The dissertation of Diego Melgar Moctezuma is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

_____

_____

_____

_____

_____
Chair

University of California, San Diego

2014

DEDICATION

To two, the loneliest number since the number one.

EPIGRAPH

*A careful quotation
conveys brilliance.*
—Smarty Pants

ACKNOWLEDGEMENTS

2009	B. Eng. in Geophysics *cum laude*, Universidad Nacional Autonoma de Mexico
2010	M. Sc in Earth Science University of California, San Diego
2014	Ph. D. in Earth Science, University of California, San Diego

PUBLICATIONS

Crowell, B.W., **Melgar, D.**, Bock, Y., Haase, J.S, and Geng, J., "Earthquake Magnitude Scaling using Seismogeodetic Data", *Geophys. Res. Lett*, 40(23), 2013.

Melgar, D. and Bock, Y. "Near-Field Tsunami Models with Rapid Earthquake Source Inversions from Land- and Ocean-Based Observations: The Potential for Forecast and Warning", *J. Geophys. Res.*, 118(11), 2013.

Geng, J., **Melgar, D.**, Bock, Y., Pantoli, E., and Restrepo, J.I., "Recovering coseismic point ground tilts from collocated high-rate GPS and accelerometers", *Geophys. Res. Lett*, 40(19), 2013.

Melgar, D., Pantoli, E., Bock, Y., and Restrepo, J.I., "Displacement Acquisition for the NEESR:BNCS Building Shaketable Test via GPS Sensors", *Network for Earthquake Engineering Simulation (distributor)*, DOI:10.4231/D3V97ZR5H, 2013.

Melgar, D., Crowell, B.W., Bock, Y., and Haase, J.S, "Rapid modeling of the 2011 Mw 9.0 Tohoku-oki earthquake with seismogeodesy", *Geophys. Res. Lett*, 40(12), 2013.

Geng, J., Bock, Y., **Melgar, D.**, Crowell, B.W., and Haase, J.S, "A new seismogeodetic approach applied to GPS and accelerometer observations of the 2012 Brawley seismic swarm: Implications for earthquake early warning", *Geochem. Geophys. Geosyst*, 14(7), 2013.

Melgar, D., Bock, Y., Sanchez, D., and Crowell, B.W., "On Robust and Reliable Automated Baseline Corrections for Strong Motion Seismology", *J. Geophys. Res.*, 118(3), 2013.

Perez-Campos, X., **Melgar, D.**, Singh, S.K., Cruz-Atienza, V., Iglesias, A., and Hjorleifsdottir, V., "Determination of tsunamigenic potential of a scenario earthquake in the Guerrero seismic gap along the Mexican subduction zone", *Seism. Res. Lett*, 84(3), 2013.

Crowell, B.W., Bock, Y., and **Melgar, D.**, "Real-time inversion of GPS data for finite fault modeling and rapid hazard assessment", *Geophys. Res. Lett*, 39(9), 2012.

Singh, S.K., Perez-Campos, X., Iglesias, A., **Melgar, D.**, "A Method for Rapid Estimation of Moment Magnitude for Early Tsunami Warning Based on Coastal GPS Networks", *Seism. Res. Lett*, 83(3), 2012.

Melgar, D., Bock, Y., and Crowell, B.W., , "Real-Time Centroid Moment Tensor Determination for Large Earthquakes from Local and Regional Displacement Records", *Geophys. J. Int.*, 188(2), 2012.

Bock, Y., **Melgar, D.**, and Crowell, B.W., "Real-Time Strong-Motion Broadband Displacements from Collocated GPS and Accelerometers", *Bull. Seism. Soc. Am.*, 101(6), 2011.

Melgar, D. and Perez-Campos, X., "Imaging the Moho and Subducted Oceanic Crust at the Isthmus of Tehuantepec, Mexico, from Receiver Functions", *Pure Appl. Geophysics*, 168, 2010.

ABSTRACT OF THE DISSERTATION

Seismogeodesy and Rapid Earthquake and Tsunami Source Assessment

by

Diego Melgar Moctezuma

Doctor of Philosophy in Earth Science

University of California, San Diego, 2014

Yehuda Bock, Chair

This dissertation will be abstract.

Chapter 1

Introduction

This is only a test.

1.1 Early Warning and Rapid Response in Natural Hazards

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Nulla odio sem, bibendum ut, aliquam ac, facilisis id, tellus. Nam posuere pede sit amet ipsum. Etiam dolor. In sodales eros quis pede. Quisque sed nulla et ligula vulputate lacinia. In venenatis, ligula id semper feugiat, ligula odio adipiscing libero, eget mollis nunc erat id orci. Nullam ante dolor, rutrum eget, vestibulum euismod, pulvinar at, nibh. In sapien. Quisque ut arcu. Suspendisse potenti. Cras consequat cursus nulla.

1.1.1 More Stuff

Blah

*

Figure 1.1: A figure of Vonnegut.

1.2 Geodesy and Seismology

1.3 Earthquake and Tsunami Hazards

Chapter 2

Seismogeodesy and Strong Motion Sensing

2.1 Strong Motion Sensing

The range of motions produced by the seismic source is broad both in frequency and dynamic range. It is well known that no one sensor can capture all signals of interest to seismology and earthquake engineering [Havskov and Alguacil, 2006]. Seismologists typically rely on seismometers, whose response is related to velocity of the ground, for measurement of small amplitude signals (weak motion), but for large amplitude signals these sensitive instruments saturate or clip. In this case, strong motion sensors, whose response is related to the acceleration of the ground and have lower gains, are preferred. Modern observatory grade accelerometers rely on the force feedback principle and can measure motions as small as 1 nm at 1 Hz and 100 nm at 0.1 Hz and accelerations of up to 4g. Furthermore their frequency response is flat from DC to 50-200 Hz [Havskov and Alguacil, 2006].

Thus, in principle there should be no difficulty in integrating a strong motion record to velocity and displacement. This is not the case; in practice the simple integration of an accelerogram produces unphysical velocity and displacement waveforms that grow unbounded as time progresses. Computation of broadband displacements from strong motion recordings is a thoroughly studied

procedure that is fraught with many known problems and has no known single solution. By "broadband dispalcement" it is meant a strong motion displacement waveform that captures both transient phenomena (waves) and permanent or static deformation, i.e. a recording reliable from zero frequency (often referred to as the DC level) to the Nyquist frequency. The problems associated with the double integration of accelerometer recordings have been comprehensively studied and many sources of error have been suggested: numerical error in the integration procedure, mechanical hysteresis, cross-axis sensitivity and unresolved rotational motions [Graizer, 1979], [Iwan et al., 1985], [Boore, 1999], [Boore, 2001], [Boore et al., 2002], [Smyth and Wu, 2007]. It is generally assumed that small offsets are introduced in the acceleration time series; upon integration these baseline offsets produce the linear and quadratic trends observed in the velocity and displacement time series, respectively. Many possible sources have been invoked as the source of these offsets with unresolved rotational motion increasingly considered the main error [Graizer, 2006], [Pillet and Virieux, 2007]. Motion is described by six degrees of freedom, three translations and three rotations. Accelerometers are incapable of discerning between rotational and translational motions, thus, rotational motions are recorded as spurious translations. Effectively this results in a change of the baseline of the accelerometer, even if by a small amount, leading to unphysical drifts in the singly integrated velocity waveforms and doubly integrated displacement waveforms. Many correction schemes, collectively known as baseline corrections, have been proposed over time to deal with this problem. Rotational motions become more prevalent close to the source and at long periods Graizer, 2006 thus the simplest baseline correction scheme is a high-pass filter Boore and Bommer, 2005. This leads to accurate recovery of the mid to high frequency part of the displacement record but suppresses completely long period information such as the static offset. To ameliorate this, a number of more elaborate correction schemes exist Boore Bommer, 2005 that rely on function fitting to the singly integrated velocity time series. The most reliable scheme that routinely produces plausible displacement waveforms (which include a measure of the static offset) is described in Boore 1999, 2001 and is a modification of the scheme proposed by Iwan

h *

Figure 2.1: A figure of Vonnegut.

et al 1985 and henceforth referred to as the Boore-Iwan or BI correction scheme. In this method a piece-wise linear function is fit to the uncorrected velocity time series, the slope of each straight line segment represents an acceleration step which is then subtracted from the original acceleration data. This baseline corrected acceleration record is subsequently integrated to velocity and displacement. If the intervals for fitting the linear functions to the velocity data are selected appropriately this algorithm will produce waveforms that look plausible. They will contain both permanent and transient motions. The difficulty then lies in determining what these appropriate time intervals are from the data themselves. As discussed by Boore 1999 2001 this is an ambiguous process. To diminish this uncertainty, subsequent research has focused on determining plausible times for the fits and then grid searching for waveforms that most resembles a ramp or step function Wu and Wu, 2007; Chao et al., 2010; Wang et al., 2011.

2.1.1 More Stuff

Blah

2.2 Geodesy and Seismology

2.3 Earthquake and Tsunami Hazards

Chapter 3

Rapid Static Modeling

This is only a test.

3.1 A section

Lorem ipsum

3.1.1 More Stuff

Blah

*

Figure 3.1: A figure of Vonnegut.

3.2 Geodesy and Seismology

3.3 Earthquake and Tsunami Hazards

Chapter 4

Kinematic Source Inversions

This is only a test.

4.1 A section

Lorem ipsum

4.1.1 More Stuff

Blah

*

Figure 4.1: A figure of Vonnegut.

4.2 Geodesy and Seismology

4.3 Earthquake and Tsunami Hazards

Chapter 5

Offshore Data and Tsunami Modeling

This is only a test.

5.1   A section

Lorem ipsum

5.1.1   More Stuff

Blah

*

Figure 5.1: A figure of Vonnegut.

5.2   Geodesy and Seismology

5.3   Earthquake and Tsunami Hazards

Chapter 6

Conclusions and Future Outlook

This is only a test.

6.1 A section

Lorem ipsum

6.1.1 More Stuff

Blah

*

Figure 6.1: A figure of Vonnegut.

6.2 Geodesy and Seismology

6.3 Earthquake and Tsunami Hazards

Bibliography

[Boore, 1999] Boore, D. M. (1999). Effect of baseline corrections on response spectra for two recordings of the 1999 chi-chi, taiwan, earthquake. *U.S. Geol. Surv. Open-File Rept.*, 99(545):1–37.

[Boore, 2001] Boore, D. M. (2001). Effect of baseline corrections on displacements and response spectra for several recordings of the 1999 chi-chi, taiwan, earthquake. *Bulletin of the Seismological Society of America*, 91(5):1199–1211.

[Boore et al., 2002] Boore, D. M., Stephens, C. D., and Joyner, W. B. (2002). Comments on baseline correction of digital strong-motion data: Examples from the 1999 hector mine, california, earthquake. *Bulletin of the Seismological Society of America*, 92(4):1543–1560.

[Graizer, 1979] Graizer, V. (1979). Determination of the true ground displacement by using strong motion records. *Izvestiya Academy of Sciences, USSR, Physics of the Solid Earth*, 15(12):875–885.

[Graizer, 2006] Graizer, V. (2006). Tilts in strong ground motion. *Bulletin of the Seismological Society of America*, 96(6):2090–2102.

[Havskov and Alguacil, 2006] Havskov, J. and Alguacil, G. (2006). *Instrumentation in Earthquake Seismology*. Springer, New York, NY, first edition.

[Iwan et al., 1985] Iwan, W. D., Moser, M. A., and Peng, C.-Y. (1985). Some observations on strong-motion earthquake measurement using a digital accelerograph. *Bulletin of the Seismological Society of America*, 75(5):1225–1246.

[Pillet and Virieux, 2007] Pillet, R. and Virieux, J. (2007). The effects of seismic rotations on inertial sensors. *Geophysical Journal International*, 171(3):1314–1323.

[Smyth and Wu, 2007] Smyth, A. and Wu, M. (2007). Multi-rate kalman filtering for the data fusion of displacement and acceleration response measurements in dynamic system monitoring. *Mechanical Systems and Signal Processing*, 21(2):706–723.