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The John A. Blume Earthquake Engineering Center

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LETTER FROM THE DIRECTOR

After ten years, Professor Helmut Krawinkler stepped down as Director of The Blume Center. Under his leadership the Center continued its growth as a world recognized organization. Significant research advances were made in earthquake ground motion characterization, -regional hazard and damage models utilizing geographic information systems, performance of steel and concrete structures, and seismic testing of adobe structures. Under Helmut's direction the Blume Center sponsored a number of workshops and the Fourth International Seismic Zonation Conference. The Affiliates Program was expanded, and the Stanford/USGS Institute on Seismology and Earthquake Engineering was founded.

All the faculty, staff, students, and researchers who have had the opportunity to work with Helmut join me in expressing our wholehearted gratitude for his leadership, dedication, and friendship. This quarter, Helmut is enjoying a long overdue sabbatical at the Technische Universitaet Wien, in Austria, his native country. Upon his return in September, he will continue as the Director of the Structural Engineering Laboratory as well as with all the other normal professorial duties.

During the 1989 Loma Prieta earthquake Building 540, the Stanford campus home of 'Me Blume Center since its founding, sustained considerable damage. In mid June we will be relocating for about nine months while The Blume Center, an unreinforced masonry building, undergoes a seismic up- grade and several other changes which will include a complete redesign of the floor plan. A new Model Laboratory will provide testing facilities for undergraduate mechanics experimentation. The Advanced Technologies Laboratory will be the home of innovative sensor technologies and new materials testing research programs.

Simultaneously with the physical renovation, the Blume Center activities will expand into new research directions. The main thrust in seismic hazard and risk assessment will be widened to include research on multi-hazard modeling and analysis utilizing modem computational tools. The program on active control will be complemented with real-time damage monitoring technology that has already been initiated over the past several months. Testing and evaluation of new materials will become another major research thrust with initial testing already underway.

As the new Director of the Blume Center I am excited about our new activities and facilities, and look forward to working with all of you.

Anne Kiremidjian

CENTER NEWS

The Blume Center now has a new Home Page on the World Wide Web, which can be accessed using **http://blume.stanford.edu.** In addition, please note the Blume Center phone and facsimile numbers and E-mail address, as indicated in the title banner above. Our new temporary locations, due to the seismic retrofitting, are noted on the back page.

After ten years of dedicated service, **Professor Helmut Krawinkler** is stepping down as Co-Director of the Blume Center. **Professor Anne Kiremidjian** assumed full responsibility as Director effective April 1. Helmut is now enjoying a sabbatical leave in Austria and will return to his faculty responsibilities at Stanford in late July.

Professors Anne Kiremidjian and **Allison Smith** were invited to give presentations at the National Science Foundation Natural Hazards Mitigation Grantee's Workshop held in April at Lake Tahoe, Nevada. Professor Kiremidjian presented her research on "Consequences of Damage to Bridges in the Northridge Earthquake," and Professor Smith presented, "Computational Issues Associated with the Analysis of Actively Controlled Structures."

Professors Haresh Shah, Anne Kiremidjian and Visiting Shimizu **Professor Jun Kanda** visited Kobe in March to investigate the building and bridge damage from the January earthquake. In April, **Professor Helmut Krawinkler** and Visiting Shimizu **Professor Peter Fajfar** traveled to Kobe to investigate the damage to steel structures.

Professors Haresh Shah and **Anne Kiremidjian** presented papers at the seminar on *Catastrophic Risk Management for the Insurance and Reinsurance Industries* held in Singapore in May. The seminar was organized by the World Sesimic Safety Initiative (WSSI) of the International Association on Earthquake Engineering (LAEE).

The Blume Center participated in Safety Week activities at Stanford University during the week of April 17-21. As part of these activities, **Professor Anne Kiremidjian** gave a lecture on the Kobe earthquake to the Stanford community on Friday, April 21.

Professor Kincho Law and his wife, Mary Cheuk, welcomed the birth of their first child, Karen, in early March.

RESEARCH SPOTLIGHT

Active Vibration Control of Structures in Seismic Zones Considering the Effects of Time-Varying Uncertainties and Actuator Saturation

Project Sponsor: National Science Foundation and Obayashi Corporation

Project Duration: September, 1992 - September, 1995

Principal Investigator: H. Allison Smith
Stanford Research Assistant: J. Geoffrey Chase

The primary goals when applying optimal control theory to civil structures is the maintenance of stability and the achievement of specific performance criteria, including control efficiency, in the presence of random disturbances such as wind and earthquake loadings. Two important issues in achieving these goals is the maintenance of stability in the presence of non-linear actuator saturation effects and achievement of the performance criteria considering the unknown, time varying, structural parametric uncertainties. Most importantly, both of these issues must be addressed concomitantly within the same control design.

The majority of civil engineering control applications employ linear quadratic regulator (LQR) methods to obtain an optimal controller. Because environmental loads are random in both time and space, analytical solutions to the LQR optimal control equations are not available. Problems typically are reduced to obtaining the analytical solution of an algebraic Riccati equation (ARE), obtained by ignoring the external excitation terms and assuming that the structure can be modeled as a linear time invariant (LTI) system. This LTI model implicitly assumes that the structural properties are not only constant, but exactly known.

Actuator saturation occurs when the actuator is given a demand requiring an output greater than the designed peak output. The result is a clipped control input that is limited by the magnitude of the actuators peak output. Failure to account for this nonlinear effect can render the structure unstable as the optimal control input is changed arbitrarily to a value which guarantees neither performance or stability.

In considering the complications associated with structural parametric uncertainty and actuator saturation, this investigation reformulates the H-infinity control algorithm specifically for application to civil structures in seismic zones [Smith and Chase, 19941. H-infinity control is a relatively new area of research in control theory. This approach minimizes the worst case response of a system over an entire family of inputs. This task is accomplished by minimizing the infinity norm of the transfer function from the disturbance inputs to the regulated outputs. Similar to the LQR algorithms, the H-infinity approach performs this minimization on a LTI state space model.

A two-part study presents the theory and application of H-infinity state feedback optimal control to civil structures in the presence of actuator limitations and time varying parametric uncertainties. Robust H-infinity state feedback controllers are developed which achieve the desired H-infinity norm bound while accounting for pre-specified bounds on the time varying parametric uncertainties. Stability of these controllers in the presence of non-linear actuator saturation can be proven through the construction of a Lyapunov function for the saturated control system using a non-linear state space model and new mathematical programming techniques. Lack of a feasible solution to these optimization problems serves as proof that stability cannot be guaranteed for these controllers with this type of Lyapunov function.

Part I represents the theoretical developments associated with reformulation of the H-infinity control algorithm for civil structures in the presence of time varying parametric uncertainties and actuator saturation. Application of this algorithm to a full scale actively controlled structure is discussed in Part 2. Specifically, a comparison is made between the LQR and H-infinity algorithms based on application of each algorithm to an actively controlled 33-story structure.

The Riverside Sumida Central Tower (see Figure 1) is a moment resisting, steel frame structure designed and constructed by Obayashi Corporation and located in Tokyo. The building is fitted with two active mass dampers (AMD's) (see Figure 2) for reduction of structural response due to small earthquake inputs and wind loads. Each AMD is designed to attenuate response in the lateral direction and, in concert, they are able to control torsional motions. Altogether, the AMD controllers are capable of controlling the first four modes of response. The controllers governing these AMD's is the LQR approach for LTI systems. The design, development, and testing of this system have been reported extensively by Suzuki et al. [1994] and Watanabe et al., [1992]. This research uses a five degree-of-freedom lateral motion model of the Tower, derived from modal data collected from five instrumented locations on the structure during full scale testing.

The goal of this research is to implement the newly developed H-infinity controller on the Riverside Sumida Central Tower and to compare the effectiveness of this controller with the LQR controller. It must be noted that the purpose of the AMD mounted on the Sumida Tower is to control vibration which may cause discomfort to building occupants.

Thus, the size of the AMD is quite small compared to the total building mass (0.06%). However, although significant vibration control due to full scale seismic excitations is not possible with this actuator, the effectiveness of various control algorithms can be tested using this structure/control model. Simulations are performed using records from the Tabas, Iran earthquake of 1978, the Imperial Valley earthquake of 1979 (Holtville Record), and the Northridge earthquake of 1994 (Sylmar record). Results of this study will be published in an upcoming Blume Center Technical Report.

References:

Smith,.H. A. and Chase, 1. G. (1994). Robust Disturbance Rejection Using H-infinity Control for Civil Structures, *Proceedings of the First World Conference on Structural Control*, Los Angeles, California.

Suzuki, T., Kageyama, M., Nobata, A., Inaba, S., and Yoshida, 0. (I 994). Active Vibration Control System Installed in a High- Rise Building, *Proceedings of the First World Conference on Structural Control,* Los Angeles, California.

Watanabe, T., Yoshida, K., Shimogo, T, and Suzuki, T. (1992). Reduced-order Active Vibration Control for High-Rise Build- *ings, Proceedings of the First International Conference on Motion and Vibration Control,* Yokohama, Japan.

Figure 1: Riverside Sumida Central Tower

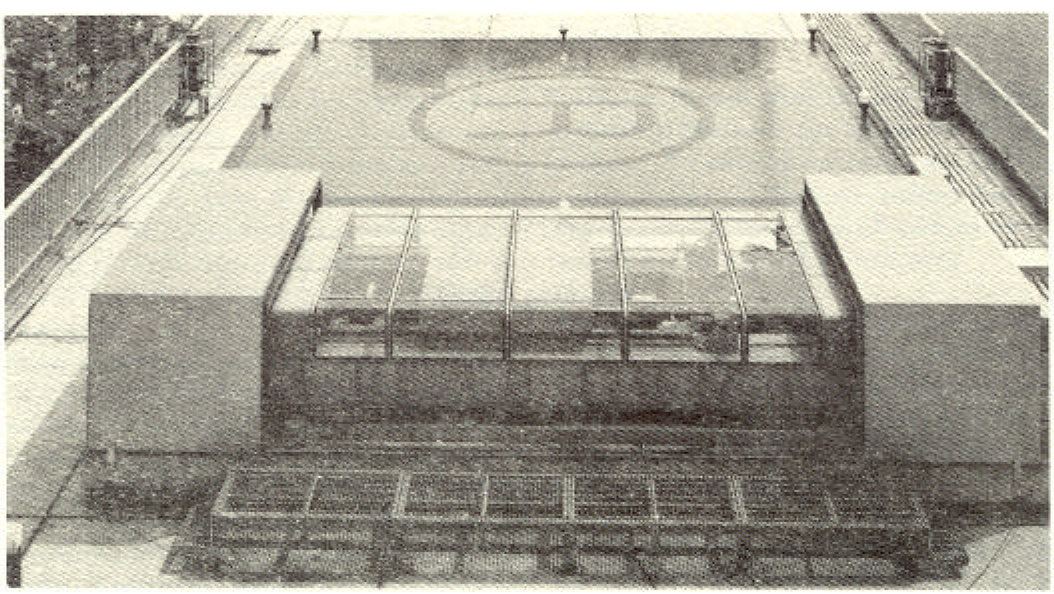
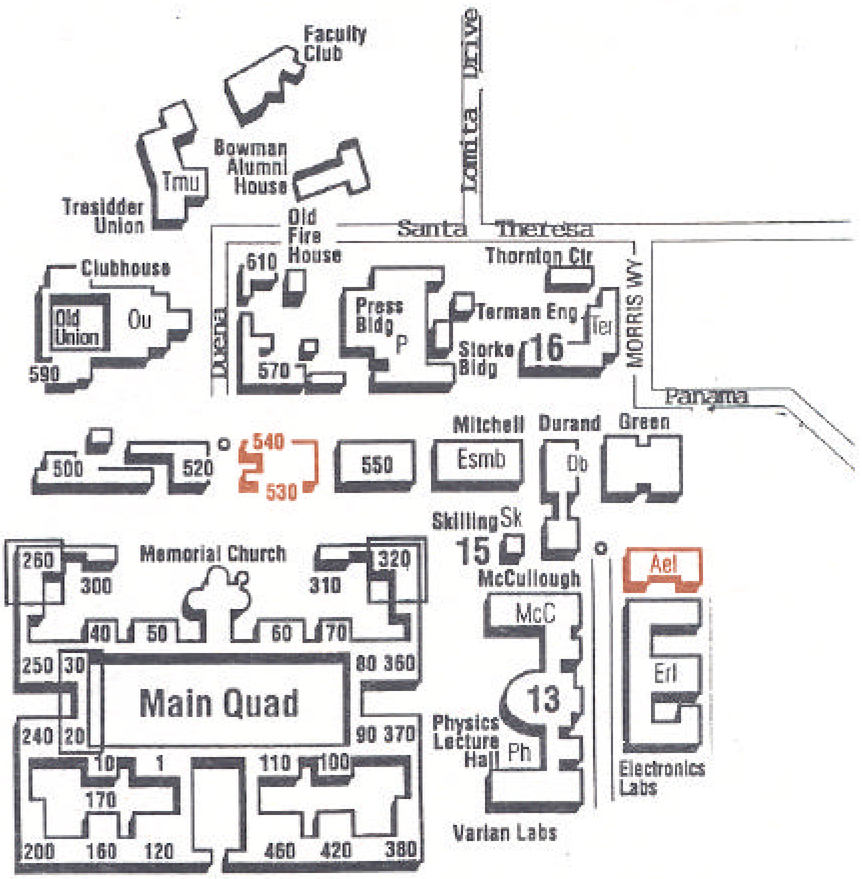


Figure 2: Active Mass Damper (AMD) Assemby on Roof of Tower

BLUME CENTER UNDERGOES SEISMIC UPGRADE

The seismic upgrade and general remodeling of The Blume Center (Building 540) will begin after Commencement. All of the Center offices and computer facilities will be temporarily relocated to Building 530 and to the AEL (Applied Electronics Laboratory), as indicated on the map. The Structural Engineering Lab will be closed down for the duration of the retrofitting process, which is' expected to take approximately nine months. Please feet free to visit us in these temporary quarters and at the newly remodeled Building 540 next spring.



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