BLUME CENTER REDEDICATED
APRIL 26, 1997

For the past 22 years, the John A. Blume Earthquake Engineering Center has been located in Building 540 on the Stanford University Campus. Building 540 was constructed in 1912 of unreinforced masonry with very lightly reinforced concrete piers. From mid-1995 to mid-1996, the Blume Center was relocated while Building 540 was renovated and seismically upgraded.

The Blume Center was officially rededicated on April 26. The rededication program began with Anne Kiremidjian, the current Director of the Blume Center, who gave an overview of the Center and its history. William Holmes [M.S., 1963] of Rutherford and Chekene, the structural engineering firm for the Blume Center project, described the renovation and seismic retrofit of the building. Stephanie King, the Associate Director of the Blume Center, summarized the current research at the Center.

A letter from John Blume was read to the attendees by Jene Blume, wife of Dr. Blume. Regretfully, Dr. Blume was unable to attend the rededication. Joseph Goodman, the Associate Dean of the School of Engineering at Stanford, and Jeffrey Koseff, the Chairman of Stanford's Civil Engineering Department gave their perspectives on the Blume Center developments. Haresh Shah, a founding Director of the Blume Center, and Helmut Krawinkler, the former Director of the Blume Center, shared memories of the Center's activities since its founding.

The presentations were followed by laboratory and computer demonstrations, including the newly remodeled shaking table, and tours of the completely remodeled office, teaching, and laboratory facilities.

BLUME CENTER NEWS

Prof. H. Allison Smith and PhD Candidate Scott Breneman participated in the ASCE Structures Congress XV in Portland, Oregon on April 14-16.

On April 24, the CUREe (California Universities for Research in Earthquake Engineering) Board of Directors held their quarterly meeting at the Blume Center.

The Executive Committee of the Technical Council on Lifeline Earthquake Engineering (TCLEE) held its meeting at the Blume Center on April 18-19.

Prof. Anne S. Kiremidjian and Consulting Prof. Richard Meehan were speakers at the Architectural Surety Conference on May 14-15 in Albuquerque, New Mexico.

Students, faculty, and staff from the Blume Center went on a field trip to Pinnacles National Monument on May 31. They stopped in Hollister and San Juan Batista to observe the effects of the San Andreas fault.

Engineer's Degree student Tomohiko Hatada participated in the 1997 American Control Conference held in Albuquerque, New Mexico on June 4-6.

Research Associate Dr. Renate Fruchter was appointed the first director of the new Project Based Learning Lab (PBL Lab) of the Civil Engineering Department at Stanford. The PBL Lab focuses on multidisciplinary, collaborative, geographically distributed Architecture/Construction/Engineering team work and integrates into the curriculum cutting edge Internet-based, Web-mediated, and videoconferencing information technologies. Funding for the lab has been provided by the President's Fund Award to the Department of Civil Engineering. Computer hardware and software was donated by Sun Microsystems and Autodesk.

Dr. Renate Fruchter participated in the 4th ASCE Congress on Computing in Civil Engineering on June 16-18 in Philadelphia, Pennsylvania.

On June 15, four graduate students from the Blume Center received their PhD degrees in Structural Engineering. The new graduates are Maya Belubekian, Rachel Davidson, Anju Gupta, and Armin Schemmann.

Photo at left: Anne Kiremidjian with (l to r) Helmut Krawinkler, Haresh Shah, Jene Blume, Jeffrey Koseff, and Joseph Goodman.
Modeling and Active Control of Cable-Stayed Bridges Subject to Multiple Support Excitation
by Armin Schemmann, Ph.D.

Research Advisor: Professor H. Allison Smith

Introduction
In structural engineering, the mitigation of damage induced by large environmental loads is of paramount interest. Specifically, in seismic regions, earthquakes can pose a threat to human lives and the infrastructure. In recent years, the idea of applying active control as a means of vibration control has grown increasingly popular. In essence, through the application of actuators and sensors, active control can reduce structural forces and vibrations such that desirable performance characteristics are achieved. While research in this area with respect to building structures has advanced considerably in the past decades, its application to large lifeline structures, such as cable-stayed bridges, under earthquake loading has not been addressed extensively.

Scope of Research
The objective of this research is to increase the understanding on how the complexities associated with modeling cable-stayed bridges, such as nonlinear behavior and the participation of coupled, high order vibration modes in the bridge’s dynamic response, affect the overall effectiveness of active control schemes. The geometrically nonlinear behavior is caused by the cables, the beam-column interaction exhibited by the longitudinal bridge deck and towers, and bridge’s geometry change due to large deformations. The nonlinearities are considered by performing a nonlinear static analysis (prior to a linear dynamic analysis) in which the stiffness matrix associated with the dead load deformed shape is obtained. Other objectives include the development of an analytical model of an actively controlled cable-stayed bridge, the development of a reduced order model suitable for control purposes, and an assessment of the effectiveness of full state feedback and output feedback control in reducing the bridge’s force time-history. Active control is focused primarily on the reduction of the deck’s force response. The bridge towers are examined under this control action; however, the attenuation of towers’ force response is not emphasized. The 316 degree of freedom analytical model studied here (illustrated in Figure 1) is based on an experimental scale model representative of the Jindo Bridge located in South Korea. Although results are obtained for a specific bridge, they remain valid for other cable-stayed bridges, as they typically exhibit similar structural dynamics.

Reduced Order Modeling
Computational considerations associated with control analyses require the size of the model to be significantly reduced, without loss of the important vibration characteristics and complexities. The improved reduced system (IRS), internal balancing, and modal reduction techniques are studied and compared on their ability to capture the complex dynamic response of cable-stayed bridges subjected to multiple-support excitation and their ability to create a viable and computationally sound state space model for control analyses.

The IRS method is based on the Guyan reduction, but improves on it by including mass effects into the reduction. The reduction technique based on the system balancing transformation method transforms the state space system into a balanced realization, where the controllability and observability Gramians are equal and diagonal. Neither the IRS nor the balanced reduction method are well suited for this study. The first method introduces spurious modes and ill-conditioning into the stiffness and mass matrices while the latter method has trouble capturing higher order modes.

The modal reduction method uses the principle of modal superposition; important modes are identified and used to form the modal transformation matrix. Results show that this technique, for its ability to select only those modes causing the largest force and displacement response, is the most effective for control applications. The final reduced order model includes modes 1 to 6, 9 to 11, 13 to 21, 26, and 35 to yield a 42nd order state space model. Control efforts are focused on attenuating primarily the force response induced by these modes.

Control Analyses
The control analysis examines the effectiveness of full state feedback control employing a linear quadratic regulator (LQR) and the effectiveness of dynamic output feedback control utilizing a Kalman-Bucy filter in attenuating the structure’s force time-history response. Results show that significant reductions of the maximum internal forces and the force/displace-
ment response can be achieved through active control. Furthermore, once effective sensor locations have been selected, output feedback control performs very well. Attenuations in the force response equal to approximately 90-97% of those obtained for full state feedback control can be achieved. Generally, only first order modes need to be controlled to reduce the displacement response; however, the control of higher order modes is essential to reduce the force response.

Considering the horizontal component of the 1994 Northridge earthquake (taken at Baldwin Hills) and uniform-support excitation, Figures 2a and 2b show the controlled and uncontrolled displacement time-history response in the lateral direction at midspan for the cases when mode 1 and modes 1, 9, 26 and 35 are controlled, respectively. Similarly, Figures 3a and 3b illustrate the controlled and uncontrolled lateral bending moments at midspan for the cases when mode 1 and modes 1, 9, 26 and 35 are controlled, respectively. Figure 3 clearly shows the impact of the higher order modes. Controlling modes 9, 26 and 35, in addition to mode 1, results in significant attenuations of the bridge’s force response. The force response of the bridge deck in the lateral direction is reduced by 21.6% (measured in terms of root mean square value over the course of the earthquake) when only mode 1 is controlled. When modes 1, 9, 26 and 35 are controlled, the force response is reduced by 70.3% while the control effort only increases by 38.4%. However, as Figure 2 indicates that the control of the higher order modes has little effect on the displacement response. In this case, the supplementary control of modes 9, 26 and 35 only yields an additional reduction of 8.5% in the bridge’s displacement response.

For this ground motion, high order modes participate less dominantly for multiple-support excitation than for uniform-support excitation. However, multiple-support excitation should be considered as it can excite entirely different modes than uniform-support excitation. Moreover, multiple-support excitation induces forces that are caused by pseudo-static displacements and cannot be controlled.

This study also demonstrates that not all modes can be controlled. When attempting to control mode 18, which is a coupled tower-deck mode, using actuators located on the bridge deck, bending moments in the bridge deck are actually increased. Although mode 18 should not be controlled, sensors must be strategically located to pick up this mode in order to assure adequate performance when output feedback control is considered.

An investigation of various actuator configurations also leads to the conclusion that actuators are most effective when located close to the center of the bridge span. Generally, actuators should be located such that all dominant modes can be controlled.

Conclusions

In summary, active control is very effective in attenuating the structure’s force and displacement responses. However, a thorough understanding of the structural dynamics of a cable-stayed bridge must be obtained prior to applying active control. Modal coupling, which can complicate the application of active control significantly, is very common for these structures and must be addressed.

References


SHAH SYMPOSIUM AND RETIREMENT BANQUET HELD APRIL 25-26

Prof. Haresh Shah has been a pioneer in the fields of risk analysis, earthquake engineering, and probabilistic methods for 30 years. He has served Stanford University in many capacities, including Chairman of the Department of Civil Engineering and Founding Director of the John A. Blume Earthquake Engineering Center. Prof. Shah has decided to retire from the university at the end of 1997. On April 25-26, the Department of Civil Engineering at Stanford held a Symposium and Banquet to honor Prof. Shah on his retirement from the university. The Symposium was titled "Risk Management and Mitigation for Natural Hazards" and was co-sponsored by the California Universities for Research in Earthquake Engineering (CUREe).

The speakers at the 2-day Symposium included: Gil Jamieson (Federal Emergency Management Agency), Wilfred Iwan (California Institute of Technology), Howard Krunreuther (Wharton School, Univ. of Pennsylvania), Edward Jobe (American Re-Insurance Company), Tsuneo Katayama (National Research Institute for Earth Science and Disaster Prevention, Japan), Yuxian Hu (State Seismological Bureau, China), Anand Arya (University of Roorkee, India), Howard Krunreuther (Wharton School, Univ. of Pennsylvania), Edward Jobe (American Re-Insurance Company), Tsuneo Katayama (National Research Institute for Earth Science and Disaster Prevention, Japan), Yuxian Hu (State Seismological Bureau, China), Anand Arya (University of Roorkee, India), Luis Esteva (Universidad Nacional Autonoma de Mexico), Giuseppe Grandori (Politecnico di Milano), Allin Cornell (Stanford University), Roger Borcherdt (United States Geological Survey), and George Mader (Spangle Associates).

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