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Panel discussion

1 Brief Summary of Discussion (H.Iemura)

To generate discussions with the participants on the current problems and future research needs, a panel discussion is held after the presentation by three panelists. Mr. A.J.Clark; Application Specialist, Advance Technology Development, MTS Systems Corporation from U.S.A., Prof. H.Iemura; Department of Civil Engineering, Kyoto University from Japan, and Prof.J.Rodellar, Department of Mathematical Application, Polytechnic University of Catalonia from Spain, reported the State-of-the Art on "Control of Seismic Response of Structures" in the U.S.A., Japan, and Europe, respectively. Critical technical issues are also reported. Their presentations and some results of the panel discussion are included in the following sections summarized by the panelists.

Many opinions on the current technical problems and future research need are raised by the participants and discussed with the session reporters and panelists. Although discussions are widely spread in many technical issues, they could be categorized as follows.

Control Device

(1) Energy efficiency should be investigated not only in actuation of control force but also in control mechanisms.

(2) It is ideal to use energy of vibration of structures to suppress their dynamic response.

(3) Maintenance and replacement of the control devices should be checked.

(4) How to evaluate the merit of active control method compared to conventional passive control.

(5) Cost-effectiveness shall be discussed for practical implementation. It is strongly needed to develop the devices with reasonable cost.

New Material

Smart material which changes stiffness and damping depending on added electricity have high potential for structural control. Intensive researches are required.

Structural Design

(1) For practical implementation, design guidelines for passive, active and hybrid control systems are needed, although most of them are under development stage.

(2) How to evaluate reliability of the controlled structures.

Research Fund

To develop innovative technology and for the their verification, large amount of research fund from different sources is strongly needed. International collaboration is also needed.

2 Presentation(1) (H.Iemura)

- Necessity, Feasibility and Research Needs -

2.1 Necessity

With vast improvement in recent construction techniques and materials, light-weight and flexible structures such as high-rise buildings and long-span bridges have been designed and constructed in Japan. It is becoming critically important to suppress dynamic response of structures due to wind and earthquake excitations, not only for their safety but also their serviceability.

In conventional earthquake engineering, earthquake ground acceleration has been considered as nonstationary random motion with broad band of frequency components. The El Centro Records of the 1940 Imperial Valley Earthquake is a typical case. This is still true for sites with good soil conditions. However, narrow frequency banded ground motion with long duration has been observed in the recent earthquakes at soft soil sites, where modern structures have been constructed. When subjected to this type of earthquake ground motion, flexible and lightly damped structures have showed resonant phenomena, which leads to high dynamic amplification of structural response. Examples of structural damages caused by the high amplification effects due to some recent earthquakes are described in the followings;

Nihonkai-Chubu Earthquake in 1983 in JAPAN

Very high sloshing in oil tanks was observed at Niigata City which is 270 km away from the epicenter. Niigata is covered by deep and soft sand. Ground motion with period of 10 seconds became predominant and continued for more than several minutes. Mended and corrected displacement and acceleration-type seismograms were found to give much higher response spectra than the design values for long-period (5-10 sec.) structures with 2 to 5% damping ratio.

Mexico Earthquake in 1985

In Mexico City which is 350 km away from the epicenter, the ground motion with predominant period of 2 seconds were observed. Acceleration response spectra with 2% damping ratio is much higher than the design spectra. The acceleration responses at 2 seconds is approximately 10 times amplified compared to the ground acceleration, which caused significant damage to 15 to 20 storied buildings.

Armenia Earthquake in 1988 in USSR

Severe damage concentration in Leninakan which is 30 km away from the epicenter is considered to have correlations with local soil conditions. Leninakan lies in an alluvial valley with 200 to 300 m of underlying sedimentary deposit. The measurement of the after shock by U.S.G.S. verifies high dynamic amplification.

Loma Prieta Earthquake in 1989

Although the earthquake was not really big one, severe damage occurred in soft soil sites. Building damage in Marina district and Viaduct damage in Cypress area are typical examples. Significant differences in acceleration records are found in hard and soft soil conditions.

Philippines Earthquake in 1990

Many of the 5 to 10 storied reinforced concrete building at Baguio City were severely damaged or collapsed. The city is located on the top of mountain area which is more than 50 km away from the detected major fault. Because of high concentration of damage compared to other cities, it is believed that narrow-banded and amplified ground motion could have been generated due to the irregular hill site effects.

Turkish Earthquake in 1992

Three to five storied buildings in Erzinkan City in Turkey were severely damaged due to the Turkish Earthquake in March 1992. Because the city is located on the soft alluvium layer, and had experienced structural damage due to previous earthquakes in 1983, 1939, 1920 and others, the local soil condition could be one of the major reasons to generate strong ground motion at the site.

2.2 Feasibility

There are many different type structural control techniques to suppress dynamic response of structures. Some of them have already been developed and installed to existing structures. However, other are still under the stage of analytical and experimental research.

The structural control devices can be grouped mainly into three following types. The first is passive-control type which does not require any sensors nor external energy supply. Energy consuming type devices such as viscous dampers, friction and elasto-plastic components, and tune mass dampers (TMD) or tuned liquid dampers (TLD) are all passive type devices. Seismic base isolators (B.I.) to reduce the seismic shear force to relatively rigid structures can be grouped into this passive type.

The second is active control type which can be grouped into control force type, i.e., active moving mass (AMD), and variable structural characteristic type, i.e., active variable stiffness (AVS) and active variable damping (AVD).

The third is hybrid type which uses merit of both passive and active control methods. Active base isolation, active tuned mass (ATMD) and active pendulum are of this type.

Classifying earthquake ground motion into nonstationary broad band random excitation and relatively stationary narrow banded harmonic excitation, and dividing structures into relatively rigid and flexible structures, feasibility and applicability of each control method are shown in Table 4.2.1, where ◎indicates highly promising, ○ indicates promising, △ indicates possible and × indicates not appropriate.

Hence this table is completed by the author's personal imagination, new innovative control devices may result in different categorization in the table.

2.3 Research Needs

It is very clear that development and application of control devices needs a lot of research, designing, verification tests and so on. At the Japan National Symposium/Workshop on Structural Response Control which is held in March 1992 in Tokyo, future research needs were discussed in three groups. The followings are brief summary of the topics in discussions at each group. It is expected that this summary contribute to generate further discussion in the field of structural seismic response control.

Group #1: Control Theory

Co-moderators:

Prof. Y.Inoue (Osaka University)
Prof. H.Iemura (Kyoto University)
Prof. K.Nonami (Chiba University)

(1) "Given the mechanical device of active control, will application of different control theories produce any significant differences in dynamic structural response?"

Keywords: LQ and LQG, H-infinite control, Feedback and feedforward controls, Criteria, Neuro and fuzzy controls, and others

(2) "Given the mechanical control system, how adaptable are control algorithms ? "

Keywords: Stability, Robustness, Saturation, Fail-safe, and others

(3) "How to design the total system consisting of structure and control device ? "

Keywords: Structure-control device, Total system

(4) "Shall control theory only be developed ? "

Keywords: Implementation, Feasibility, and others

Group #2: Devices and Systems

Co-moderators:

Prof. S.Yamamoto (Kyoto Institute of Technology)
Mr. S.Aizawa (Takenaka Corporation)

(1) Feasible maximum capacity of active moving mass damper

Keywords: Weight, Stroke, Maximum intensity of earthquake acceleration, Effective only for small earthquakes & winds

(2) Possible control devices to large-scale earthquake ground motion

Keywords: Hybrid Control Type (ATMD, HMD), Variable Structural Characteristic Type (AVS, AVSD), New innovation, and others

(3) Control systems and maintenance

Keywords: Reliability, Durability, Fail-Safe, and others

Group #3: Structural Design Based on Structural Control Techniques

Co-moderators:

Prof. S.Ishimaru (Nihon University)
Prof. K.Tagawa (Fukui University)
Dr. T.Teramoto (Nikken Sekkei)

(1) "What is favorable control-performance?"

Keywords: Reliability, Capability, Efficiency, Adaptability, Robustness, and others

(2) "How are controlled structures evaluated and classified ? "

Keywords: Target intensity of dynamic Load, System reliability, Efficiency, Equivalent damping, Energy source, Maintenance, and others

Table 4.2.1 Feasibility and Applicability of Control Method

Control Methods		Passive		Active		Hybrid	
Earthquake Motion	Structural Stiffness	B. I.	TMD TLD	AMD	AVS AVD	Active B. I.	Active TMD, TLD
Nonstationary Broad Band	Rigid	◎	×	×	×	◎	×
	Flexible	△	△	◎	◎	○	◎
Stationary Narrow Band	Rigid	△	×	×	×	○	×
	Flexible	×	○	◎	◎	△	◎

(3) "What is future research required to promote development and wide acceptance of response controlled structures ? "

Keywords: Design Method, and others

3 Presentation (2) (A. Clark)

This presentation reports on recent structural response control research activity in the U.S.A., comments on economical issues of reducing to full scale practice, and gives some overall technical observations from the literature.

3.1 Recent U.S.A. Basic Research

In the past 2 to 3 years, there has been a lot of activity in applying the most recent multidisciplinary control theories and hardware systems to the field of civil structural control (Soong, 1992). Research has been conducted in the use of acceleration and velocity feedback, adaptive algorithms, fuzzy logic, traveling wave-based control, frequency domain analysis, feedback-feedforward control, and pole-placement optimal techniques. The use of neural net computing and optical fiber technology for signal processing and sensing, shape memory alloys and piezo-electric elements for actuators, and object oriented software for digital motion control have been investigated. Active-passive or hybrid systems, primarily combining base isolation with active control have been refined. Control designs have been studied for systems with structural nonlinearities from large amplitude earthquakes. An example is when the base isolation elements of the hybrid system undergo large displacements. A related development is the investigation of active intelligence for controlling dissipators of environmental disturbance energy. For more detailed information and a reference list, see (Soong, 1992).

3.2 Recent full-scale implementations

Beginning in 1990, an active bracing system for a full-scale 6 story building in Japan has been constructed and tested in-situ as part of a joint U.S.-Japan cooperative research effort (Soong, 1992). Its performance under wind and ground motions is recorded, and the system's reliability is also being evaluated. Funding for a similar full-scale demonstration project in the U.S., a simple tower, is being pursued. Part of the total funding needed is already committed. Finally, two designs for active control retrofit of existing U.S. structures have been done and are currently being evaluated.

3.3 National Science Foundation Initiative

Much of the U.S. support for the research described above has come from the National Science Foundation (N.S.F.) (Liu, Lagorio, and Chong, 1992). N.S.F. recognizes the importance of structural control research for modern improvements to existing and future civil infrastructure systems. Beginning in 1989, a focused effort to foster coordinated multidisciplinary research and development in the U.S. was made.

Funding was supplied for: (1) creating a U.S. Panel on Structural Control Research, 1989, (2) attending the International Workshop on Intelligent Structures, Taipei, Taiwan, July 1990, (3) conducting the N.S.F.-E.P.R.I. Joint Workshop on Intelligent Control Systems, October 1990, (4) sponsoring the U.S. National Workshop on Structural Control Research at the University of Southern California, October 1990, and (5) conducting the N.S.F. Workshop on Sensors and Signal Processing for Structural Control, February 1991.

Following these meetings, in the summer of 1991, N.S.F. established a research initiative for structural control for safety, performance, and hazard mitigation in cooperation with the Strategic Highway Research Program (S.H.R.P.) of the U. S. National Research Council (N.R.C.). A five year program was defined with a budget of $1,000,000. per year. The goal of the program was to fund research for developing control systems, robots, actuators, sensors, and energy absorbers for structures, and to investigate practical designs, fabrication, and installation techniques for field use of the systems.

There was high interest from the U.S. academic research community in the program. 67 proposals were submitted to N.S.F. by October 1991. Almost 50 per cent dealt with earthquake hazard mitigation by structural control. Only 12 of the total submitted could be funded with the level of funding available per year.

3.4 Economic Implementation Considerations

As discussed above there is a lot of positive activity in the U.S. in the national scientific community in the field of structural control. Another country very active in the field, Japan, has about the same level of funding to the university research community.

However, Japanese private industry in construction and other fields has invested much more than U.S. private industry in the research area. This has expedited reduction to practice and full-scale installations and implementations. Many different devices are available after research and development (Fujita, 1991). In contrast, U.S. construction related industries at the present time are very conservative. Possible reasons for this difference with Japan is the current lack of new construction of high rise and high technology structures in the U.S. due to a recessed economy and a current virtual moratorium on nuclear power. There is also a high incentive for Japanese industry to invest in research and development through tax incentives.

It is interesting to note that in 1980 the U.S.

was a leader in implementation of full-scale actual systems. In 1980 two actively tuned mass dampers, in Boston in the John Hancock tower, and in Manhattan in the Citicorps Center were reported operational (Clark, 1992). They are still currently performing their structural control functions about 300 hours a year. These systems were servohydraulic and actively programmed to simulate the ideal Den Hartog linear tuned mass damper. The use of the systems was judged economical for combining occupant comfort with maximum utilization of up-to-date high rise construction materials. Although this significant full scale implementation of active control was done 12 years ago, economic conditions and conservative behavior in the U.S. has not further realized the benefits of active systems.

3.5 Some technical observations and conclusions

It has been observed that the field of structural control spans from high accuracy and small forces for space structures to lower accuracy requirements and high forces for buildings (Housner, 1992). It is also common knowledge in system design that high accuracy servo systems are often very energy inefficient, with a tradeoff between accuracy and speed and energy efficiency. Energy considerations are important ecological and reliability concerns. Recent research reported by Kajima (Mizuno, Kobori, Hirai, Matsunaga, and Niwa, 1992), and the University of Michigan (Hanson, 1992) propose energy efficient systems that dissipate environmental disturbance energy with extremely low supplied electrical energy. This supplied energy is for sensing and the active control intelligence.

Another important energy consideration reported by the Jet Propulsion Laboratory (Wada, 1992), and studied by the State University of New York at Buffalo (Reinhorn and Soong, 1990) recommends placing the active control actuators at the base of the building (the location of the maximum structural strain energy) for maximum energy efficiency.

The application of active structural control for comfort during earthquakes and wind disturbances is reduced to practice and can be justified according to economic conditions. The next challenge is designing structures that utilize an active system for safety and strength. The modern aerospace vehicle (aircraft, helicopter, spacecraft, etc) routinely uses active control system for safety and strength. Many of those vehicles can experience catastrophic failure is the active control fails, yet such total structural control is common place and economically accepted by the marketplace. By analogy, maybe we can predict common place civil structures that depend on active control for safety and strength in the near future.

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4.4. Presentation (J. Rodellar)

As the only european member in this panel discussion, I would like to devote this presentation to give some comments about the situation of the activities on seismic active control in Europe.

There is not an organized group within the european scope as those existing in USA and Japan in the form of panels for structural control research in civil engineering, whose activities have been reported in this session. However, in the last few years an increasing number of researchers have been involved in active control for civil structures within european universities. Assuming the risk of forgetting some of them, we can mention the work done in Aachen University from passive to hybrid seismic isolation (Hirsch and Józsa 1992), the studies on active control of suspension bridges performed in Polytechnic of Milan (Carotti et al. 1987), the studies on tendon control in the Technical University of Munich (Okubo and Schmidt 1992), the work carried out in the Ecole Céntrale de Lyon (Jezequel and Roberti 1991), the work in Università di Pavia concerning neural networks (Casciati 1992) and in Universitá di Napoli (Baratta 1992). Also the work done in the Technical University of Catalunya, Barcelona. This work has been mainly focussed on methodological aspects of control, including development of predictive control methods (Rodellar et al. 1987; tendon control strategies (López Almansa and Rodellar 1989), robustness and implementation issues of predictive controllers (López Almansa and Rodellar 1990), hybrid control (Inaudi et al. 1992), decentralized control strategies (Bakule et al. 1992), robust controllers (Rodellar et al. 1992) and optimal location of actuators (Holnicki et al. 1992). Experimental applications have been conducted in cooperation with the group of the State University of New York at Buffalo (Rodellar et al. 1989).

Having different individual groups, it should be convenient to have a coordinated activity to carry out joint research and development. In this respect, with the existing framework of the European Community to finantially support research activities, could be not only convenient but necessary to integrate groups from different countries in joint projects. It is difficult at the present time to think of having finantial support from institutions other than the research funding agencies. In this sense, the experience of our group in Barcelona is that we have been regularly funded by the DGICYT (national spanish research agency) within general programs for basic research. But, even given that national agencies are able to supply funds to their own researchers, the trend is to ask them to join their efforts, define bigger projects and submit proposals to the European Community. We particularly believe that this has to be the way for the european researchers to increase their contributions in the area of structural control in the near future.

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