Issue No. 17

Autumn Quarter, 1998

The John A. Blume Earthquake Engineering Center

Dept. of Civil & Environmental Engineering, Stanford University, Stanford, California, USA, 94305-4020

Telephone: (650) 723-4150

Fax: (650) 725-9755

E-mail: earthquake@ce.stanford.edu

WWW: http://blume.stanford.edu

Director: Professor Anne S. Kiremidjian

Associate Director: Dr. Stephanie A. King

Administrative Associate: Racquel Hagen

LAURA LOWES JOINS STANFORD'S FACULTY IN CIVIL AND ENVIRONMENTAL ENGINEERING

The Blume Center is pleased to announce that Laura Lowes will be joining the Stanford faculty in the Department of Civil and Environmental Engineering as an Assistant Professor. She will join the Structural Engineering and Geomechanics Group and be an integral part of the research and teaching activities at the Blume Center.

Lowes is currently completing her doctoral degree at U.C. Berkeley, and will join Stanford in the Spring Quarter of 1999 to teach a graduate level class in finite element analysis. While at Berkeley, her research has focused on the analysis and design of reinforced concrete beam-column joints, and she has taught undergraduate and graduate classes on concrete design and structural analysis.

At Stanford, Lowes will continue her research on the development of numerical models for investigating and predicting the behavior of structural systems subjected to dynamic and static loading. Her areas of interest include constitutive theory; finite element modeling of reinforced-concrete components; non-linear analysis of structural systems; experimental investigation of structural material, element and system response; and development of analytical models for use in structural design.

ALLIN CORNELL CHOSEN TO GIVE EERI'S 1999 DISTINGUISHED LECTURE

Prof. C. Allin Cornell was selected by the Earthquake Engineering Research Institute (EERI) to give their 1999 Distinguished Lecture. He will present the lecture several times throughout the year at various locations. The first of these was delivered at the 1999 EERI Annual Meeting held February 3-6, 1999 in San Diego. In his lecture, Cornell characterizes the evolution of the seismological-engineering interface where ground motions are specified for structural design and assessment, then explores how best to extend that process into explicit, site-specific, structure-specific, ground motion specifications.

BLUME CENTER NEWS

On October 5, **Prof. Anne Kiremidjian** presented a guest lecture on "Ground Motion Simulation using Complete Fourier Spectra" at the Politecnico di Milano in Milan, Italy.

On October 5-7, **Prof. Greg Deierlein** co-chaired the RCS Technical Subcommittee at the Fifth Joint Technical Coordinating Committee Meeting of the US-Japan Cooperative Earthquake Research Program on Composite and Hybrid Structures held in Tokyo, Japan.

Prof. Helmut Krawinkler attended a coordination meeting for the US-Japan Initiative for Urban Disaster Mitigation, held at the University of Tokyo on October 7-8.

Prof. Ronnie Borja presented a paper entitled "Computational modeling of strain localization in soft rock" at the Second International Symposium on Hard Soils-Soft Rocks held in Naples, Italy from October 12-14, which he co-authored with graduate students **Richard Regueiro** and **Timothy Lai**. Following the conference, he was invited to give a doctoral lecture on strain localization by finite elements at the University of Naples, Federico II, from October 15-16.

On November 7, **Prof. Helmut Krawinkler** together with Ph.D. students **Luciana Barroso** and **Akshay Gupta** attended the CUREe Annual Meeting in Los Angeles.

In November, **Prof. Greg Deierlein** participated in the AISC Specification Committee annual meeting in Chicago, where he agreed to co-chair a new ad-hoc committee to develop new stability provisions that recognize emerging methods second-order inelastic analysis to evaluate stability limit states in steel-framed structures.

Prof. Anne Kiremidjian gave a keynote lecture at the 10th Japan Earthquake Engineering Symposium in Yokohama, Japan on November 26.

On November 30, **Prof. Helmut Krawinkler** gave a lecture on "Analytical Methods for Prediction of Seismic Performance" as part of the CUREe-SCEC Course on the Earth Science - Engineering Interface in Seismic Design.

Dr. Renate Fruchter was a guest keynote speaker at several events in Europe and Japan this fall, including Statoil's Research Summit, Trondheim Norway; the German 10th Building Informatik Conference, at Bauhaus University in Weimar; the MEMEX meeting at the Stanford Japan Center in Kyoto, and the Kansai Silicon Venture Forum, Osaka, Japan. The topic of the presentations focused on Global Teamwork and Collaboration Technologies.

RESEARCH SPOTLIGHT

Simulation of Earthquake Accelerograms using Conditional Distributions for Fourier Phase Differences

by: Hjörtur Thráinsson, Ph.D. Candidate
Research Advisor: Professor Anne S. Kiremidjian

Introduction

Reliable information on the earthquake ground motion at the location of a damaged structure is essential in order to investigate the causes of damage and to correlate ground motion to building damage. Furthermore, dependable estimate of the earthquake ground motion is necessary for the design and analysis of building structures. However, it is very unlikely that a recording will be available for all sites and conditions of interest. Hence, there is a need for efficient methods for the simulation of earthquake ground motion.

The objective of the research summarized here is to develop a model to generate a field of earthquake ground motion that is continuous in space and time, based on readily available source, path and site characteristics. The model takes into account the non-stationarity of the ground motion, as well as the spatial correlation between neighboring sites. A key component in the model is the simulation of ground motion using the inverse Fourier transform. This summary focuses on the simulation of earthquake accelerograms at a given site using the inverse Fourier transform. A significant difference between the approach presented here and previously developed simulation methods is the use of statistical distributions for Fourier phase difference conditional on the Fourier amplitude, to capture the non-stationarity in the time domain with respect to intensity and frequency content.

Data and Data Processing

In order to develop general formulations that can be used to predict the parameters of the ground motion simulation model, a uniformly processed database of strong motion recordings is developed. Approximately 300 uncorrected accelerograms are obtained from 11 recent California earthquakes. The database includes recordings from events ranging in moment magnitudes from 5.8 to 7.3 and source to site distances up to 100 kilometers. The distance metric used in this study is the shortest distance from the site to the surface projection of the seismogenic rupture.

The uncorrected accelerograms are baseline and instrument corrected, as well as band-pass filtered. The lower cut-off frequency of the band-pass filter is between 0.1 and 0.2 Hz, and the upper cut-off is between 23 Hz and 25 Hz. A sampling frequency of 50 Hz and a total duration of approximately 41 seconds (2048 points) is used for all records.

The Inverse Discrete Fourier Transform

A digital time history can be represented in terms of the inverse discrete Fourier transform as follows:

$$f(t_k) = \sum_{n=-\frac{N}{2}+1}^{\frac{N}{2}} F(w_n)\cdot \exp(i w_n t_k) \qquad (1)$$

where $f(t_k)$ is the value of the time history at time t_k, $F(w_n)$ is the discrete Fourier transform at frequency w_n, and N is the order of the discrete Fourier transform. The Fourier transform is a complex number, which can be characterized by its amplitude and phase:

$$F(w_n) = A_n \cdot \exp(i F_n) \qquad (2)$$

Here, A_n represents the Fourier amplitude corresponding to w_n and F_n is the phase angle. While the Fourier amplitude spectrum has been studied extensively, the phase spectrum has received only a limited attention. The following discussion will emphasize the characteristics of the phase spectrum.

Conditional Phase Differences

Traditionally, the phase angles have been assumed to follow a uniform distribution. As can be seen from Figure 1(a), this is a good assumption. Figure 1(a) shows a histogram of phase angles from a typical recorded ground motion. In Figure 1(b), the phase angles are plotted as function of the Fourier amplitude. For any given amplitude, the phase angles appear to follow a uniform distribution. If, however, the phase differences are considered, the results are very different.

The phase difference is defined as the difference in phase angle between adjacent, non-negative frequencies:

$$DF_n = F_{n+1} - F_n; \quad n = 0,1,\ldots, \frac{N}{2}-1 \qquad (3)$$

In Equation 3, DF_n is the phase difference corresponding to the n-th frequency. Figure 1(c) shows an example of an observed phase difference histogram. The histogram exhibits a specific pattern as is evident in Figure 1(d), where the phase difference is plotted as function of Fourier amplitude. The dispersion of the phase differences around the apparently constant mean decreases with increasing amplitude.

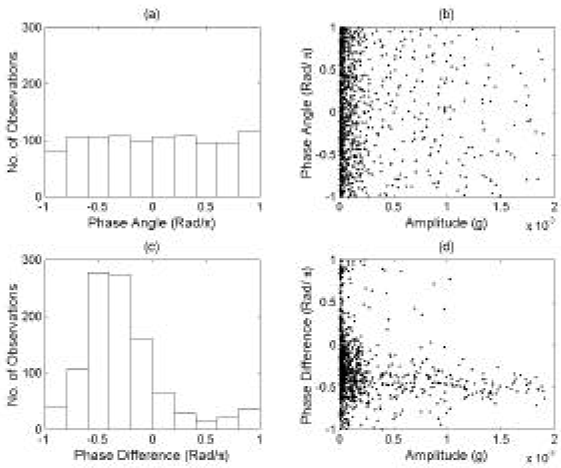

Figure 1: (a) Histogram of observed phase angles. (b) Observed phase angles vs. Fourier amplitudes. (c) Histogram of observed phase differences. (d) Observed phase differences vs. Fourier amplitude.

By properly modeling the distribution of phase differences conditional on Fourier amplitude, the Fourier transform of an accelerogram can be adequately described. The acceleration time history is then obtained by evaluating the inverse transform. Two methods have been developed to simulate the phase differences. The first approach is referred to as the parametric approach, where the Fourier amplitudes are classified into three categories: small, intermediate, and large. For each amplitude range, a beta distribution is defined and its parameters are obtained from empirical data. The second approach is based on an analogy from random vibration theory, where a Gaussian distribution is used to simulate the phase differences. The mean phase difference is independent of the Fourier amplitude, while the standard deviation is a continuous, decreasing function of the amplitude.

Simulated Time Histories

Figure 2 shows an example of a recorded accelerogram and two simulations, using the conditional beta distributions. In this particular example, the recorded peak ground acceleration is 0.157 g. The average peak ground acceleration from ten simulations is 0.16 g and the standard deviation is 0.02 g. The agreement in peak values is very good.

The peak values are not the only attribute of interest. Oftentimes, the temporal distribution of the energy content has a great effect on the structural response. This evolutionary behavior is examined in Figure 3. The dashed lines represent the cumulative normalized Arias intensity of the ten simulated time histories, while the solid line represents the cumulative normalized Arias intensity of the recorded time history. In general, the simulated time histories capture well the evolutionary characteristics of the recorded ground motion.

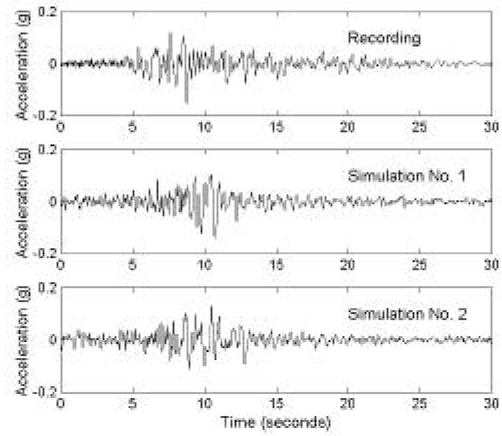

Figure 2: An example of a recorded accelerogram (top) and two simulated time histories.

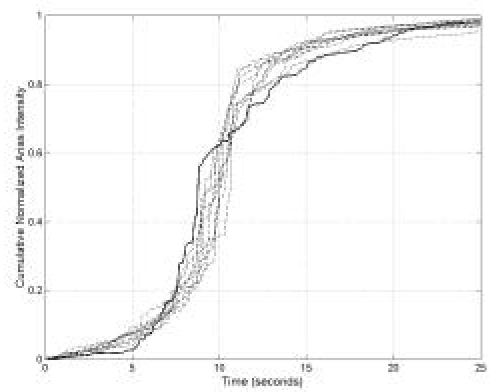

Figure 3: Cumulative normalized Arias intensity as function of time. Dashed lines: ten simulations; solid line: recording.

Regression analyses have been performed on the California strong ground motion data to obtain prediction formulas for the model parameters, using readily available source, site, and path characteristics. The source parameters used in this study are the moment magnitude of the earthquake, the type of fault mechanism (strike-slip or reverse-slip) and the projection of the seismogenic rupture on the surface of the Earth. The path effects are characterized by the source to site distance, and the site characteristics are accounted for by using the soil classification proposed by the National Earthquake Hazard Reduction Program.

Conclusions

The ground motion simulation method summarized above captures pertinent characteristics of recorded time histories, such as peak values and temporal energy distribution by proper modeling of the Fourier phase differences. This simulation approach is not intended to replace more robust geophysical models. Instead, it provides for a rapid simulation of acceleration time histories for engineering purposes over a wide range of magnitudes and distances.

RECENTLY PUBLISHED TECHNICAL REPORTS

TR No. 126 - *Methodologies for Evaluating the Socio-Economic Consequences of Large Earthquakes* by Anne S. Kiremidjian, Stephanie A. King, Nesrin I. Basoz, Kincho H. Law, Mladen Vucetic, Macan Doroudian, Veronica Iskandar, Robert Olson, John Eidinger, Kenneth Goettel, and Gerald Horner, October, 1997.

TR No. 127 - *Evaluation of Bridge Damage Data from the Loma Prieta and Northridge, CA Earthquakes* by Nesrin I. Basoz and Anne S. Kiremidjian, November, 1997.

TR No. 128 - *A Modular, Wireless Damage Monitoring System for Structures* by Erik Gregory Straser and Anne S. Kiremidjian, September, 1998.

TR No. 129 - *Nonlinear Dynamic Soil-Structure Interaction Analysis and Application to Lotung Problem* by Heng Yih Chao and Ronaldo I. Borja, November, 1998.

TR No. 130 - *Effects of Vertical Irregularities on Seismic Behavior of Building Structures* by Ali A.K. Al-Ali and Helmut Krawinkler, December, 1998.

TR No. 131 - *A Bayesian Probabilistic Approach to Damage Detection for Civil Structures* by Hoon Sohn and Kincho H. Law, January, 1999.

To order or receive more information on these Blume Center Technical Reports, please contact Racquel Hagen at the Blume Center, or see the Blume Center web site.

BLUME CENTER AFFILIATE'S MEETING ON APRIL 30, 1999

The bi-annual Blume Center Affiliate's Meeting will be held on Friday, April 30, 1999. Members of the Blume Center Affiliates Program and other donors to the Center are invited to this event, which showcases the current research activities in earthquake engineering at Stanford University. As in previous meetings, we will have general sessions in which faculty and students will share their research findings. In addition, this year's meeting will feature a special event - an open forum for the general public. The open forum will follow the student and faculty presentations and include a panel of experts in the field who will highlight key findings in earthquake engineering and earthquake resistant design. We hope to raise public awareness to the threat of earthquakes in our region, and encourage individuals to prepare for the next earthquake through mitigation actions that may reduce the consequences of large earthquakes in the Bay area.

This year's Affiliate's Meeting is also dedicated to Dr. John A. Blume, founder of the Blume Earthquake Engineering Center, on the occasion of his 90th birthday. We plan to celebrate this special event and honor Dr. Blume during the meeting and during the banquet that will follow the day's program.

For more information on the Blume Center Affiliate's Program or the meeting on April 30, please contact Anne Kiremidjian, Blume Center Director. Additional information about this year's Affiliate's Meeting and open public forum will be available on the Blume Center web site at http://blume.stanford.edu.

The John A. Blume Earthquake Engineering Center
Dept. of Civil & Environmental Engineering
Stanford University
Stanford, CA 94305-4020

(mailing label)