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The John A. Blume Earthquake Engineering Center

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SHAH AND DAVIDSON HONORED AT EERI ANNUAL MEETING

Professor Haresh Shah and Ph.D. candidate **Rachel Davidson** were honored at the 1997 Annual Meeting of the Earthquake Engineering Research Institute (EERI) held February 12-15 in Austin, Texas.

Professor Shah was named an Honorary Member of EERI for his outstanding contributions in the field of earthquake engineering. He has been a pioneer in the fields of risk analysis, earthquake engineering, and probabilistic methods for over 30 years. At Stanford, he has served as the Chairman of the Department of Civil Engineering and the Founding Director of the Blume Center. Professor Shah is currently the Chairman of the Board of the World Seismic Safety Initiative.

Ph.D. candidate Rachel Davidson's paper entitled "A Multidisciplinary Urban Earthquake Disaster Risk Index" was selected as the winner of this year's EERI Student Paper Competition. In the paper she proposes an Earthquake Disaster Risk Index (EDRI), a composite index that describes the relative contributions of various factors including geological, engineering, social, economic, political, and cultural, to the overall earthquake disaster risk of cities worldwide.

CONSULTING PROFESSOR PREDICTS LEVEE FAILURE

Department of Civil Engineering **Consulting Professor Richard Meehan**, a practicing civil engineer in Palo Alto, testified in a 1991 trial in Sacramento that a levee on the Feather River in an area called Star Bend was prone to collapse during high water. His analysis was based on the unusual geology of the site, a mistake in the placement of the levee there, and a history of problems with the levee itself. On January 2, 1997, the levee collapsed about 1,500 feet from the area that Meehan pinpointed as prone to failure in his 1991 testimony. The flood that followed the levee failure inundated the town of Olivehurst and about 15 square miles of farmland and towns, causing more than $200 million in damage.

For the past seven years, Professor Meehan has taught the popular graduate course "Geotechnical Failures" in the Civil Engineering Department at Stanford. For more information on the course, as well as other cases involving civil and geotechnical engineering litigation, see the WWW page http://www-leland.stanford.edu/~meehan.

BLUME CENTER NEWS

Prof. Helmut Krawinkler began his term as the president of CUREe (California Universities for Research in Earthquake Engineering) in February, 1997.

On January 17, 1997, the Applied Technology Council Board of Directors visited the Blume Center in conjunction with their Annual Board Meeting in Northern California. The ATC Board viewed presentations of current research in earthquake engineering and toured the upgraded Blume Center facilities.

Prof. Anne S. Kiremidjian was recently appointed to the Editorial Board of the EERI Journal *Earthquake Spectra*.

On February 13, 1997 and March 3, 1997 **Prof. Helmut Krawinkler** gave invited lectures at Caltech and U.C. Berkeley, respectively. His topic was "Seismic Design Based on Inelastic Behavior."

On February 7, 1997 **Prof. H. Allison Smith** gave an invited lecture at the National Center for Earthquake Engineering Research on "Active Control of Cable-Stayed Bridges."

Prof. Helmut Krawinkler was recently appointed as a member of the EERI Performance Based Design Project Steering Committee.

In February, 1997 **Prof. Haresh Shah** traveled to Costa Rica as part of the World Seismic Safety Initiative International Review Panel for the University of Costa Rica's project "Engineering Impact of a M 7.5 Earthquake in the Nicoya Peninsula, Costa Rica."

Prof. Helmut Krawinkler and Ph.D. candidate **Ali Al-Ali** received an award for the "Outstanding 1996 Journal Paper" by the Los Angeles Tall Building Structural Design Council.

On March 17-19, 1997 **Prof. Anne S. Kiremidjian** participated in the CUREe/Kajima meeting on the Social, Economic, and System Aspects of Earthquake Recovery and Reconstruction held in Kobe, Japan.

The Blume Center is pleased to have Professor Makoto Watabe from Keio University in Tokyo as a Visiting Professor. Several other visiting scholars are currently at the Blume Center including Dr. Graham Archer, who will be joining the faculty at Purdue University in the fall, Dr. Taiji Matsuda, an Associate Professor in the Civil Engineering Department at Kyushu University in Japan, and Dr. Kuei-Hsiang Cheng, an Associate Professor at the Kao Yuan Technical College in Taiwan.

RESEARCH SPOTLIGHT

Use of Automata Network for Estimation of Seismic Hazard from Several Faults

by Maya Belubekian, Ph.D. Candidate
Research Advisor: Professor Anne S. Kiremidjian

Introduction

Estimation of hazard at a site due to earthquake ground motion may be performed by different methods because of the uncertainty in the size, time and location of the future earthquakes. Traditionally, seismic hazard is analyzed deterministically by considering a scenario earthquake or probabilistically by assuming a certain stochastic process of earthquake occurrences. On the other hand, the processes of fault rupture and slip distribution in an earthquake are studied from a mechanistic point of view, which provides an insight into the underlying physical processes that generate earthquakes.

The earthquake occurrence model developed in this project combines a physical (mechanistic) approach for the earthquake generating process along a fault with stochastic simulation of event occurrences by representing the fault behavior as a stochastic automata network. Several faults in the vicinity of a specified site are analyzed using this model to estimate the site hazard from these faults simultaneously.

The parameters of the model are adjusted in an iterative manner to a set of “target” event samples. The target samples are obtained using a statistical technique called bootstrap. The bootstrap method allows for the mean values and the confidence bounds on the model parameters to be estimated. In the automata network model, the bootstrap method is also used for the construction of the confidence bounds on the seismic hazard forecast.

Automata Network for Earthquake Occurrences on a Fault

In the model of event occurrences, a fault is divided into cells. Each cell represents a rectangular dislocation surface embedded into an elastic half-space. The system of such surfaces is used to determine the distribution of slip in large events (which rupture several cells) by using results from dislocation theory. The dislocation model is formulated for an N-cell fault. The model requires that the boundary value problem for the cases of 1, 2, ..., or N-cell ruptures be solved to obtain the slip released on each of the rupturing cells. The slip distributions from the dislocation model are obtained and stored before the simulation of the automata network and are used in the process of simulation when a rupture spans to more than one cell.

In terms of the automata network, each cell represents a mathematical information-processing device called *automaton*. An automaton is a mathematical device that can perform any defined function depending on the information on its inputs and its current state; and give the resulting information on its output. The interaction among the cells is achieved by a certain connection of their inputs and outputs into an *automata network*. The automata framework allows one to capture the evolution of the earthquake occurrence process on a fault.

The behavior of the fault automata network depends on the assumed mechanisms for slip accumulation and release on the individual cells and the scheduling of event occurrences on different cells. The state of an automaton in the fault network is represented by two parameters: the level of the accumulated slip and the time to the next event scheduled on the cell. In this research, it is assumed that the slip is accumulated linearly on each cell until it reaches its maximum level. The time of activation of the automata network (an earthquake occurrence) is determined as the minimum of times to the next event scheduled for every fault cell. The information exchanged between inputs and outputs of the automata in the network is the released slip in an earthquake. The summary information from all the fault cells is stored in an automaton called the resulting cell. Unlike a fault cell, the resulting cell does not have any physical meaning. It is a simple summator which gives the total slip released in an earthquake.

The interaction between the fault cells takes place in large events (magnitude 6 or greater) when the rupture spans to several cells. Events of smaller magnitudes occur within a single cell and do not affect the slip state on the other cells. This mechanism enables the simulation of the small to moderate events as a Poissonian sequence and the incorporation of time- and space-dependence into the process of large event occurrence.

Adjustment and Forecast Modes of the Network Operation

The described automata network is operated in two modes: adjustment and forecast. The parameters of the network, such as the slip accumulation rate, maximum level of accumulated slip, time to the next event and the proportion of the released slip in an earthquake are adjusted to a target sample of events constructed using *bootstrap* statistical technique at the adjustment mode. The bootstrap method represents sampling with replacement from the original sample of data (earthquake catalog). After obtaining several bootstrap samples, the mean and the confidence bounds on the parameters of interest can be estimated.

The network is operated in the forecast mode to estimate the hazard in the form of a site hazard curve. The site hazard curve is defined as the relationship between a ground motion parameter and the probability of exceeding this parameter at least once in T years. Ground motion can be represented by the peak ground acceleration (PGA), peak ground displacement (PGD), peak ground velocity (PGV), spectral acceleration (S_a), spectral velocity (Sv), or spectral displacement (Sd). These parameters are obtained for each simulated event using an attenuation law and depend on the magnitude, distance from the site to the rupture zone and the soil type at the site. The logic of the network operation is shown in Figure 1.

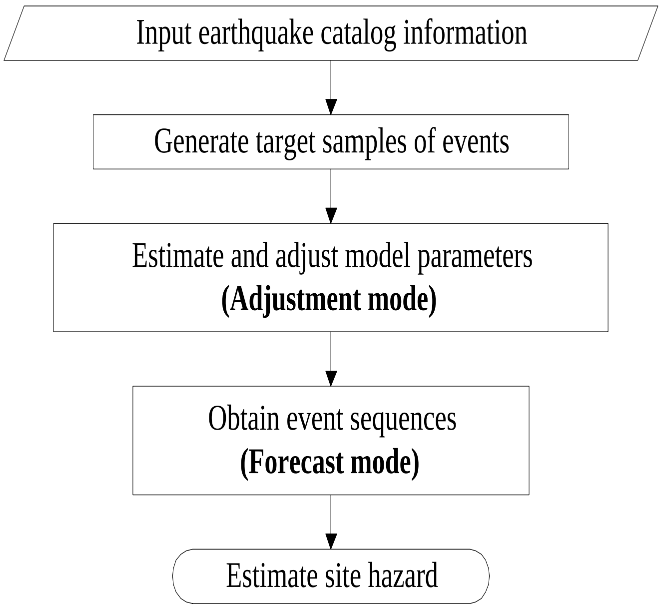

Figure 1. Flowchart of network operation.

Figure 2 shows an example PGA site hazard curve for the mean and the 95% confidence bounds. This curve was obtained for the city of Palo Alto by considering the influence of the San Andreas, Hayward and Calaveras faults. The Boore et al. (1993) attenuation law was used in this application. The site hazard curve obtained by the Poisson earthquake occurrence model is also shown for comparison. The hazard curve from the Poisson model is close to the one obtained by the automata model for ground shaking levels greater than 0.5g. The hazard forecast based on the Poisson model, however, does not depend on absolute time and remains the same for any 50 year interval. The automata model, in contrast, provides hazard forecasts that are dependent on absolute time. Thus the forecasts of these two models will not always be the same. After a large seismic gap, the automata model is expected to predict a higher hazard than the Poisson model, whereas right after a large earthquake the Poisson model over-estimates the hazard.

Conclusions

The automata network is a convenient tool for formulating a complex information-processing system, such as a seismic fault. It makes the dynamics of the system's evolution relatively simple to follow.

The automata network for seismic activity on a fault developed in this project can be used to simulate small and moderate events as a Poisson process. These events release a small amount of accumulated slip, occur within a single cell and do not affect other fault cells. Hence, they are time- and space-independent. In contrast, a large event releases a large proportion of the accumulated slip not only on the triggering cell but also on several neighboring cells, which prevents another large event from rupturing the same cells within a time shortly after the event. This property is consistent with the seismic gap hypothesis, which states that on a particular fault seismic hazard increases with the time elapsed since the last large earthquake.

The earthquake occurrence model formulated as an automata network evaluates the site hazard from several faults. The bootstrap statistical method provides estimates of the confidence bounds on the mean site hazard curve and on the estimated parameters. Different ground motion attenuation functions can be imbedded in the model to produce hazard curves for various ground motion parameters. Since events are simulated one at a time, the model also lends itself to building damage and loss estimation.

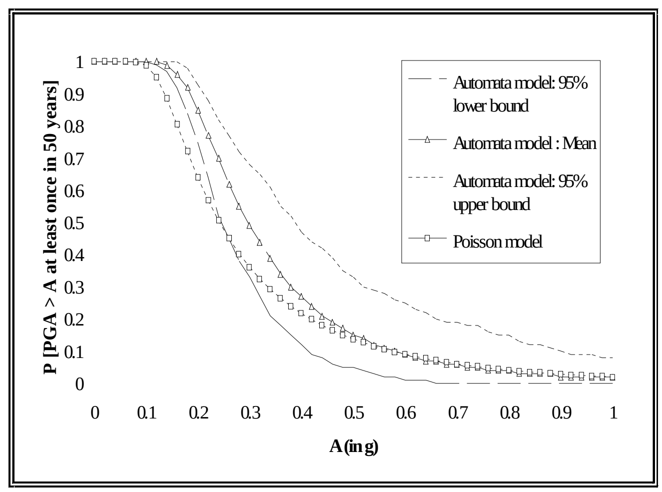

Figure 2. Site hazard curve for Palo Alto, California.

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THE RELIABILITY OF MARINE STRUCTURES PROGRAM

The Reliability of Marine Structures (RMS) Program is one of the advanced graduate research programs within the Department of Civil Engineering at Stanford. The RMS program has been affiliated with the Blume Center since the program was formed in 1988. The RMS program is directed by Professor Allin Cornell and Senior Research Scientist Dr. Steven Winterstein and generally includes about 6-8 Ph.D. students at any one time. Funding for the program is provided both by federal sponsors, such as the Office of Naval Research and the National Science Foundation, and by industry affiliate sponsors including AGIP, Amoco, British Petroleum, Chevron, Exxon, Mobil, Norsk Hydro, Saga, Shell, Statoil, and Texaco.

The RMS program combines post-M.S. graduate study and basic research in structural reliability applications. These applications range across a spectrum of topics, from the modelling of joint ocean environmental processes (wind-wave-current), through the modelling and analysis of the resulting hydrodynamic loads and gross responses, to the development of probability-based design codes. Research interests are often motivated by specific offshore structural concepts, which vary greatly with the properties of the oil/gas field to be mined and its water depth. Resulting structural concepts range from familiar rigid piled steel frames ("jackets") to massive gravity-based concrete structures, and most recently to tethered floating structures and ships. Technical challenges for these offshore structures include a number of nonlinear mechanisms. The hydrodynamic forces on these structures are complex nonlinear transformations of the random wave elevation history and current speed. The structure itself may also behave in nonlinear ways, especially under extreme conditions that challenge the safety of the facility.

Because these marine facilities are large investments (installation costs for deep-water platforms may now range into the billions of dollars) the offshore industry is ready to study their reliability with care. It is often more prepared than the building or bridge industry to invest in new technology. One result is the possibility of transferring the offshore structural technology into other fields of structural engineering. The bridge and building fields are moving rapidly into the widespread use of nonlinear structural analysis for seismic loadings; the offshore industry pioneered it and codified it in 1980. Researchers in the RMS program are applying a dynamic structural analysis code first developed for offshore steel jacket structures to bridge and building structures.

Other research projects within the RMS program focus on the reliability of wind turbines (primarily against fatigue during the millions of revolutions) and of buildings against seismic threats. The common theme of the RMS program is to assess the reliability of various engineered structures in uncertain load environments, and to design to maximize this reliability.

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