RECENT ACTIVITY OF STRUCTURAL CONTROL RESEARCH AND DEVELOPMENT IN JAPAN

by
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This is a summary of the most recent activity on structural control research and development in Japan. The Japan Panel, which is the center of the promotion for structural response control research, was established in September 1989 by the researchers and practitioners in the field of earthquake engineering, forming the Liaison Committee on Structural Response Control sponsored by Science Council of Japan (Chairman: T. Kobori). Recently, the Panel was expanded through the participation of researchers from wind engineering, and the sub-committee on structural control (Chairman: T. Miyata) was established in 1996. Under the Japan Panel, several Committees have been organized with participating organizations such as the Architectural Institute of Japan (AIJ), the Japan Society of Civil Engineers (JSCE), and the Japan Society of Mechanical Engineering (JSME). Each Institution has been doing individual activities: the Special Research Committee on Active Structural Response Control and the Sub-Committee for Structural Response Control in the Managing Committee for Vibration in Research Committee on Structures in AIJ, the Committee on Vibration Control and the Committee on Structural Control in JSCE, and the committee on Vibration Control and the Committee on Structural Control in JSME.

In order to integrate the interests of these several research committees, with the aim of establishing collaborative efforts between Universities and Industries, the 157 Committee on Structural Control (Chairman: Y. Inoue) was established by the Japan Society for Promotion of Science (JSPS) in 1994 and has been promoting the interaction of researchers, the transfer of information, and helping in the organization of national and international conferences through financial support. The organization of these committees is schematically illustrated in Figure 1. (cont. back cover)
ACTIVE CONTROL TEST OF A FULL-SCALE FRAME STRUCTURE AT KYOTO UNIVERSITY

by

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Introduction

A university-industry joint research project “Development of intelligent structural control system for strong earthquakes” (Principal Investigator: Yutaka Inoue) sponsored by Japan Society for Promotion of Science (JSPS) was conducted in order to develop intelligent seismic response control systems for strong earthquakes with a large capacity and a wide dynamic range, thus drastically enhancing the seismic safety of various structures, using the experience of the industry, university researchers and the academic resources in this field. As the structural model control experiment phase in this project, a verification test program using a real size 5-story steel frame at the campus of Disaster Prevention Research Institute, Kyoto University was carried out. An Active Mass Damper (AMD) and an excitation system were installed on the existing steel frame structure for this verification test program.

One of the problems of main concern for seismic response control systems for strong earthquakes is the engineering issue associated with the capacity or performance limitation of the control devices. Typical examples of such problems are control force or stroke limitation of the actuator used in the control systems, including the AMD. If the control system is designed for a small level earthquake, the requirement for the control device becomes proportionally larger in the case of strong earthquakes; it may result in a device failure, otherwise the device would be forced to stop functioning in order to avoid breakdown of the system. In those cases, the control system cannot make full use of its potential capability expected in the design of the control device. Therefore, one of the significant requirements for the seismic response control algorithm for strong earthquakes is that the control signal does not exceed the performance limit of the device at any input level.

In order to solve these two problems, a nonlinear control scheme using variable control gain is employed. The objective of the development of the control algorithm used in this test program is to satisfy the constraint on the displacement of the auxiliary mass in the AMD system independent of the excitation level. This method is expected to allow a reliable operation of an AMD device in the event of strong earthquakes.

Test System and Real-size Frame Structure

The outline of the test system is shown in Fig. 1. Lateral response of the frame was generated by an excitation device installed on the 4th floor level. The excitation device, or shaker used an auxiliary mass driver mechanism similar to the AMD system in order to allow excitation with random waveforms. The control device i.e. the AMD system, is installed on the top floor.

The 5-story steel frame structure (1 X 2 spans) built at the campus of DPRI, Kyoto University is shown in Fig. 2. The total weight of the structure is approximately 150 tons, equivalent to the effective mass of 75 tons. The photograph of the AMD device is shown in Fig. 3. The weight of the auxiliary mass of the AMD system was approximately 2 tons, corresponding to the mass ratio of 2.5%, and the maximum stroke is 50cm. The shaker is a system of the same type as the AMD device, with the auxiliary mass weight of 5 tons, and the stroke of 100 cm. The excitation of the test frame structure with any specified waveforms can be achieved with this device to test the performance of the seismic response control system.

Nonlinear Control Law with Auxiliary Mass Displacement Constraint

The nonlinear control law used in the verification test is based on the variable gain control scheme. The relative displacement of the structure (measured from the ground), the relative displacement of the auxiliary mass and the displacement of the ground are denoted by \( x(t) \), \( y(t) \) and \( z(t) \), respectively, as shown in Fig.4. Using these notations, the control law can be expressed as follows

\[
\frac{dy}{dt} = \beta(E) - \alpha y
\]

where \( \alpha \) and \( \beta \) are the control gain parameters, and the control gain, \( \beta \), is defined as the function of the vibration energy of the system \( E = M(\frac{dx}{dt})^2 + kx^2 \), so that the gain decreases when the amplitude of the system response grows to a high level. Since the variable control gain is applied to general nonstationary seismic input cases, the vibration energy is updated based on the real time measurement of the structural response. The control algorithm automatically adjusts the control gain on a real time basis so that the auxiliary mass displacement is limited to the predefined range, while the damping of the structural response is maximized for a small input.

Although a SDOF system is assumed in the derivation and the above description of the variable control concept, the real size test frame structure is considered to be a 5-DOF system. In the application of the algorithm in the tests, the lowest mode of the structure is controlled using a modal filter.
Figure 1 - Outline of Test System

Figure 2 - Full-Scale Steel Frame Structure

Figure 3 - Active Mass Damper (AMD)
Figure 4 - Modeling of the Structure and AMD

Figure 5 - Test Results: El Centro Record (Scale Factor 0.7)

Figure 6 - Test Results: El Centro Record (Scale Factor 0.5, 1.0)

Figure 7 - Free Vibration Test (Top Floor Acceleration)
Representative Test Results

The results of the test using the El Centro record as the input are shown in Fig. 5. The El Centro record was first scaled to the peak acceleration of 50 Gal, and was used as the standard reference input level. Furthermore, the scale factor of 0.7 was used in the test shown in Fig. 5. A comparison between the cases of input scale factors 0.5 and 1.0 is shown in Fig. 6. As can be expected, the input acceleration for the case of scale factor 1.0 is 2 times as the case of scale factor 0.5. However, the displacement amplitude of the auxiliary mass is similar in these two cases, indicating that the displacement range of AMD is constant for different levels of input excitation.

Figures 7 and 8 show a comparison between the variable gain control and the LQ control method (optimal regulator theory), which is conventionally used as the linear control algorithm. The top floor acceleration and AMD displacement response are shown in Figs. 8 and 9, respectively. The initial AMD displacement amplitude is almost the same in both cases. In the LQ control case, the auxiliary mass displacement amplitude decreases in proportion to the top floor acceleration, in contrast to the variable gain control case in which the auxiliary mass displacement amplitude remained constant for most of the duration of the time. For this reason, the response in the top floor acceleration decreases considerably faster in the variable gain control case than the LQ control case. This example clearly demonstrates that the variable gain control is more effective in reducing the structural dynamic response for a given AMD stroke range than the conventional linear control while the damping of the vibration is effective.

Concluding Remarks

The verification test results successfully show that the proposed variable gain control algorithm makes use of the stroke range of the auxiliary mass in the cases of sinusoidal, and seismic inputs, and shows superior performance in the seismic response control, compared with the conventional LQ control method. Combined with the ease of the implementation, the variable gain control was proved to be a feasible and promising method in the actual application to full-size structures.

A Message from former IASC President, Professor George W. Housner

The magazine Sound & Vibration has been published for the past 30 years and served as a forum for those persons interested in solving practical problems. Now it describes itself as “The Noise and Vibration Control Journal” which presumably reflects the fact that in the future the focus will on be “control.”

The January, 1997 issue contains an interesting review articles titled “Perspectives on Active Noise and Vibration Control” by E. F. Beckman and E. K. Bender. As explained in this paper noise and vibration control is almost an exact analog of structural control. The main differences are that structural control is concerned with large masses vibrating in the frequency range of 0.1 cps to 10 cps, whereas the noise control is concerned with small masses vibrating in the frequency range of 100 cps to 10,000 cps. A further differences is that noise control has been mainly funded by military agencies and, hence, has funding that is orders of magnitude greater than the funding for structural control and this has lead to more rapid progress. While the results in noise control cannot be directly applied to structural control, the subject is of some interest to researchers in structural control, if only to see what can be accomplished with almost unlimited funding.

Abstract Deadline for
Second World Conference on Structural Control
June 28 - July 1, 1998 Kyoto, Japan

The abstract deadline for the Second World Conference on Structural Control (2WCSC) is October 15, 1997. Conference and abstract submission information can be obtained by contacting: E-mail: 2wcsc@nstn.arch.waseda.ac.jp or 2wcsc Steering Committee c/o Professor Akira Nishitani Department of Architecture Waseda University Fax: 813-5286-3286

ASCE Journal of Engineering Mechanics features
Structural Control: Past, Present, and Future

The September issue of the ASCE Journal of Engineering Mechanics features a paper entitled, “Structural Control: Past, Present and Future,” co-authored by Professor G. W. Housner (Caltech), Professor L.A. Bergman (Univ. of Illinois), Professor T. K. Caughey (Caltech), Professor A. G. Chassiakos (Cal State, Long Beach), Professor R. O. Claus (Virginia Tech), Professor Sami Masri (USC), Professor R. E. Skeleton (UC-San Diego), Professor T. T. Soong (SUNY-Buffalo), Professor B. F. Spencer (Univ. of Notre Dame) and Professor J. T. P. Yao (Texas A&M). In addition to its appearance in the special issue, the paper has been released as a book edition. Copies can be obtained using the following bibliographic information:

Structural Control: Past, Present, and Future
List Price $36.00 (Outside U. S. $43.20)
ASCE Members are entitled to a 25% discount
Kobori Article (continued)

As one of the activities of the 157 Committee, about $700,000 was funded by the government research aid program and the experimental research for active control was conducted at the Disaster Prevention Institute of Kyoto University in the fiscal year of 1995. After that, the US-Japan Symposium was convened at Kyoto on March, 1996, and the major accomplishments of the experiment were reported and discussed. The Japan Panel supported the participation of several members to attend the Second International Workshop on Structural Control held in Hong Kong last December. In addition, the five-year research proposal under the title of “Development of Dynamic Intelligent Structures for Large Earthquakes” is scheduled to be conducted during fiscal years of 1996 through 2000.

New Project for 21 Century

The research proposal regarding Structural Control submitted by Japanese researchers group was selected as one of the JSPS Research for the Future project. The research is conducted by Professor A. Nishitani as the project leader and Professors Y. Inoue and H. Iemura as the core members. The purpose of the research is:

1. Development of non-linear control algorithm accounting for various kinds of constraints related to hard/software for active control of structures;
2. Development of next-generation intelligent control system working successfully in case of large earthquake; and
3. Establishment of design concept and guidelines for dynamic intelligent structures having the ability to maintain high performance even for the case of strong, large earthquake.

To accomplish such goals, experimental works such as active control experiments with large-scale building structures and shaking table tests with small structure models are carried out along with computer simulations. The funding expected to be about $4,000,000 in total for five years.

Lastly, all members of the Committees aforementioned above are planning to incorporate and participate in the Second World Conference on Structural Control scheduled to be held in Kyoto from June 28 - July 1, 1998.

The 157th Committee on Structural Response Control Research, Japan Society for Promotion of Science

Architectural Institute of Japan (AIJ)
- Special Research Committee on Active Structural Response Control
- Sub-committee for Structural Response Control in Managing Committee for Vibration Research Committee on Structures

Japan Society of Civil Engineers (JSCE)
- Structural Control Committee
- Seismic Response Control Committee

Japan Society of Mechanical Engineers (JSME)
- Advance Control for Motion and Control
- Control of Response of Structures for Vibration

Figure 1: Japan Panel (Organizing Committees on Structure Response Control Research in Japan)