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The John A. Blume Earthquake Engineering Center

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NEW RESEARCHERS AT THE BLUME CENTER

The Blume Center is pleased to have several new graduate students and visiting scholars join us this year. The graduate students include Babak Alavi, who is working with Professor Helmut Krawinkler, Shalva Marjanishvili and Keith Porter, who are working with Professor Anne Kiremidjian, and Thatra Murlidharan, who is working with Professor Haresh Shah. The visiting scholars include Michihiro Ohori from the Obayashi Corporation in Japan, Hirotsugu Takata from the NHK News Department in Japan, and E-Doo Kim, an Associate Professor in the Department of Architecture at the University of Ulsan in Korea.

RECENT PUBLICATIONS

TR No. 120 - *Evaluation of Inelastic MDOF Effects for Seismic Design* by G.D.P.K. Seneviratna and Helmut Krawinkler, June, 1997.

TR No. 121 - *An Urban Earthquake Disaster Risk Index* by Rachel A. Davidson and Haresh C. Shah, June, 1997.

TR No. 122 - *Performance Based Strategy Evaluation Methodology for Earthquake Risk Management* by Anju Gupta and Haresh C. Shah, June, 1997.

TR No. 123 - *Modeling and Active Control of Cable-Stayed Bridges Subject to Multiple-Support Seismic Excitation* by Armin G. Schemmann and H. Allison Smith, June, 1997.

TR No. 124 - *A Stochastic Automata Network for Earthquake Simulation and Hazard Estimation* by Maya E. Belubekian and Anne S. Kiremidjian, August, 1997.

TR No. 125 - *Nonlinear Controller Using Variable Damping Elements for Civil Structures* by Tomohiko Hatada and H. Allison Smith, September, 1997.

MP No. 9 - *Seismic Hazard and Risk Analysis with Geographic Information Systems (Short Course Notes)* by Anne S. Kiremidjian and Stephanie A. King, Short Course given April 19-20, 1996.

In addition, several copies of publications distributed at the Shah Symposium and Blume Center Rededication are still available. These include a biographical booklet about Prof. Haresh Shah and a booklet describing the seismic retrofit and upgrading of the Blume Earthquake Engineering Center. To order or receive information on any of the publications listed here, please contact Carol Strovers at the Blume Center.

BLUME CENTER NEWS

Prof. Helmut Krawinkler organized a very successful international workshop on "Seismic Design Methodologies for the Next Generation of Codes." The workshop was held June 24-27 in Bled, Slovenia, and was attended by 40 of the leading seismic design experts from the US, Europe, Japan, and New Zealand. The workshop proceedings will appear soon in a book published by Balkema.

On an invitation by the Universidad Politecnica de Madrid in Spain, **Prof. Ronnie Borja** served as a member of the Board of Examiners for the Ph.D. thesis defense of Dr. Alberto Fraile de Lerma on Reliability of Underground Structures held on July 2. While in Madrid, Prof. Borja also gave a seminar on his current research in computational geomechanics.

On July 1-2, **Prof. Helmut Krawinkler** was in Tsukuba, Japan to attend a planning meeting for the construction of a 20x15 meter shaking table facility. This facility will be built close to Kobe at a cost of about $500 million. It will be the first table that can faithfully reproduce ground motions of the magnitude recorded in Northridge and Kobe.

On July 16-19, **Prof. Anne Kiremidjian** and **Dr. Stephanie King** participated in the ASCE Conference on Geotechnical Engineering in Logan, Utah.

Prof. Allin Cornell and **Prof. Anne Kiremidjian** participated in the ATC-35/USGS Ground Motion Initiatives Workshop in San Diego, California on July 30-31.

On July 30, **Prof. Helmut Krawinkler** presented an invited paper on "Deformation and Ductility Demands in Steel Moment Frame Structures" at the International Colloquim on Stability and Ductility of Steel Structures in Nagoya, Japan.

Prof. Allison Smith participated in a post-workshop meeting for the Second International Workshop on Structural Control held in Maui in July, and in the Sixth NSF Coordination Meeting for Structural Control held at the University of Nevada at Reno in August.

On August 6-7, **Prof. Anne Kiremidjian** participated in the NCEER Workshop on Transportation Systems held in San Francisco.

Prof. Helmut Krawinkler, **Dr. Stephanie King**, and Ph.D. Candidate **Ali Al-Ali** participated in the CUREe-organized Northridge Earthquake Research Conference held August 20-22 in Los Angeles.

RESEARCH SPOTLIGHT

Toward Wireless, Modular Monitoring Systems for Civil Structures

by Erik Straser, Ph.D. Candidate
Research Advisor: Professor Anne S. Kiremidjian

Introduction

Recent natural disasters such as the earthquakes of January 17, 1994 in Northridge, California, and January 17, 1995, in Kobe, Japan, and hurricanes Andrew and Iniki of 1989, have demonstrated the need for near real-time damage assessment of civil structures. Several months after the Northridge event, engineers were still trying to establish the health of steel structures in the greater Los Angeles area. Inspection of damaged buildings and bridges is often time consuming and costly because critical members and connections are difficult to access or concealed under architectural surface coverings.

In addition to earthquakes, service loading and extreme climatic conditions have caused extensive deterioration of the United States' aging infrastructure. Extending the life cycle of our built environment in light of economic constraints will become critical as we enter the next millennium.

This research addresses the development of a near real-time damage monitoring system that can evaluate both the extreme event and long term health of civil structures. A cross-disciplinary team of researchers from the Civil, Electrical, and Mechanical Engineering Departments at Stanford has been assembled to take a fundamental look at both the hardware and software issues and design novel solutions.

Societal Benefits

The societal benefits of such a system are wide and demonstrable. For natural hazards, such as earthquakes, dissemination of information to emergency response officials on major collapses of structures within minutes can result in lives saved and prudent resource allocation. Quick, accurate estimates of the level of damage to a structure may also be used to indicate loss of function. Structure specific loss of function estimates could provide significant savings to large manufacturing operations. Often such information is delayed due to weather conditions, lack of daylight, inappropriate survey equipment, or lack of access due to terrain obstacles.

A long term monitoring system will have the following benefits to structural inventory managers: (1) provide a numerical benchmark to improve the fidelity of the subjective visual inspection, (2) reduce inspection costs by focusing inspection efforts on regions where damage may be located, and (3) increase the manual inspection period by conducting inspections only when needed.

System Design

A new approach to the monitoring problem is necessary as conventional test and measurement systems create substantial problems on large civil structures. High per channel costs, extensive cabling, signal deterioration over large distances, maintenance costs, and environmental exposure are common problems. In addition the velocity of technical innovation in the fields of communication, embedded computation, and sensing is overwhelming conventional systems.

A modular damage monitoring system incorporating embedded microprocessors and wireless communications is designed as an effective, inexpensive platform for the measurement and analysis of critical civil structures. Key design factors for our system include: ease of installation, low per unit cost, portability, and broad functionality. These design constraints are manifested in our hardware component choices: embedded microprocessor, radio modem, data acquisition including sensors, and battery. Tight integration of these hardware components and their software complements give birth to our "sensor unit." The "sensor units" form a wireless network that operates in a client-server relationship with the "site master" PC. The "site master" is the controller of system communication, data storage, and global structural analysis. Data reduction and synthesis is necessary to provide managers and owners with a simple indicator for emergency response.

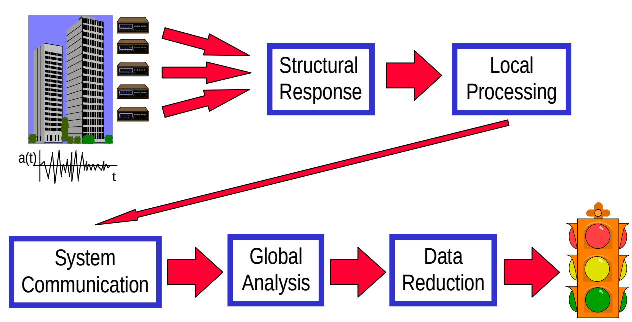

Figure 1. Overview of the Problem

Monitoring strategies for extreme events and periodic monitoring have been developed. For extreme events, the "sensor units" await a significant earthquake and self-actuate. They record data from their sensors until a minimum signal threshold is reached. A system synchronization occurs to align all time series signals. Finally, the recorded data is requested by the "site master" and transmitted over the radio modem for processing and analysis at the "site master." For periodic monitoring, the "sensor units" are programmed to awake on specified intervals. The "sensor units" receive instructions from the "site master" and acquire the sensor data. Time synchronization and data transfer complete the process. The system then returns to sleep mode awaiting an extreme event.

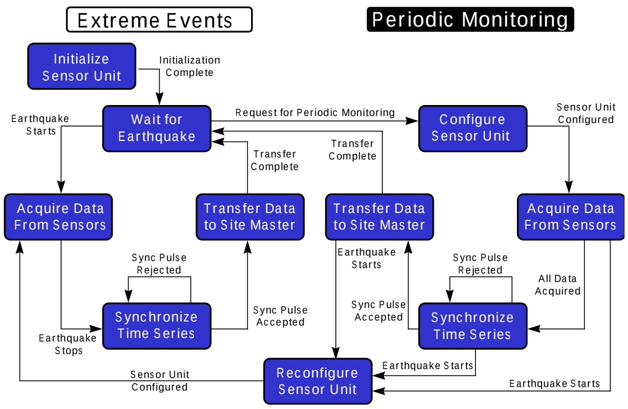

Figure 2. Monitoring Strategies Flowchart

Sensor Unit Design

The enabling component in this research is the "sensor unit." The operation of each unit is a synthesis of various subsystems. Figure 3 highlights the functional relationships and interfaces for the subsystems of the "sensor unit." Development of the sensor unit has led to the filing of a provisional patent through Stanford University.

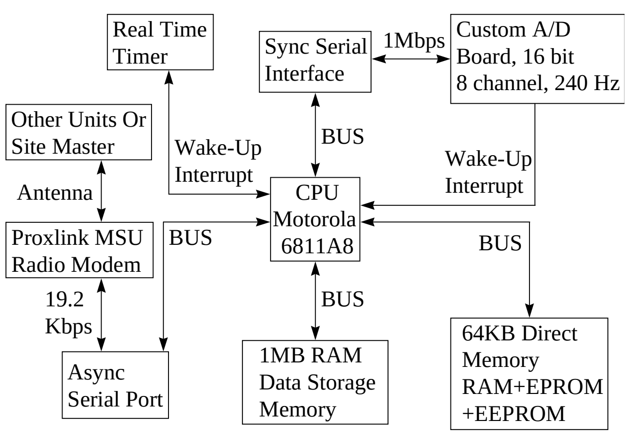

Figure 3. Sensor Unit Subsystems and Interfaces

Experimental Testing

Experimental efforts have focused on practical implementation issues. In particular, an experimental test of the Alamosa Canyon Bridge in New Mexico was conducted, in conjunction with Los Alamos National Laboratory (LANL), to determine the effects of environmental factors, such as temperature, on the modal properties of a six span steel girder bridge. The results of the study indicate that temperature effects, and specifically differential heating, causes the bridge to undergo a 7% change in first three modal frequencies over the course of one day. Additionally, heating of the sensor cables created significant routing and measurement problems in the field. Clearly the issue of natural variation of modal parameters, the typical input to damage identification software, needs to be addressed before confidence can be placed in the results of monitoring efforts based on modal properties.

Analysis Software

In the event of an earthquake, a report of the gross state of the structure must be completed in a matter of minutes. For this purpose, the use of simple response estimators are employed. Inter-story drift and Arias Intensity are ideal candidates as they have been or can be benchmarked to damage for various structural systems.

For periodic monitoring, we are collaborating with researchers at LANL on the development of a combined modal analysis, model correlation, and damage detection application called DIAMOND. DIAMOND is a Matlab toolbox with graphical user interface which can be used for all aspects of structural damage monitoring: modal analysis, finite element model correlation, and structural damage identification. DIAMOND provides statistical analysis allowing the user to incorporate multiple data sets and quantify modal parameter distributions.

Conclusions and Future Directions

The deliverables of this research are a prototype network of "sensor units" and the "site master" computer that can perform extreme event and periodic monitoring. Overall, the field of damage monitoring is still in its infancy. Unresolved issues include the sensor placement, new sensors, and damage algorithms. Current hardware systems are ill-suited to this application and damage algorithms have shown limited success with field data. This research is a step toward the type of instrumentation system required for monitoring civil structures, especially those subjected to extreme events.

Acknowledgments

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References

Straser, E.G. and Kiremidjian, A.S., "A Modular, Visual Approach to Damage Monitoring for Civil Structures," Proceedings of the 2nd International Workshop on Structural Control, Hong Kong, December 1996.

Farrar, C.R., Doebling, S.W., Cornwell, P.J., Straser, E.G., "Variability of Modal Parameters Measured on the Alamosa Canyon Bridge," Proceedings of the 15th International Modal Analysis Conference, Orlando, Florida, January 1997.

NEWLY SPONSORED RESEARCH PROJECTS

Finite Element Analysis of Strain Localization in Excavations, sponsored by the National Science Foundation. Principal Investigator: **Prof. Ronaldo Borja**. 9/15/1997 - 9/14/2000.

Modeling Lateral Flow and Liquefaction-Induced Ground Movement, sponsored by the National Science Foundation. Principal Investigator: **Prof. Ronaldo Borja**. 10/1/1997 - 9/30/2000.

ALUMNI NEWS

Vicki Vance [M.S., 1992; Ph.D., 1996] married Dr. Scott May on July 26 in Pasadena, California. Vicki is now a Lecturer in the Department of Architectural Engineering at Cal Poly San Luis Obispo.

Armin Schemmann [M.S., 1993; Ph.D., 1997] recently joined **Cliff Lange [Ph.D., 1996]** in the Advanced Reliability Department at Novellus Systems in San Jose, California.

Nesrin Basoz [Ph.D., 1996], **Ajay Singhal [Ph.D., 1996]**, and **Jeremy Blanchard [M.S., 1997]** are working at K2 Technologies, Inc. in San Jose, California.

Jim Snow [M.S., 1997] and **Brandon Erickson [M.S., 1997]** recently joined several Stanford graduates at the structural engineering firm Degenkolb Engineers.

FACULTY POSITIONS IN STRUCTURAL ENGINEERING

Stanford University's Department of Civil Engineering invites applicants for faculty positions in Structural Engineering in the areas of (1) Performance Based Structural Engineering and (2) Multi-Hazard Risk Analysis, Management, and Mitigation. Applications will be accepted until the positions are filled. Applicants should indicate which positions they are applying for and send a resume, transcripts, a vision statement, a description of teaching and research experience and interests, and a list of potential references to: Prof. Kincho Law, Chair of Faculty Search Committee, Dept. of Civil Engineering, Stanford University, Stanford, CA, 94305-4020. Further information can be found on the Dept. of Civil Engineering World Wide Web site at http://www.ce.stanford.edu. Stanford University is an equal opportunity employer and encourages applications from women, members of ethnic minorities, and disabled individuals.

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