

## Activities in structural control in the USA

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**ABSTRACT:** An overview is presented of activities related to structural control research in the USA. In 1989 the U.S. Panel on Structural Control Research was established and in 1990 the U.S. National Workshop on Structural Control Research was held. In 1991 the National Science Foundation established a program for funding research in structural control and related topics. A variety of research projects on various aspects of structural control have been undertaken, both theoretical and experimental.

### INTRODUCTION

In recent years there has developed a growing interest in structural control research. Studies were undertaken to explore possibilities of controlling the motions of structures and equipment during the action of wind, earthquake, etc. It was felt that this activity could be strengthened by identifying the field and organizing a Panel that would correlate activities. Accordingly, the U.S. Panel on Structural Control Research was organized in 1989 under the auspices of the Consortium: California Universities for Research in Earthquake Engineering (CUREe); and funding was provided by the National Science Foundation. The Panel members are: A. Clark, M.T.S. Systems; W. J. Hall, University of Illinois; G. W. Housner, California Institute of Technology; S. F. Masri, University of Southern California; M. Shinozuka, Princeton University; T. T. Soong, State University of New York-Buffalo; and B. K. Wada, Jet Propulsion Laboratory. Seven Working Groups were organized: 1) Analytical Methods, 2) Experimental Methods, 3) Building Applications, 4) Non-building Applications, 5) Interdisciplinary Approaches, 6) International Coordination, 7) Information Dissemination.

The Panel was charged with the following responsibilities:

1. To develop a plan for a U.S. program in the active (hybrid) control of structures.
2. To conduct, in collaboration with a counterpart panel in Japan established by the Japan Science Council, a joint U.S.-Japan cooperative Plan for research, development, and implementation of controlled structural systems.
3. To develop a plan of action under the auspices of the International Decade for Natural Disaster Reduction for U.S. participation in collaborative international research in active control.

4. To monitor U.S. efforts in this area.

In October 1990 the U.S. National Workshop on Structural Control Research was held and the Proceedings was published. In March 1992 Panel members attended the Workshop-Symposium on Structural Response Control in Tokyo. This was organized by the Japan Committee on Structural Response Control Research, Japan Science Council, and plans were made for organizing a Workshop in Honolulu in 1993. The U.S. Panel is preparing a report and the Japan Committee is also preparing a report. These reports will form the basis for the 1993 Workshop.

### NSF INITIATIVE ON STRUCTURAL CONTROL RESEARCH

In 1991 the National Science Foundation established a Program in structural control research. The objectives of the Program are to encourage innovations in passive, active, and hybrid control systems. To advance sensor and actuator technology and signal processing techniques and their applications. To develop intelligent robots, other devices and computer systems for structural safety. To develop innovative systems for energy absorption, added damping, and variable stiffness. To study the robustness and system reliability of control systems. To develop guidelines, standards and practical approaches and techniques for design, fabrication and field installation. To investigate emerging technology subjects in innovative structural systems, smart materials, sensors, and devices for detection, sensing, monitoring, and diagnosis. For the first year the distribution of submitted proposals was as

follows: earthquake, 40; wind, 24; general vibration, 13; waves, 1; chaotic motion, 1.

## RESEARCH PROJECTS IN THE U.S.

A number of research projects have been carried out or are currently being worked on.

### Active Bracing Systems

Active tendon control has been studied analytically in connection with control of slender structures, tall buildings, bridges and offshore structures. Early experiments involving the use of tendons were performed on a series of small-scale structural models (Roorda, 1980). More recently a comprehensive experimental study was designed and carried out to study the feasibility of active bracing control using carefully calibrated structural models. Results from this series of experiments are reported in Chung, et al. (1988, 1989), and Reinhorn, et al. (1989).

### Active Mass Damper and Active Mass Driver

This control mechanism and its sensors has the potential for controlling the motions of a structure to very small values. A series of feasibility studies of active and semi-active mass dampers have been made.

### Variable Stiffness Systems

The primary objective of the variable stiffness system is to use active control to vary the structural stiffness so as to minimize the energy input and to maximize the energy absorption.

### Pulse Generators

Control by means of applied impulses has been the subject of experimental research in the laboratory (Miller, et al., 1987; Traina, et al., 1988; Masri, et al., 1989).

### Other Control Systems

Discussed in the above are some of the most studied control mechanisms for structural applications. Many others have been proposed. Furthermore the combined use of active-passive (hybrid) systems have been suggested for specific structural applications. The force requirement of an active control system can be significantly reduced by combining it with a passive system. For example, in combination with a passive system, the force

requirement of an active control system can be significantly reduced, which allows the active control device to operate at a much higher efficiency and effectiveness.

### Full-Scale Implementation and Testing

In the United States passive control systems have been used on actual buildings. Tuned-mass dampers have been used on a number of buildings to control wind-induced motions; and elastomeric bearings have been used on buildings to control earthquake-induced motions. Active control and hybrid control have not been implemented on any buildings in the U.S.

## CONCLUSIONS

Research activities in the U.S. are mainly in the exploratory stage; that is, studies are exploring the potentials of active control. In addition to studying the physics of structural control, it is also necessary to examine such items as cost, reliability, effectiveness, etc.

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## APPENDIX

### INTRODUCTION TO STRUCTURAL CONTROL

The first concepts of controlling earthquake stresses by reducing the transmission of force from the foundation into the structure originated a little more than 100 years ago in Japan. It was proposed to place a building on roller bearings, thus controlling the magnitude of the force transmitted into the building. In more recent years other methods have been proposed and implemented: supporting the building on deformable pedestals of steel-rubber sandwich construction; supporting the structure on sliding bearings; introducing a flexible first-story; supporting the structure on springs; providing special mechanisms to introduce increased damping; etc. Wind-induced oscillations of buildings have been controlled by introducing damping; using tuned-mass dampers on the upper floor; etc. The foregoing are "passive controls" and in recent years the concept of "active control" has entered the picture, as has "hybrid control" in which both passive and active elements are utilized. In structural engineering, active structural

control is an area of research in which the motion of a structure is controlled or modified by means of the action of a control system through some external energy supply. In comparison with passive systems, a number of advantages associated with active systems can be cited; among them are (a) enhanced effectiveness in motion control; (b) relative insensitivity to site conditions and ground motion; (c) applicability to multi-hazard mitigation situations; and (d) selectivity of control objectives, for example, human comfort or stress limitations.

In recent years considerable attention has been paid to active structural control research. It is now at the stage where actual systems have been designed, fabricated and installed in full-scale structures. A number of review articles (Miller, 1987; Kobori, 1988; Masri, 1988; Soong, 1988; Yang, 1988; Soong, 1991; and a book, Soong, 1990), provide information and assessment on recent advances.

An active structural control system has the basic configuration shown in Fig. 1. It consists of sensors located about the structure to measure either external excitations or structural response variables, or both. Computational devices are needed to process the measured information and to indicate the necessary control forces as based on a particular control algorithm. Powered actuators produce the required forces. When only the structural response variables are measured, the control configuration is referred to as closed-loop control since the structural response is continually monitored and this information is used to make continual corrections to the applied control forces. An open-loop control results when the control forces are regulated by the measured excitations, which can be achieved, for earthquake inputs by measuring accelerations at the foundation. In the case where the information on both the response quantities and excitation are utilized for control design, the term open-closed loop control is used. The effect of open-closed loop control is to modify the structural parameters (stiffness and damping) so that it can respond more favorably to the external excitation. The effect of the open loop component is a modification of the excitation.

The concept of active control is very interesting, especially when combined with passive control elements. An overview of active structural control under seismic loads is given in the paper Soong, 1991.

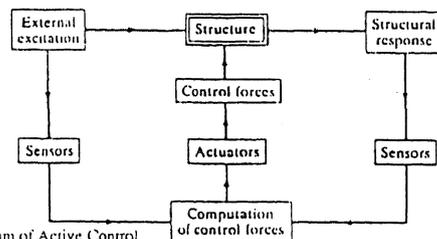


Figure 1  
Block Diagram of Active Control