Summary of Activities while at the Earthquake Research Institute, the University of Tokyo.

(DRAFT)

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Overview

I am extremely grateful to ERI for inviting me to spend a significant fraction of my sabbatical leave in Tokyo. This has been a very rewarding time.

The activities listed below identify what I consider to be the more significant completed projects, and the more interesting ideas for projects to work on over the coming months.

1. Publications completed while in Japan.

Anderson, J. G., I. Tibuleac, A. Anooshehpoor, G. Biasi, K. Smith and D. von Seggern (2009). Exceptional ground motions recorded during the 26 April 2008 MW 5.0 earthquake in Mogul, Nevada, Bulletin of the Seismological Society of America 99, 3475-3486.

Anderson, J. G. (2010). Source and site characteristics of earthquakes that have caused exceptional ground accelerations and velocities, Bulletin of the Seismological Society of America, Vol. 100, No. 1, pp. 1–36, February 2010, doi: 10.1785/0120080375.

(Both were submitted for publication before coming to Japan. Journal reviews were considered and the manuscripts completed while at ERI.)

2. Research papers submitted while in Japan.

"A METHODOLOGY TO IMPROVE GROUND MOTION PREDICTION EQUATIONS BY INCLUDING SOURCE-TO-SITE CORRECTIONS", Anderson, J. G., Uchiyama, Y., *Bulletin of the Seismological Society of America*.

Path effects that are unique to the source-path geometry increase the uncertainties in ground motion prediction equations (GMPEs). A methodology, made possible by digital accelerograph networks that record moderate as well as large earthquakes, is proposed to deal with this issue. A ground motion prediction model is developed including site and event terms. A map of the residuals shows that the residuals are not random, but rather there are regions in which the spatial average is different from zero. The smoothed residuals become an additional correction to the ground motion prediction equation. In principal the contour maps of these corrections are unique to each strong motion station, but maps of nearby stations should be correlated. The potential for this method to significantly reduce the aleatory uncertainty is tested, in a simplified pilot application, to a small subset of the peak acceleration and peak velocity strong motion data in Japan. For this data, the standard deviations to GMPEs without station or path corrections is in the range of 0.76 to 0.85 (in natural log units). With the corrections the standard deviations are reduced to the range from 0.25 to 0.35. The method is also applied to the prediction of peak acceleration and peak velocity in Guerrero, Mexico. The result there is reduction in the estimated standard deviation from about 0.89 to 0.53 for both peak acceleration and peak velocity.

This approach may be particularly appropriate for the design of critical structures with long lead times in their planning and design. If broadband and strong motion stations are installed at the intended site immediately after site selection, then the site-specific corrections can be determined by data from background seismicity during the design stages, and used to refine and defend the design during the approval process.

(Status: Reviews are received, and I am in the process of responding to the reviewer comments.)

Submitted

"Ground Motion Simulation for the 2008 Wenchuan, China, Earthquake Using the Stochastic Finite-Fault Method", Ghasemi, H., Fukushima, Y., Koketsu, K., Miyake, H., Wang, Z., Anderson, J. G., *Bulletin of the Seismological Society of America*.

Strong ground motions recorded during the 2008 Wenchuan, China, earthquake (Mw 7.9) have been simulated using the stochastic finite-fault method proposed by Beresnev and Atkinson (1997, 1998). The simulations were made for two source models. Both models are based on the fault geometry that was proposed by Koketsu et al. (2008) through inversion of teleseismic body wave data. The slip distribution obtained by this inversion was used for the first source model, while a random slip distribution was used for the second source model. The performance of each source model is quantified by calculating the bias and standard deviation of response spectra predicted by each model. For the first source model, the results show overall agreement between the simulated and observed response spectra in a period range of 0.05 to 1 s, as well as 4 to 10 s, but the model over-predicts ground motions in a period range of 1 to 4 s. For the second source model the model is biased over a slightely wider period range at longer periods. The performance of the stochastic model to predict observed ground motions is also compared with several empirical ground motion models, by means of statistical tools.

(Status: Hadi Gahsemi invited me to join the team on this paper after the first journal review. It has been revised and resubmitted.)

3. Conference papers completed while in Japan

"Joint Conference Proceedings 7th International Conference on Urban Earthquake Engineering (7CUEE) & 5th International Conference on Earthquake Engineering (5ICEE)", Anderson, J. G., *Center for Urban Earthquake Engineering, Tokyo Institute of Technology*, **2010**: 1-10 of 2091. http://www.cuee.titech.ac.jp/Conference_2010/index.htm.

The goal of probabilistic seismic hazard analysis (PSHA) is to estimate the answer to a question that is conceptually simple: how often do different levels of ground motion occur at the site. Obviously, since engineering interest is in the answer to this question at occurrence rates of 10-3 per year or lower, the experiment is impossible to perform. However, based on geological observations, comparison with the largest observed ground motions, and/or comparisons of different regions, the estimates of some specific PSHA studies are very surprising, particularly at small exceedance rates. High standard deviations in ground motion prediction equations are a leading candidate to explain the surprising hazard predictions. The high standard deviation is caused by the use of an ergodic assumption in development of the ground motion prediction equations. Especially thanks to the development of relatively dense strong motion networks in Taiwan and Japan, it is now possible to partially remove the ergodic assumption, and recent studies indicate that the result is a significant reduction of the standard deviation. The median reduction of the standard deviation from five studies is applied to simplified PSHA models for Yucca Mountain, Nevada, and for the central United States. Estimated ground motions at annual occurrence rates below 10-3 per year are significantly reduced in both cases.

"The University of Tokyo Symposium on Long-Period Ground Motion and Urban Disaster Mitigation Proceedings", Anderson, J. G., Miyake, H., Koketsu, K., Singh, S. K., Quaas, R., Yanez, C. P., *Earthquake Research Institute, University of Tokyo*, **2010**, *3*: 1-6 of 77. http://taro.eri.u-tokyo.ac.jp/workshop/ground_motion3.html. (95%)

This paper considers 277 exceptional recordings of strong earthquake ground motions. It finds an empirical upper bound of observed pseudo-acceleration (PSA) response spectra. Statistics of peak vector accelerations and velocities are shown for accelerograms that have been low-pass filtered with several filter corner frequencies. The amplitudes of peak vector velocity from synthetic models of rupture on the San Andreas fault are sometimes greater than the current empirical limit of appropriately filtered accelerograms. Similarly, the amplitude of PSA (3 sec), and mean horizontal response spectra, sometimes exceed the current empirical limit.

This paper considers three additional records that are notable for their high amplitudes at long periods. The Kawaguchi-cho record from the 1964 Niigata earthquake and the SCT record from the 1985 Michoacan earthquake cause, respectively, PSA amplitudes at 5-6 s and 2 s periods close to the current empirical limit.

4. Projects not completed – potentially to be completed over the next few months (not in any particular order)

Earthquake Clusters in the Western United States and in Japan (with Kazu Nanjo)

Spectral Characteristics and Low-Frequency Components of Exceptional Ground Motions (with Kazuki Koketsu, Hiroe Miyake)

Predicting the ground motions of the 2008 Mogul earthquake, M_W=5.0 (with Hadi Ghasemi, Tetsuo Masuda)

Comparison of accelerograms showing liquefaction in Niigata in 1964 and in Kashiwazaki in 2008 (with Kazuyoshi Kudo)

Estimate of the standard deviation of ground motion prediction in the 2004 Tokachi-oki earthquake (with Hiroe Miyata)

A Test for Effects of Changes in the Length of Day on the Global Distribution and Occurrence Times of Earthquakes (I worked with Teruyuki Kato to obtain data, but he did not think he did enough work to be an author)

Upthrow of objects by exceptional ground motions (with Saburoh Midorikawa)

Causes of exceptional ground motions in northern Japan (with Hiroe Miyake, Shin Aoi)

An observation of anisotropic values of kappa (with Hiroe Miyake, Shin Aoi, Tsuyoshi Ichimura)

A close look at the Bam, Iran, accelerogram: possible recognition of the building damage (with Hadi Ghasemi, Hossein Sadeghi)

Blog on earthquake hazards and response – impressions from Tokyo that might be helpful in the United States

5. Oral Presentations while at ERI

"*The 2008 Mogul, Nevada Earthquake Sequence: Seismicity and Significance*", J. G. Anderson (Oral Presentation, Earthquake Research Institute, The University of Tokyo, Japan, scheduled for April 8, 2010).

Although the largest earthquake in the sequence was only MW=5.0, this earthquake swarm was reasonably well recorded, and one of the more intense swarms on record in Nevada. The sequence was shallow: most events had depth of less than 5 km. The main shock was preceded by a two month long sequence of foreshocks that raised issues of earthquake prediction, revised our ideas of the tectonics in the area, and yielded data set that should be helpful for deciphering the source processes. To develop a perspective on the significance of this swarm, statistics of earthquake clusters in Nevada and Japan are examined.

"*Spectral Characteristics and Low-Frequency Components of Exceptional Ground Motions*", (Oral Presentation), J. G. Anderson, The University of Tokyo Symposium on Long-Period Ground Motions and Urban Disaster Mitigation, Earthquake Research Institute, The University of Tokyo, Tokyo, Japan. (March 17, 2010).

This paper considers 277 exceptional recordings of strong earthquake ground motions. It finds an empirical upper bound of observed pseudo-acceleration (PSA) response spectra. Statistics of peak vector accelerations and velocities are shown for accelerograms that have been low-pass filtered with several filter corner frequencies. The amplitudes of peak vector velocity from synthetic models of rupture on the San Andreas fault are sometimes greater than the current empirical limit of appropriately filtered accelerograms. Similarly, the amplitude of PSA (3 sec), and mean horizontal response spectra, sometimes exceed the current empirical limit.

This paper considers three additional records that are notable for their high amplitudes at long periods. The Kawaguchi-cho record from the 1964 Niigata earthquake and the SCT record from the 1985 Michoacan earthquake cause, respectively, PSA amplitudes at 5-6 s and 2 s periods close to the current empirical limit.

"*ENGINEERING SEISMOLOGY: DIRECTIONS IN SEISMIC HAZARD ANALYSIS*", (Keynote Address), J. G. Anderson, 7th CUEE and 5th ICEE Joint Conference, Center for Urban Earthquake Engineering, Tokyo Institute of Technoloyg, Tokyo Institute of Technology, Ookayama Campus, Tokyo, Japan. (March 3, 2010).

This paper will focus on probabilistic seismic hazard analysis. The goal of PSHA is to predict the answer to an experiment that is conceptually simple: how often do different levels of ground motion occur at the site of interest. Obviously, since engineering interest is in the answer to this question at occurrence rates of 10-3 per year or lower, the experiment is impossible to perform. However, considering geological observations and/or comparison with the largest observed ground motions suggest that the predictions of some specific PSHA studies are not reasonable, particularly at small exceedance rates. High standard deviations in ground motion prediction equations are a leading candidate to explain these seemingly unreasonable hazard levels. The high standard deviation is caused by the use of an ergodic assumption in development of the ground motion prediction equations. Especially thanks to the development of relatively dense strong motion networks in Taiwan and Japan, it is now possible to estimate the improvements that are possible through removal of the ergodic assumption. Several recent studies, which will be discussed in the paper, have demonstrated that the gain is a significant reduction of the standard deviation. The paper will give examples of how, if these results had been known at the time, the consequences of improved handling of uncertainties might have reduced or eliminated controversies over PSHA results.

"*New Results on Characteristics and Statistics of Exceptional Ground Motions*", (Keynote Lecture), J. G. Anderson, Annual Symposium on Earthquake Hazard Reduction by the Consortium of Universities in Kyoto, Disaster Prevention Research Institute, Kyoto University, Kyoto. (January 7, 2010).

This report will summarize a project to collect and study the characteristics of exceptional strong motion accelerograms. For the sake of this project, exceptional records are those for which peak acceleration exceeds 500 cm/s2 or peak velocity exceeds 50 cm/s on one or more a component. Defining the peak as the maximum zero-to-peak amplitude of the acceleration or velocity vector during the strong shaking, this compilation found 35 records with peak acceleration greater than 1g (980 cm/s2), and 41 records with peak velocities greater than 100 cm/s. The results sample an estimated 150,000 instrument-years of strong-motion recordings. The geometric mean of the two horizontal components of acceleration or velocity, as used in many ground motion prediction equations, is typically 0.76 times the magnitude of this vector peak. Accelerations in the top 100 come from earthquakes as small as magnitude 4.8, while velocities in the top 100 all come from earthquakes with magnitude 5.7 or larger. These records are dominated by crustal earthquakes with thrust, oblique-thrust, or strike-slip mechanisms. All NEHRP site categories have contributed exceptional records, in proportions similar to the extent that they are represented in larger databases. Somewhat stronger ground motions are to be expected, since none of these records are capable of significant upthrow of objects.

"*First Results on the 2008 Mogul, Nevada Earthquake Sequence*", (Oral Presentation), J. G. Anderson, Kyoto University Seminar, Disaster Prevention Research Institute, Uji Campus, Kyoto University. (October 26, 2009).

Although the largest earthquake in the sequence was only MW=5.0, it was reasonably well recorded, generated peak accelerations over 1g at one station, and has a distance dependence differing from the NGA earthquake ground motion prediction equations. The main shock was preceded by a two month long sequence of foreshocks that raised issues of earthquake prediction, revised our ideas of the tectonics in the area, provided data to study the response of the Reno basin, and gave us a data set that should be great for deciphering what happened at the source.

"*Source and Site Characteristics of Earthquakes that have Caused Exceptional Ground Accelerations and Velocities*", (Oral Presentation), J. G. Anderson, SSJ 2009 Fall Meeting, The Seismological Society of Japan, Kyoto. (October 22, 2009).

"*Source and Site Characteristics of Earthquakes that have Caused Exceptional Ground Accelerations and Velocities*", (Oral Presentation), J. G. Anderson, Earthquake Research Institute Seminar, Earthquake Research Institute, The University of Tokyo, Tokyo. (September 11, 2009).

This study investigates the characteristics of the freefield strong-motion records that have yielded the 100 largest peak accelerations and the 100 largest peak velocities available from any of several data sources through July, 2007. The peak is defined as the maximum zero-to-peak amplitude of the acceleration or velocity vector. This compilation found 35 records with peak acceleration greater than 1g (980 cm/s2), and 41 records with peak velocity greater than 100 cm/s. The results sample an estimated 150,000 instrument-years of strong-motion recordings. The geometric mean of the two horizontal components of acceleration or velocity, as used in many ground motion prediction equations, is typically 0.76 times the magnitude of this vector peak. Accelerations in the top 100 come from earthquakes as small as magnitude 4.8, while velocities in the top 100 all come from earthquakes with M 5.7. These records are dominated by crustal earthquakes with thrust, oblique-thrust, or strike-slip mechanisms. Normal faulting mechanisms in crustal earthquakes constitute under 5% of the records in the databases searched, and an even smaller percentage of the 100 largest acceleration or velocity records. All NEHRP site categories have contributed exceptional records, in proportions similar to the extent that they are represented in larger databases.