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U.S.-JAPAN WORKSHOP ON COOPERATIVE RESEARCH FOR MITIGATION OF URBAN EARTHQUAKE DISASTERS. LEARNING FROM KOBE AND NORTHRIDGE: RECOMMENDATIONS AND RESOLUTIONS. HELD IN MAUI, HAWAII ON DECEMBER 14-16, 1995

CALIFORNIA UNIV., RICHMOND

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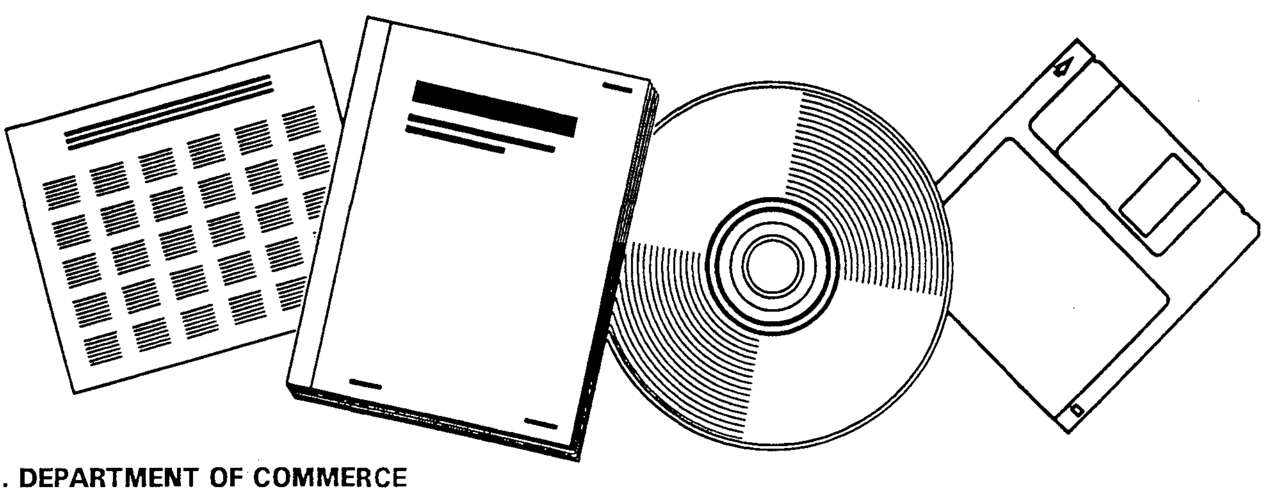

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EARTHQUAKE ENGINEERING RESEARCH CENTER

U.S.-JAPAN WORKSHOP ON COOPERATIVE RESEARCH FOR MITIGATION OF URBAN EARTHQUAKE DISASTERS: LEARNING FROM KOBE AND NORTHRIDGE—RECOMMENDATIONS AND RESOLUTIONS

by

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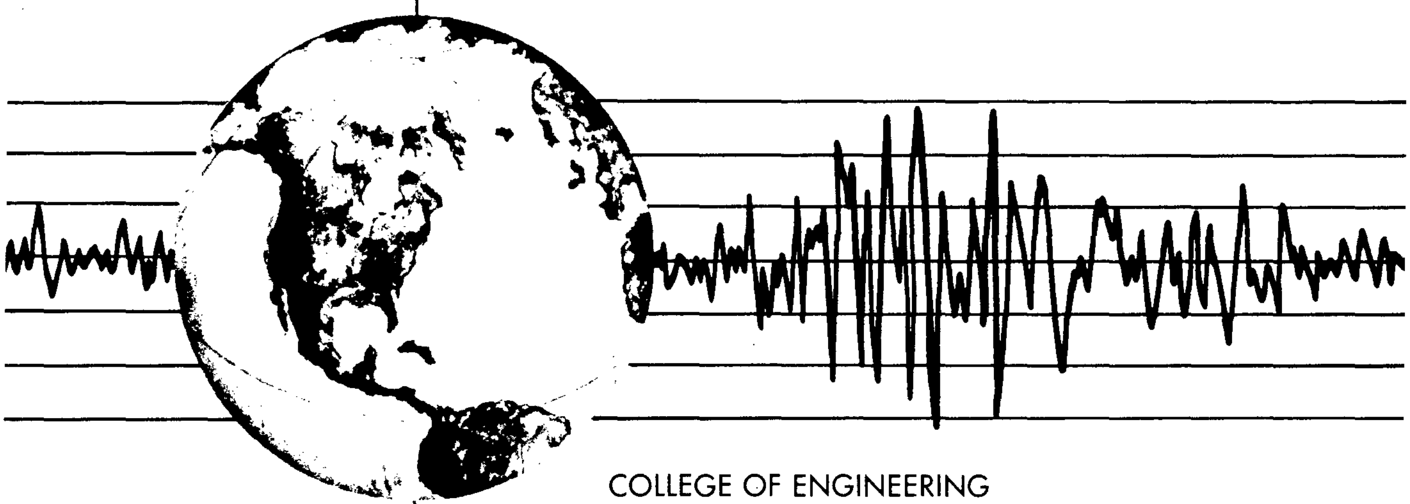
Sponsored by The National Science Foundation



COLLEGE OF ENGINEERING

UNIVERSITY OF CALIFORNIA AT BERKELEY

US - Japan Workshop on

COOPERATIVE RESEARCH FOR MITIGATION OF URBAN EARTHQUAKE DISASTERS:

Learning from Kobe and Northridge

Recommendations and Resolutions

Workshop Organizing Committee

Stephen Mahin, University of California at Berkeley
Tsuneo Okada, University of Tokyo
Masanobu Shinozuka, University of Southern California
Kenzo Toki, Kyoto University

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The feasibility of accelerating the discovery of new knowledge on the seismic behavior and response of the built environment and the complex civil infrastructure systems comprising major urban centers, and of synthesizing, transferring and utilizing this knowledge effectively in mitigating the potential life, physical, social and economic losses resulting from a major urban earthquake was explored at a bilateral Workshop convened in Maui, Hawaii during December 14 through 16, 1995. The 51 participants at the workshop were selected from leading experts from Japan, the U.S. and elsewhere in a wide variety of disciplines from engineering, social science and public policy research.

The objective of this Workshop was to identify a research agenda related to urban earthquake loss reduction through a synthesis of available knowledge about the Hyogo-ken Nanbu and Northridge earthquake disasters.

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EXECUTIVE SUMMARY

The feasibility of accelerating the discovery of new knowledge on the seismic behavior and response of the built environment and the complex civil infrastructure systems comprising major urban centers, and of synthesizing, transferring and utilizing this knowledge effectively in mitigating the potential life, physical, social and economic losses resulting from a major urban earthquake was explored at a bilateral Workshop convened in Maui, Hawaii during December 14 through 16, 1995. The 51 participants at the workshop were selected from leading experts from Japan, the U.S. and elsewhere in a wide variety of disciplines from engineering, social science and public policy research.

The objective of this Workshop was to identify a research agenda related to urban earthquake loss reduction through a synthesis of available knowledge about the Hyogo-ken Nanbu and Northridge earthquake disasters. In general, there was much agreement among the participants on the areas of urgent need and on the significant benefit of addressing these problems through cooperative research. The research agenda developed includes identification of high priority investigation needs, opportunities for cooperative research between the U.S. and Japan, potential benefits of sharing unique experimental and analytical research facilities and data, requirements for new research facilities and resources, and mechanisms for improved international cooperation and communication.

Subjects discussed included a broad array of issues related to urban earthquake disasters, and to actions that can be undertaken by engineers, public officials, contractors and others to mitigate these catastrophic events. Detailed recommendations and resolutions were developed by the participants of the workshop. These recommendations and resolutions are presented later in this document. It is hoped that these recommendations and resolutions can be used to: Guide researchers into productive areas for collaborative research; Identify key mechanisms for exchange of information and ideas, promote first-hand interchange of information resulting from the unique and shared problems faced by each country, and provide concerned funding agencies and organizations in both countries with a basis for developing research and budget plans for urban earthquake disaster mitigation.

DEDICATION

The Workshop on Cooperative Research for Mitigation of Urban Earthquake Disasters is dedicated to the memories of Professors H. Umemura and T. Kubo. The vision, leadership and charm of these two gentlemen provided the cornerstone upon which the successful cooperative research between the United States and Japan in the field of earthquake engineering has been built. Their example continues to inspire and enrich this continuing partnership.

ACKNOWLEDGMENTS

The U.S.-Japan Workshop on Cooperative Research for Mitigation of Urban Earthquake Disaster: Learning from Kobe and Northridge was hosted by the U.S. delegation under a grant from the U.S. National Science Foundation. The grant was administered by the Earthquake Engineering Research Center, University of California at Berkeley. Professors Jack Moehle and Stephen Mahin served as Principal Investigators for this project.

The financial support of the U.S. National Science Foundation is gratefully appreciated. The Workshop would not have been possible without the leadership and advice of Drs. S. C. Liu and William Anderson of the Earthquake Hazard Mitigation program at the National Science Foundation.

An advance team from the U.S., consisting of George Lee, Stephen Mahin, Jack Moehle (U.S.-side Chair), Mete Sozen, Chia-Ming Uang, Jim Wight, and Sharon Wood, met with a small group of Japanese researchers (S. Nakata, M. Nakashima, T. Okada, S. Otani (Japan-side Chair), F. Watanabe, K. Takanashi and H. Yamanouchi) in Tsukuba, Japan from June 11 through 13, 1995 to discuss the effects of the Hyogo-ken Nanbu and Northridge earthquakes, and to examine the desirability and feasibility of cooperative research related to urban earthquake disaster mitigation. The organizers of this Workshop appreciate the initial efforts of this group, especially those of the Co-Chairs Jack Moehle and Shunsuke Otani, in laying the ground work for this Workshop.

The assistance of Professor Yoshiaki Nakano of the Institute of Industrial Science at the University of Tokyo was of great assistance in coordinating the activities of the Japanese delegation and in helping conduct the Workshop. Parshaw Vaziri, of the California Universities for Research in Earthquake Engineering, made the local arrangements for the Workshop and prepared the Proceedings.

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INTRODUCTION

Recently, the U.S. and Japan have experienced two major earthquake disasters. The 1995 Hyogo-ken Nanbu and the 1994 Northridge earthquakes exposed many important problems that adversely impacted these urban areas in terms of the well-being and safety of individual citizens, the operation of essential social services and lifeline systems, and the productivity and economic vitality of the business, financial and industrial sectors. These problems must be quickly addressed by the earthquake engineering research community to develop effective and technically sound methods for mitigating the destructive consequences and social impacts on urban centers of future earthquakes in the U.S., Japan, and elsewhere.

Many major urban areas throughout the U.S. and Japan are located in regions susceptible to strong earthquake ground shaking. The consequences of even a moderate earthquake occurring near such an urban area are grave for the health and welfare of its citizens. However catastrophic these consequences may be for the individual citizen, they are compounded in urban areas by having hundreds or even thousands of structures damaged and vital water, power, communication and transportation lifelines disrupted. These aggregate effects have pervasive, long-term impacts on the vitality of the business, industrial, financial, and public sectors, not only for the region shaken, but for the affected nation and for the world.

For example, losses estimated for a major earthquake occurring near Tokyo or Osaka, Japan are several times those realized for Kobe, already the most costly earthquake event ever. Recent loss estimates for San Francisco and Los Angeles equal or exceed those seen in Kobe. Similarly severe losses will be expected in other major metropolitan areas in Japan or the U.S., if they are shaken by a nearby major earthquake.

Clearly, such disasters are of paramount national and international importance. Mitigation of these potential disasters through effective and economical engineering practices and public policies based on sound engineering and scientific principles and knowledge is an issue of the highest priority.

Every earthquake provides many valuable lessons to the engineering profession, public officials, building regulators and others concerned with earthquake loss mitigation. The disasters in Kobe and Northridge were no exception to this. Many different types of buildings and structures suffered damage in both regions. Among the many lessons learned and re-learned by engineering professionals and by the construction industry as a whole were several major surprises. These surprises included:

- Damage to modern steel buildings. Until these earthquakes, steel buildings were thought to be among the most seismically resilient forms of construction possible. In both cities modern steel buildings were so severely damaged as to effectively invalidate current building codes. Welded steel frame buildings suffered many brittle fractures in their connections during the Northridge earthquake, and many of these structures collapsed during the stronger motions experienced in Kobe.
- Damage to civil infrastructure systems. As with the earlier Loma Prieta earthquake in California, the Northridge and Hyogo-ken Nanbu events demonstrated the fragility of civil infrastructure systems. Damage to bridges and highway structures seriously hampered emergency response and recovery efforts following these earthquakes and disrupted the local economy . Many undamaged industrial plants were forced to shut down because local port facilities were disabled and unable to deliver needed components or ship completed products. It has been generally believed that buried structures, such as subway tunnels, pile foundations, and pipelines, perform well during earthquakes. However, the behavior of such structures in Northridge and Kobe was often poor, resulting in a serious loss of important lifeline services.
- Damage to older reinforced concrete buildings. Existing reinforced concrete building designed and constructed before the advent of modern building codes, were also significantly damaged in Kobe and Northridge. Damage was higher than expected, especially in Japan, and many older reinforced concrete structures collapsed. Had the earthquakes occurred during the daytime, the devastation caused by these buildings could have resulted in significantly increased loss of human life.
- Performance of wooden residential and commercial structures. Wooden buildings have generally been thought to provide a safe shelter for their occupants during earthquakes. However, in Kobe and Northridge, thousands of homes, apartments and small businesses were damaged, resulting in numerous deaths, and displacing many citizens thereby exacerbating recovery efforts and imposing serious economic

strains on the community. These structures also provide the fuel for major fires in both earthquakes, exacerbating the degree and consequences of the damage.

It is necessary to identify the reasons for these and other unusual and unanticipated types of behavior, and to synthesize the lessons that can be gleaned from this information and relay them to the hazard mitigation community as soon as possible. Similarly, lessons from emergency response management agencies, and those involved in conducting recovery and reconstruction efforts, must be gathered and distilled so that other seismically vulnerable regions can effectively prepare. We cannot afford to wait for the next urban earthquake to implement these lessons.

Research in earthquake engineering, the social sciences and public policy will provide an integrated rational framework for the development of viable procedures and policies that will lead Japan and the U.S. into the 21st century.

Already researchers in Japan and the U.S. have initiated field investigations and analyses to assess the causes of observed damage resulting from the Hyogo-ken Nanbu and Northridge earthquakes, and to identify the implications of this damage for preparedness efforts and design practice. This research is expected to have significant results. However, to date, none of these research activities have been developed on a systematic and cooperative basis building upon the considerable combined intellectual, financial, and institutional resources of the two countries. Nor have any of these activities been cast in an interdisciplinary conceptual framework necessary for protecting our urban civil infrastructure systems from future destructive earthquakes. In addition, many important factors of a diverse nature from science, engineering and materials remain to be considered or integrated into the development of an effective solution to these complex problems.

WORKSHOP ON COOPERATIVE RESEARCH ON MITIGATION OF URBAN EARTHQUAKE DISASTERS

The feasibility of accelerating the discovery of new knowledge on the seismic behavior and response of the built environment and the complex civil infrastructure systems comprising major urban centers, and of synthesizing, transferring and utilizing this knowledge effectively in mitigating the potential life, physical, social and economic losses resulting from a major urban earthquake was explored at a bilateral Workshop convened in Maui, Hawaii during December 14 through 16, 1995. Participants at the workshop were selected from leading experts from Japan, the U.S. and elsewhere in a wide variety of disciplines from engineering, social science and public policy research. Participants are listed in Appendix A.

The objective of this Workshop was to identify a research agenda related to urban earthquake risk reduction through a synthesis of available data and knowledge about the Hyogo-ken Nanbu and Northridge earthquake disasters. The research agenda would include:

- Investigation needs,
- Opportunities for cooperative research,
- Funding requirements,
- Implementation needs, and so on.

Subjects discussed included a broad array of issues related to urban earthquake disasters, and to actions that can be undertaken by engineers, public officials, contractors and others to mitigate these catastrophic events. The scope of the topics discussed at the Workshop and the Workshop Program are contained in Appendices B and C, respectively.

Recommendations and resolutions were developed by the participants of the workshop. These recommendations and resolutions are presented later in this document. It is hoped that these recommendations and resolutions can be used to:

1. Guide researchers into productive areas for collaborative research,

2. Identify key mechanisms for exchange of information and ideas,
3. Promote first-hand interchange of information resulting from the unique and shared problems faced by each country, and
4. Provide concerned funding agencies and organizations in both countries with a basis for developing research and budget plans for urban earthquake disaster mitigation.

The Workshop on Cooperative Research for Mitigation of Urban Earthquake Disasters was hosted by the U.S. National Science Foundation, and was organized by a steering committee consisting of Stephen Mahin (University of California at Berkeley), Tsuneo Okada (University of Tokyo), Masonobu Shinozuka (University of Southern California), and Kenzo Toki (Kyoto University). Of the fifty-one experts attending the meeting, 23 came from Japan and 27 from the U.S. A listing of the participants is provided in Appendix A.

A wide variety of topics were addressed by the workshop participants in plenary sessions and in working group discussions (see Appendices B through L). Issues were carefully and thoroughly examined to identify issues of criticality and which are of mutual concern to the U.S. and Japan. Special consideration was given to problems necessitating the use of unique research facilities.

In general, there was much agreement among the participants on the areas of urgent need and on the significant benefit of addressing these problems through cooperative research.

OBSERVATIONS

The Workshop participants agreed that earthquakes occurring near major urban centers pose a special hazard that has not adequately been addressed in the past. The recent earthquake disasters in Kobe, Northridge and other urban areas demonstrate the urgent need for research focused on mitigating losses from such events. Specifically, an accelerated program of integrated research is needed to address systematically the many technical challenges within each discipline contributing to seismic safety, as well as to address the critical interrelationships among these disciplines.

The participants of the Workshop agreed that while there were many important differences in the social, economic, political and technological conditions and the types of structures and construction utilized in the U.S. and Japan, much could be achieved through sharing of ideas, intellectual resources, and unique facilities, as well as by conducting cooperative research on topics of mutual concern.

Cooperative research between the U.S. and Japan has a long history of successful accomplishment. Activities, such as the U.S. - Japan Cooperative Earthquake Research Program utilizing Large-Scale Tests Facilities, have over the course of nearly twenty years systematically addressed critical issues related to reinforced concrete buildings with structural walls, braced steel frames, precast concrete buildings, masonry structures and buildings constructed using composite materials and hybrid systems. U.S. and Japanese researchers have cooperated effectively in reconnaissance and field investigations following major earthquakes. These and similar projects have demonstrated the ability of such cooperative efforts to achieve significant results of benefit to both countries.

RECOMMENDATIONS REGARDING RESEARCH NEEDED FOR URBAN DISASTER MITIGATION

More than 50 high priority topics for cooperative research were identified by the participants. These topics were developed by working groups formed to examine specific technical or policy issues, and subsequently discussed by all participants during Plenary Sessions. The operation of the Working Groups is described in Appendix D. Reports summarizing the discussions and recommendations of each Working Group are presented in Appendices E - L).

The high priority research topics recommended by the Workshop participants relate to the following overarching areas:

1. Effects of ground motions on structures and lifelines, especially of those motions experienced close to the earthquake fault rupture;
2. Design, analysis, construction and quality assurance procedures leading to improved seismic performance of new structures and lifelines;
3. Reliable and cost-effective techniques to improve the safety of existing seismically vulnerable buildings, bridges and lifelines;
4. Practical and effective procedures to evaluate and restore (repair) damaged structures following an earthquake;
5. Innovative technologies to protect structures from the consequences of earthquakes, including the use of seismic isolation, supplemental energy dissipation, active control, high performance materials, and so on;
6. Methods for increasing the earthquake resistance of urban lifeline systems. This includes understanding system response, the nature and consequences of interruption of service, and the effects of the interactions of different lifeline systems and facilities with each other. In addition, effective methods for system management, repair and restoration need to be developed;
7. Methods for estimating the social, economic and political impacts of major urban earthquakes, assessing the efficacy of alternative programs and policies for ameliorating adverse impacts, and devising effective actions for pre-event

preparedness planning, and post-earthquake response management, recovery and reconstruction strategies;

8. Methods to reduce the vulnerability of urban areas to fire and environmental emergencies instigated by earthquakes; and

9. Immediate attention is needed to understand those instances where the observed behavior of structures differed dramatically from what was expected based on past earthquake performance and laboratory testing. Special high priority cooperative efforts are believed to be needed related to:

    a. Steel buildings;

    b. Bridges and buried lifeline elements;

    c. Evaluation and rehabilitation of existing structures;

    d. Reconstruction and recovery studies (including business and industry restoration); and

    e. Innovative techniques to control and suppress the spread of urban fires caused by earthquakes.

RESOLUTIONS

The Workshop participants discussed and evaluated the various recommendations of the Working Groups and the various presentations made in Plenary sessions. On the basis of these deliberations, the participants developed and unanimously agreed upon the following resolutions.

1. The research topics recommended above to mitigate urban earthquake disasters are of utmost importance and immediate action is needed. To this end, those concerned with research on specific issues should take maximum efforts to seek necessary funds through ordinary channels as well as to explore new channels for research funding. Groups of researchers in the U.S. and Japan are strongly encouraged to work together, sharing information and coordinating their activities, to maximize the generation and application of new knowledge regarding the mitigation of urban earthquake disasters. Funding agencies are encouraged to be flexible in their funding decisions and distributions so that the best research resources available can be promptly mobilized in the search for this knowledge.

2. Cooperative and coordinated research between the U.S. and Japan has been found to be an effective means of addressing complex problems of mutual concern related to earthquake hazard mitigation. The disasters suffered in Kobe and Northridge due to the close proximity of these cities to a major seismic event, strongly suggests that cooperative research would be an effective and expeditious means of solving these problems not only for the U.S. and Japan, but for other countries as well.

3. Earthquake hazard mitigation, as highlighted by the joint statement of the summit meeting in 1995 between the President of the U.S. and the Prime Minister of Japan, should be given increased and continued formal emphasis as a subject for scientific cooperation between Japan and the U.S. Government agencies involved from both countries are encouraged to improve collaboration, coordination, and integration of their respective programs while actively seeking

the advice of the research community. Where possible, new sources of funding should be applied to accelerate the goal of urban earthquake disaster mitigation on a cooperative basis.

4. To facilitate progress toward cooperative efforts to conduct research for mitigation of urban earthquake disasters, an effective joint coordinating mechanism which can carry out sustained operation should be established. To this end, a Joint Technical Coordinating Committee consisting of approximately 10 individuals from both countries should be formed to facilitate the harmonious progress of research throughout the entire cooperative effort. Topics with widespread interest and complexity should be identified for formal cooperative action. Joint Working Groups should be established among researchers actively pursuing research on such specific bilateral projects. Multiple channels for funding these research areas should be developed within each country. Possible Joint Working Groups with a high priority for initial consideration include:
   a. Steel structures
   b. Social, political and economic issues
   c. Infrastructure systems
   d. Near-source ground motions and their effects on structures
   e. Performance-based design
   f. Evaluation and rehabilitation (retrofit) of existing reinforced concrete structures.

5. Because of the rapid pace of developments in these research areas, and the need by the broad research and user communities for the knowledge and data being generated, specific mechanisms should be developed for the synthesis and exchange of information. These mechanisms should include utilization of the World Wide Web and Internet, holding of frequent meetings, workshops and symposia on various topics, and the exchange of personnel.

6. Efforts should continue within each country to improve experimental and other facilities available to conduct research related to the seismic performance of buildings, bridges and lifeline facilities. Initiatives to upgrade and expand experimental facilities are strongly supported, such as the Experimental Facilities Initiative formulated by the National Science Foundation in the U.S., and similar

activities in Japan being undertaken by the Ministry of Construction, Ministry of Education, Science and Culture, the Science and Technology Agency, and others.

Efforts should be undertaken to facilitate the sharing of unique experimental and analytical facilities in both countries in order to accelerate the pace of research. New experimental facilities may provide a useful technical focal point for cooperative research on certain topics.

7. Because of the intellectual resources available within the academic community, and the importance of educating new generations of engineers and researchers to have the knowledge and skills needed to effectively improve the seismic safety of urban areas, it is paramount that researchers at universities have a key role in these efforts. At the same time, the manpower resources and research facilities available in government research institutions and private industry must be brought to bear in the development of reliable and cost effective methods for mitigating urban disasters due to earthquakes.

8. To facilitate the conduct of this research, conventional channels of joint U.S. Japan cooperation, such as the U.S.- Japan Panel for Natural Resources (UJNR), US-Japan Common Agenda on Joint Economic Development and Cooperation, and bi-lateral agreements between universities, government agencies, and organizations, should be utilized to the fullest. At the same time, introduction of innovative arrangements and inclusion of new agencies and organizations as participants and sponsors of these research and information dissemination activities should be vigorously explored.

9. The possibility of establishing a jointly operated Information Clearinghouse that would be tasked with the responsibility for collecting and sharing information on proposed and on-going research and testing work and results occurring in both countries should be explored. The Clearinghouse could be initially focus on information related to steel research as there is considerable research activity underway already in both countries. The Clearinghouse could be established using existing facilities and would be governed by a steering committee of experts in various fields from both countries.

10. Because of the infrequent occurrence of damaging earthquakes, lessons learned from Kobe and Northridge are particularly valuable and will have far-reaching impacts on design and construction practices in both countries. Many of these lessons were first discovered during reconnaissance visits to the affected regions by research teams from both countries. These cooperative visits are extremely useful and every effort should be made to encourage and facilitate future exchange visits as the opportunities arise. In particular, improved efforts to capture perishable data immediately following an earthquake are encouraged.

11. While there are many issues suitable for cooperative research, some high priority topics related to urban disaster mitigation are related to the specific needs of a particular country. For example, while the participants of the Workshop acknowledged that engineering, economic, social and political issues related to the seismic performance of wooden structures were of very high priority, it was felt that this and similar topics were not ideally suited at this time for cooperative research between the U.S. and Japan. This is due to the substantial differences between the two countries in construction types and design methods as well as in the economic and social conditions related to these structures that would make cooperative research difficult. However, the participants agreed that each country should actively pursue such topics.

APPENDIX A
WORKSHOP PARTICIPANTS AND OBSERVERS

U.S. Participants/Observers

Stephen. Mahin, Univ. of California, Berkeley
Masanobu Shinozuka, Univ. of Southern Calif.

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S.C. Liu, National Science Foundation
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Canada Observer

Michel Bruneau, Univ. of Ottawa

APPENDIX B
WORKSHOP SCOPE

1.* **Performance of Structures**
   a. Buildings (steel, reinforced concrete, wood, etc.)
   b. Infrastructure Facilities (bridges, roads, ports, dams, retaining walls, tunnels, pumping stations, electric power substations and distribution systems, control buildings, pipelines (above and below ground), etc.)

2. **Performance of Lifeline Systems**
   a. System Performance, including Interruption.
   b. System Interaction
   c. Social, Economic and Political Consequences of System Performance

3. **Structural Response and Design Issues**
   a. Development and Verification of New Design Procedures (performance-based design methods, damage tolerant design methods, etc.)
   b. Life Cycle Cost Issues considering Operational Loads and Natural Hazard Effects (potential benefits of seismic resistant design on safety, durability, reliability and performance under other hazards)
   c. Multi-hazard (wind, earthquake, fire, etc.) Design Issues
   d. Design Considering Reparability of Structure or Facility after Future Earthquake
   e. Effects of Special Ground Motions (near-field, soft soil, etc.) on Structures
   f. Issues related to Non-structural Components and Contents
   g. Development and Verification of Improved Analysis and Modeling Procedures

4. **Economic, Social and Political Aspects of Urban Earthquake Disaster Mitigation**
   a. Preparedness
   b. Emergency Response
   c. Crisis Management
   d. Direct and Indirect Loss Estimation
   e. Strategies for Loss Mitigation (including physical, social and economic losses)
   f. Evaluation of the Effectiveness of Various Loss Mitigation Strategies and Disaster Scenarios
   g. Strategies for Post-earthquake Economic Recovery

5. **Pre-earthquake Vulnerability Assessment and Rehabilitation (Retrofit)**
   a. Preliminary Screening Procedures
   b. Detailed Performance Evaluation Procedures
   c. Triggers for Action
   d. Rehabilitation (Retrofit) Criteria
   e. Development and Verification of Rehabilitation (Retrofit) Procedures

6. **Post-Earthquake Evaluation and Repair**
   a. Post-earthquake Damage Evaluation (safety assessment and actions)
   b. Post-earthquake Inspection of Earthquake Damage (policies, procedures and inspection technologies)
   c. Development and Verification of Repair Procedures For Earthquake-Induced Damage
   d. Advanced Technologies for Health Monitoring.

7. **Post-earthquake Reconstruction and Urban Planning**
   a. Strategies for Urban and Regional Renewal
   b. Demolition Procedures including Safety and Environmental Issues
   c. Policy Issues Related To Repair, Demolition And Rehabilitation (retrofit)
   d. Economic, Social and Political Issues

8. **Materials, Construction and Advanced Technologies for Urban Earthquake Disaster Reduction**
   a. Suitability of Materials/Material Properties/Construction Details For Damage Tolerant Design.
   b. Development and Verification of Improved Structural Details and Construction Procedures for Specific Types of Elements and Systems Constructed from Various Materials (concrete, steel, wood, etc.)
   c. Quality Control and Quality Assurance
   d. Advanced and High Performance Materials
   e. Deterioration of Materials (detection, mitigation and repair)
   f. Modern Telecommunications and Sensor Technologies for Near Real Time Disaster Assessment and Decision Making
   g. Integrated System for Post-earthquake Fire Prevention and Suppression
   h. Protective Systems, including Active and Passive Control Technologies
   i. Robots and other Advanced Technologies for Search and Rescue
   j. Testing of Large Scale Structural Models (Laboratory and Field Tests)
   k. Advanced Nondestructive Evaluation Techniques

9. **Improved Communications and Cooperation**
   a. Archiving and Distribution of Experimental and Other Technical Data
   b. Synthesis and Dissemination of Technical Information to User Community
   c. Improved Communication between Disciplines and with Policy Makers
   d. Improved International Cooperation and Communications

10. **Engineering Seismology and Geotechnical Engineering.**

    While not officially a part of this workshop, experts in engineering seismology and geotechnical engineering have been invited to provide liaison with a separate U.S. - Japan Workshop being organized on this topic.

* Numbers refer to working group identification numbers.

APPENDIX C
WORKSHOP PROGRAM

Day 1 (Thursday, December 14, 1995)

Time	Activity	Topic	Speaker
8:30	Session 1	Opening Session	S.C. Liu T. Okada Others
		Goals of Workshop	S. Mahin
9:00	Session 2	Performance of Structures and Research Needs: Buildings	Y. Fujino /M. Sozen
		Performance of Structures and Research Needs: Infrastructure Facilities	Y. Fujino / I. Buckle
10:00	Break		
10:15	Session 3	Economic, Social and Political Aspects of Urban Earthquake Disasters	J. Nigg
10:30		Post-earthquake Reconstruction and Urban Planning	S. Herath / G. Lee
11:00		Structural Response and Design Issues	T. Okada / T. Ohmachi / H. Krawinkler
11:45	Lunch		
13:00	Session 4	Materials and Construction Issues and Advanced Technologies for Urban Disaster Reduction	H. Yamanouchi / T. Soong
13:30		Performance of Lifeline Systems	H. Kameda / M. Shinozuka
14:00		Pre-earthquake Vulnerability Assessment, Retrofit and Urban Planning	S. Sadohara / D. Foutch
14:30		Post-Earthquake Evaluation and Repair	Y. Nakano / S. Mahin
15:00	Break		
15:15	Session 5	Engineering Seismology and Geotechnical Engineering	T. Sato
15:45		Improved Communication and Cooperation	M. Watabe / P. Jennings
16:05		Post-Hyogo-ken Nanbu and Northridge Mitigation Research	M. Midorikawa, K. Takanashi, T. Okada,, S. Masri, S. Mahin
17:20	Session 6	Discussion of Working Group Assignments and Duties	S. Mahin / T. Okada
17:30	Recess		
18:30	Dinner Hosted by U.S. side		

Day 2 - Friday, December 15, 1995

Time	Activity	Working Group	Working Group
8:30	Working Groups	Buildings - 1	Bridges / Infrastructure Facilities
10:30	Break		
10:30	Working Groups	Buildings - 2	Lifeline systems
12:15	Lunch		
13:15	Plenary	Presentation of draft recommendations and general discussion	
14:30	Break		
14:45	Working Groups	Structural Response and Design	Reconstruction and Socio-economic Issues
16:45	Plenary	Presentation of draft recommendations and general discussion	
17:15	Recess / Executive Session		
18:00	Free Evening		

Day 3 - Saturday, December 16, 1995

Time	Activity	Working Group	Working Group
7:30	Working Groups	Pre-and Post- earthquake	Materials/Advanced Technology
9:15	Break		
9:30	Plenary	Presentation of final Working Group recommendations and general discussion	
10:30	Plenary	Mechanisms for Improved Communications and Cooperation	
11:00	Plenary	Develop and Adopt Workshop Resolutions	
12:00	Adjourn Workshop		
18:00	Executive Session		

APPENDIX D

WORKING GROUPS

The participants of the Workshop divided into a number of groups to carry out detailed discussions on a variety of specific subjects. Working Groups focused on the following topics:

1. Performance of Buildings,
2. Performance of Infrastructure Facilities (including Bridges),
3. Lifeline Systems,
4. Structural Response and Design Issues,
5. Reconstruction and Socio-economic Issues,
6. Pre- and Post-Earthquake Evaluation, Rehabilitation, and Urban Planning,
7. Materials, Construction and Advanced Technology for Urban Earthquake Disaster Reduction, and
8. Improved International Cooperation and Communications.

During the Plenary Sessions on the first day of the Workshop, invited presentations were made by researchers and others from the U.S. and Japan on the subject of each of the Working Groups. These presentations reviewed the current state of knowledge, the impacts of the Kobe and Northridge earthquake disasters on needs for earthquake hazard mitigation research in these areas, and potential benefits of undertaking cooperative research. In addition, presentations were made in the Plenary sessions regarding other major research efforts being undertaken in each country. These presentations were intended to inform the participants of current and pending activities and to help stimulate and focus discussions.

During the Working Group sessions, participants from each country were able to make brief presentations on current or recent research activities. In addition, an attempt was made to identify other relevant research projects being conducted in each country by individuals or organizations not in attendance. The Working Groups then reviewed the work underway to:

1. Assess gaps in knowledge needed to mitigate the scope and consequences of urban earthquake disasters,
2. Assess the opportunities for cooperative research activities between the U.S. and Japan to close these gaps, and
3. Prioritize these cooperative research activities with special attention to:
    a. opportunities for sharing special research facilities, technical resources and data available in each country,
    b. exchanging personnel, and

c. needs for new research facilities, equipment and other technical resources.

As shown in Appendix C, the working group sessions were arranged so that only two groups met simultaneously. In this manner, participants could participate in several working groups. In addition, Plenary Sessions were interspersed with working group sessions so that all participants would be able to hear of the issues and discussions being examined by the other groups. This schedule maximized the input by all participants into each of the working group reports, encouraged cross fertilization of recommendations by all disciplines represented at the Workshop, and had the working group discussions to build upon, rather than duplicate, discussions held at earlier group sessions.

Because the scope of the discussions within each Working Group was narrowly focused, detailed technical discussions were possible. Each group was, however, requested to identify information that might be of use to or needed from other groups not present within each working group discussions or at the Workshop at all.

Appendices E through L contain the reports of the various Working Groups.

The Co-Chairs and Recorders for the Working Groups are as tabulated below.

Table D.1 Working Group Co-Chairs and Recorders

Working Group	Co-Chairs	Recorders
Performance of Buildings	Takanashi/Sozen	Nakano/Uang
Performance of Bridges and Infrastructure Facilities	Fujino/Buckle	Sato/Hawkins
Lifeline Systems	Kameda/Shinozuka	Nakata/Kiremidjian
Structural Response and Design Issues	Shibata/Krawinkler	Nakashima/Wood
Reconstruction, Urban Planning, and Socio-economic Issues	Ohmachi/Nigg	Herath/Lee
Pre- and Post-Earthquake Evaluation and Rehabilitation	Midorikawa/Foutch	Nakano/Hawkins
Materials, Construction and Advanced Technology for Urban Earthquake Disaster Reduction	Yamanouchi/Soong	Watabe/Whittaker
Improved International Cooperation and Communications	Watabe/Jennings	–

APPENDIX E

WORKING GROUP REPORT ON PERFORMANCE OF BUILDINGS

Overview

At the beginning of the Working Group session, each participant was asked to suggest topics for research. These were ranked by the participants to facilitate and set priorities for discussion. Each potential topic was discussed, considering the need for the research, opportunities for cooperation among researchers in the U.S. and Japan, and available resources to conduct the research. To enable full discussion of the potential research issues on this topic, two working group sessions were held with an opportunity for changing of participants between sessions.

Following these discussions, the research topics were again prioritized by voting within the Working Group. A general framework containing all of the high priority research issues was then identified.

The group felt that the research being suggested in this area needs to be coordinated with recommendations made by other groups, especially with those related to structural response and design issues. Minor modifications in the report were made based on comments that followed presentation of the Working Group's findings at the Plenary Session.

Initial Ranking of Research Topics

The participants of the initial working group discussion were asked to suggest high priority research topics that might be suitable for cooperative research. Among 27 initial topics proposed, the following 11 items were decided by voting to have higher priorities:

1. Steel connections (welded);
2. Damage mitigation of nonstructural elements;
3. Capacity requirements due to near-field ground motions;
4. Improvement of seismic performance of existing buildings;
5. Behavior of steel frame building systems;
6. Understanding non-damaged building behavior;
7. Repair methods;

8. Structures with controlled damage;
9. Timber structures;
10. Acceptable damage levels; and
11. Recorded versus design ground motions.

Review of Group Discussions on Research Issues

Discussion of each item followed. It was suggested by Lu that item 10 above be forwarded to the group on Structural Response and Design Issues. Soong suggested that items 4 and 7 be merged. A few participants believed that Item 9 (Timber structures) be dropped since the construction practices in Japan and the U.S. are completely different. Uang suggested reconsideration; and Okada and Yamanouchi pointed out a recent trend in Japanese construction practice toward those practices used in the U.S. As a result of further discussion, Item 9 was not dropped.

Liu pointed out that several items in the list are well recognized; he urged that the emphasis of the discussions be placed on some non-traditional ideas.

Items 1, 3, and 5 surfaced by voting as the top three priorities. Okada pointed out that many items on the overall list, including items 1 and 5, are inter-related and could be fit into a more general framework.

The importance of the construction reliability issue was raised by Iwan. Yamanouchi pointed out the difficulty of conducting a cooperative research program on this topic would be difficult because of the differing economic and social differences. Nigg stated that a technique is available to measure the quality of construction from the social -economic view point. This item was then added to the list of possible cooperative research projects.

Nakata of BRI presented a possible U.S.-Japan cooperative program entitled "Improvement of Seismic Performance for Existing Buildings in Urban Areas." BRI's recent research activities in this area have focused on "low cost" repair methods. Soong presented information on a few projects in the U.S. which parallel Japanese research activities on repair and retrofitting.

Possible ways to facilitate cooperative research were discussed by several participants. Whittaker emphasized the importance of technology transfer. Krawinkler suggested that joint ventures of experimental projects would benefit both countries.

It was agreed that working groups should be established and the administrative bureaucracy should be simplified. Foutch pointed out that a super level is needed in order to have a common voice to funding agencies; he also suggested small group discussions to identify and define potential cooperative research projects.

Okada then suggested a structure for future cooperation on buildings, and it was accepted by the Working Group.

Recommendations

The Working Group discussed the final research priorities and decided on the following framework for cooperative work.

1. **Demand**
    - Near-source effects
    - Design criteria
    - Acceptable damage levels
    - Response of non-damaged buildings
2. **Steel Structures**
    - Frame behavior
    - Connections
    - Damage mitigation for non-structural elements
3. **New Concepts for Strengthening and Repair**
    - Strengthening
    - Repair
4. **Structural Fuses**
5. **Timber Structures**
6. **Quality Assurance**

APPENDIX F

WORKING GROUP REPORT ON PERFORMANCE OF INFRASTRUCTURE FACILITIES

Overview

This group held far-ranging discussions on a variety of infrastructure facilities, including bridges. Damage to infrastructure components had a major impact to the overall lifeline systems in the Kobe and Northridge earthquake disasters, as well as on the overall well-being of the urban areas affected. The commonality of several types of problems in Northridge and Kobe demonstrates the desirability for joint research between the U.S. and Japan.

For the purposes of this report, the Working Group restricted the definition of infrastructure facilities to the components of five major lifelines (transportation, water, gas, electric power and telecommunications). Topics excluded from this discussion therefore included buildings (regardless of their use) and the system's aspects of lifeline performance. Both of these issues are covered elsewhere by other Working Groups.

Based on discussions within the Working Group, several high priority areas for cooperative research were identified, along with opportunities for cooperative activities and sharing of facilities, improved methods for exchange of information, and needs for new facilities. These items are described below.

Research Areas

Many important research needs were identified by the Working Group and these have been summarized below under three general headings: soil-structure interaction; retrofitting existing facilities; and special studies. The group's recommendations follow:

1. Soil-Structure Interaction

   The substandard performance of many infrastructure facilities in both the Kobe and Northridge earthquake disasters reinforces earlier experiences in San Fernando (1971) and Loma Prieta (1989). Research is clearly required to improve basic knowledge in soil-structure interaction, as in the following areas:

   - Estimation of the extent of lateral spreading during liquefaction and the tolerance of infrastructure elements (such as bridge substructures and pipelines) to lateral spreading.

- Performance of pile foundations in soft soils and development of simplified models for characterizing this performance.
- Assessment of foundation damage and methods for repair.
- Influence of foundation flexibility on ductility demands, particularly in bridge structures.
- Performance of underground structures, such as rail tunnels and subway stations.

2. Retrofitting of Existing Facilities

Reliable, cost-effective methods of retrofitting existing infrastructure facilities are urgently needed. Research is required to help achieve this purpose and the most pressing needs include:

- Development of protective systems for bridges such as intelligent restrainers (energy absorbing restrainers), high performance isolators, and maintenance-free dampers.
- Development of retrofitting techniques for columns and foundations using advanced materials and innovative construction procedures.
- Site remediation using soil strengthening techniques for bridge foundations, buried pipelines and underground structures.
- Studies of the cost effectiveness of retrofitting for various infrastructure facilities including life-cycle cost analyses.
- Performance of retrofitted bridges and other infrastructure facilities in recent earthquakes.

3. Special Studies

Several elements of infrastructure facilities require studies which are unique to these particular elements. Examples include:

- Design procedures for steel bridges including allowable ductility demands on superstructure elements; distribution of seismic loads to steel bearings; and acceptable failure modes for steel columns (for example, local buckling vs. flexural yielding).
- Design procedures for very large concrete and steel columns (investigations of the ductility capacity of large structural members).
- Design of structures with conflicting performance requirements, such as those required to be almost rigid under large service loads, but ductile during moderate to large earthquakes (e.g., wharves, elevated rail stations, etc.).

Opportunities for Cooperative Activities and Sharing Facilities

All of the research needs noted above are well-suited for cooperation between researchers in the U.S. and Japan. Research programs on many of these topics will be greatly strengthened through joint effort.

Particular opportunities also exist for sharing experiences and data, and these include the development of electronic databases of damaged infrastructure facilities such as bridges, pipelines, electrical supply systems and telecommunications. For example, the bridge database might contain a listing of all bridges damaged in recent California and Japanese earthquakes and include a description of the damage sustained, estimated peak ground acceleration, repair cost and restoration time.

Methods for Exchange of Information

In addition to workshops, technical reports and papers, methods for information exchange should include use of the Internet and the ability to store and retrieve data files, graphical images, video segments using FTP's and equivalent. However, to be useful to the greater research community agreement will need to be reached regarding standardized test procedures, archiving and retrieval protocols.

Needs for New Facilities and Resources

The instrumentation of a large number of bridge and other infrastructure elements was assigned highest priority by this Working Group under this heading. Furthermore, the Working Group recommends the development and use of instruments that cannot only record three components of acceleration and displacement, but also process the data by remote command. The instruments should be inexpensive and maintenance-free. Downloading of recorded and processed data by satellite link or broadcast transmission must also be possible.

Another high priority need identified under this topic was that for additional qualified researchers and support personnel, particularly for laboratories undertaking experimental research. Furthermore, many experimental facilities are in urgent need of upgrading and expansion in order to satisfy current demands for experimental research on complex and large-scale structural systems.

APPENDIX G

WORKING GROUP REPORT ON LIFELINE SYSTEMS

Overview

The Lifeline Systems Working Group discussed several ongoing and pending research efforts being undertaken in the U.S. and Japan. This session followed upon related discussions held earlier in the day by the Infrastructure Facilities group.

Discussions focused on identifying high priority topics for joint research, potential areas of cooperative activity, opportunities for sharing facilities, innovative methods for exchanging information, and new facilities and resources needed to conduct this research.

Recommended Joint Research Areas and Priorities

Based on the discussions within this group, the following areas of cooperative research are recommended. These are viewed as being well-suited for joint U.S.-Japan research effort. Higher priority topics are listed earlier in the list.

1. Development of near-real time post-earthquake damage assessment systems

   Such a system requires the design of a sensor, communication and evaluation components that will enable the identification of damage occurrence, the location and the severity of damage. The main advantage of such a system will be that vital information can be transmitted within a short (a few hours) time period after the occurrence of a major earthquake event to a central monitoring station for timely decisions for emergency response and crisis management.

   Research issues include the design, testing and evaluation of various components of the overall system, development of robust damage assessment algorithms, and full-scale field and laboratory testing.

2. Performance-based design

   There is a great need for identifying different performance levels for lifeline systems that are acceptable to the public and are consistent with individual public/industry objectives. Based on such criteria, prudent design procedures can be developed. Research issues that need to be addressed under this topic include the development of simple systems' reliability analysis formulations that lead to design guidelines and codes. At present structural systems' reliability analysis methods do not lend themselves to simple design code formulation. Furthermore, lifeline system performance issues have been addressed only to a limited extent and require that they be studied in great detail.

3. Emergency response and crisis management systems

   Currently, very few, if any, emergency response and crisis management systems exist both in the U.S. and Japan. Emergency response and crisis management systems include information and discussion support systems. The information should provide data on the extent of the affected lifeline system, identify critically damaged components and system interruption. Preferably, this information can be made available in near-real time at a central monitoring station. The decision support system requires that decision software be developed enabling emergency personnel to make timely decisions on repair and allocation of resources. Successful development of these research area can be achieved primarily though the utilization of advanced software tools such as geographic information system, databases management systems, and decision support systems.

4. Model calibration

   Significant number of models have been and continue to be developed for assessing the damage and functionality of various lifeline systems. The Kobe and Northridge earthquake disasters provide a unique opportunity for calibrating these models. Such a calibration will identify differences and gaps in these models and foster new research that will address these differences.

5. Enhance current risk assessment methods with emphasis on system interaction and system interruption

   Lifeline risk assessment is performed with the objective of evaluating the functionality of the system, estimating overall losses, identifying critical components and prioritizing component retrofitting. Current systems analysis methods address primarily issues related to overall losses of the system. Thus, there is a need for extending the existing lifeline risk assessment methods to respond to the remaining objective. In order to achieve this goal, it has amply been demonstrated by the Kobe and Northridge earthquake disasters that it is necessary to include the interaction of various lifeline systems and their interruption. This requires the modeling of dependencies and correlations among various systems.

Cooperative Activities

In addition to the specific research efforts proposed above, various existing cooperative activities were discussed. These include:

1. UJNR Workshops on Performance of lifeline systems (T/C C: Evaluation and improvement of structures and T/C F: Disaster prevention methods for lifeline systems)

2. US-Japan Workshops on Urban Earthquake Hazard Reduction (U.S.: EERI and Japan: Institute for Social Safety Science). H. Kameda and M. Shinozuka are involved in this these workshops.

3. U.S.-Japan joint research on "Consensus on Acceptable Risk in Urban Earthquake Disaster" (a pending activity with M. Shinozuka and H. Kameda as Principal Investigators for the U.S. and Japanese sides, respectively).

Based on the discussion on these ongoing and pending activities and a review of the research needs related to lifeline systems, the following general activities are believed to be of high priority. These will supplement the existing or pending activities to facilitate achievement of the goals of cooperative research for mitigation of urban earthquake disasters.

1. Workshops for lifeline earthquake engineers, social scientists and economists to address and develop cooperative activities on specific issues such as:
    a. Near-real time post-earthquake damage assessment and utilization of advanced technologies; condition monitoring shutoff valves, telemetric information collection, helicopter reconnaissance, satellite photos, etc.; and
    b. Socio-economic impact of system interaction and interruption.

Opportunities for Sharing Unique Facilities

Opportunities for sharing in the area of infrastructure components involve experimental facilities discussed by the Infrastructure Working Group in this Workshop. On the other hand, lifeline systems performance evaluation requires sharing of GIS database information through Internet communication. It is of vital importance, therefore, to develop cooperative mechanism for exchange of near-real time post-earthquake disaster data as well as standard inventory data in a GIS format. This is considered to be relatively easy to accomplish the recent availability of Internet capability.

Methods for Exchange of Information

Exchange of information should take place in the form of Internet and fax communications, exchange of personnel and workshops periodically held and/or convened for dealing with specific and urgent technical and organizational matters as they present themselves. Internet communication is most important and efficient in exchanging of digital data that are the major ingredient of GIS applications for lifeline system performance evaluation.

Needs for New Facilities, Personnel, etc.

Instrumentation equipment and devices are required to initiate new efforts on seismic damage estimation, particularly real time post-earthquake damage assessment that is of vital importance for emergency response and crisis management. Existing system condition monitoring technologies should be taken advantage of and new technologies unique to lifeline system monitoring be developed at different levels of sophistication depending on the purpose. This effort for instrumentation of lifelines should be coordinated between efforts recommended by the Working Groups on Lifeline Systems and Infrastructure Facilities in order to benefit from the commonality in the need that exist in these two groups.

Personnel with experimental, data acquisition and processing capability with professional and supporting qualifications plays a crucial role in this respect. Looking into the future, the Lifeline Systems' Working Group concurs with the Infrastructure Facilities Working Group in recommending that a mechanism be developed for educating and training more researchers and engineers with instrumentation capability.

APPENDIX H

WORKING GROUP REPORT ON STRUCTURAL RESPONSE AND DESIGN ISSUES

Overview

This working group focused on issues related to the process of implementing protection (loss mitigation) measures for individual structures and systems. Both the Northridge and Hyogo-ken Nanbu earthquakes have caused ground motions and damage that were larger than expected, demonstrating that presently employed measures are inadequate to provide consistent protection commensurate with design intent and expectations of the public.

Following considerable discussion the members of the Working Group agreed upon a single over-arching recommendation related to improving the design and analysis of structural systems. Several specific issues were elaborated upon covering certain high priority aspects of this general recommendation.

General Recommendation

The deliberations of the working group are summarized in the following single recommendation:

> An urgent need exists to develop, verify, and implement an advanced design procedure in which explicit consideration is given to performance objectives that express the needs of the public and of owners. To this end, research is required to:
>
> (a) develop and validate the best possible performance based design methodology,
>
> (b) describe the ground motion in a manner best suited for design,
>
> (c) develop and verify improved analytical techniques that permit reliable predictions of seismic demands and capacities at different performance levels, and
>
> (d) provide adequate protection against collateral hazards such as fire following earthquakes.

Cooperation between researchers in Japan and the U.S., in which advantage is taken of complementary expertise and of the wealth of information generated by recent major earthquakes in both countries, will contribute significantly to advancements in this topic of critical importance to seismic loss mitigation.

The following issues elaborate on the individual aspects of this summary recommendation.

Development and Validation of Advanced Design Procedures

Research is needed to develop and validate a design methodology that permits explicit consideration of performance objectives addressing important socio-economic community and owners' concerns. Advantage should be taken of the damage data and the lessons learned from the recent major earthquakes in Japan and the U.S. The focus needs to be on the following aspects of the design methodology:

- Development of prescriptive (quantitative) engineering criteria based on descriptive (qualitative) performance objectives.
- Development of acceptability criteria based on element and system capacities, including nonstructural and content considerations
- Incorporation of risk assessment methodologies
- Incorporation of reliability concepts
- Emphasis on a systems approach to design
- Considerations of life cycle issues
- Formalization of the design process
- Design validation at all important performance levels.

Description of Design Ground Motions

Performance-based design necessitates a description of the "design ground motion" at the different performance levels. The ground motion description has a dominant effect on the design process, and needs to incorporate all parameters that may have an important effect on the response of the structure. The Hyogoken-Nanbu, Northridge, and Loma Prieta earthquakes have demonstrated that many of the ground motion parameters are not fully understood, and that the relationship between recorded ground motions and the ground motion descriptions useful for design has not been clearly established. Research is needed in the following areas:

- Description of ground motion characteristics, incorporating all important source, travel path, and site effects (e.g., near field effects)
- Identification of ground motion parameters most relevant for design
- Understanding of the differences between recorded ground motions and design ground motions
- Description of ground motions in the design process (elastic vs. inelastic behavior).

Development and Validation of Advanced Analysis and Modeling Procedures

The implementation of a performance-based design procedure necessitates reliable analytical predictions of important seismic demands (strength, deformation, and energy dissipation demands). Research needs to be performed to develop reliable analytical techniques and tools that permit performance evaluation of irregular 3-D soil-foundation-structure systems and its components at all levels of performance, ranging from elastic behavior to degradation leading to collapse.

The focus of these technical investigations needs to be on the following important issues:

- 3-D modeling procedures
- Reliable modeling of strength and stiffness irregularities in plan and elevation
- Modeling of deteriorating systems
- Modeling of ground failures (liquefaction, lateral spreading)
- Validation of modeling procedures through
    1. The utilization of laboratory and field experimentation
    2. The utilization of earthquake damage data
    3. The use of data from instrument structures.

The specific research issuesfor joint cooperative activity between the U.S. and Japan include:

- Develop reliable procedures and tools that permit performance evaluation of irregular 3-D soil-foundation-structure systems and their components

Collateral Hazards

The fire following problem and other collateral hazards, such as toxic spills, are major issues in earthquake hazard mitigation. Joint research on all aspects that will lead to a reduction in losses due to collateral hazards is strongly recommended.

APPENDIX I

WORKING GROUP REPORT ON RECONSTRUCTION AND SOCIO-ECONOMIC ISSUES

Overview

In both the Northridge and Hyogo-ken Nanbu earthquakes, disaster impacts had both immediate as well as longer term consequences for the Kobe and Los Angeles metropolitan areas. In considering the types of cooperative research that would be mutually beneficial to future hazard reduction and planning efforts in both the United States and Japan, the multi-disciplinary work group that focused on socio-economic and reconstruction policy issues divided its recommendations into two general categories:

- problems emerging in the response period, and
- problems related to recovery and reconstruction.

In both cases, concerns about pre-disaster planning and mitigation -- in order to reduce future disaster consequences -- were also considered. Detailed technical issues regarding engineering aspects of reconstruction were not addressed by this group, as they were discussed elsewhere within the workshop.

Since one of the primary charges to the working groups was to suggest methods of improving the exchange of information and increasing the success of cooperative projects, this working group also identified a number of mechanisms that would increase the participation of social scientists in these activities.

The working group strongly endorsed the need to funding social scientists, policy analyst's, and urban planners in both countries to conduct research in order to accelerate and improve understanding of the destructive and disruptive impacts of urban earthquakes and to improve programs and policies that can effectively reduce those impacts in future earthquakes occurring in urban areas.

Cooperative Research Activities Addressing Gaps in Knowledge Related to Mitigation of Urban Earthquake Disasters

The following items were identified by the Working Group as being suitable for cooperative research activity and technical exchange. As indicated above the items are categorized into activities occurring during the immediate response period, and those related to recovery and reconstruction. Within each category, items are listed in order of decreasing priority.

I. Emergency Response and Crisis Management Topics

These items focus on relations among various governmental organizations involved as well as analysis of differing units.

1. Collection and dissemination of hazard, disaster and recovery information. This effort would include studies of media, government, organizations, public.
2. Assessments of social and health service needs after the disaster. For example, studies would include assessment of needs for medical care, mental health services, emergency food and clothing, and so on.
3. Projection and assessments of need for mass care (sheltering) during the immediate post-earthquake period.
4. Investigation of organizational response coordination and decision making to handle problems and resource allocations during response period. This effort would include:
   a) Horizontal and vertical relationships among governmental units,
   b) Use of volunteers in emergency response.

II. Recovery and Reconstruction Topics

A. Projection and assessments of need for temporary and replacement housing;

B. Impacts on and consequences of urban earthquakes for:
   1. Economic sector (direct and indirect impacts, both in the short and long term)
   2. Lifeline disruption as it effects for business, health care system, emergency response, etc.

C. Physical damage and its relationship to various social groups and activities.

III. Life loss as it effects community well-being and recovery as well as emergency response and productive activity.

A. Research on Pre-disaster recovery planing (e.g., effectiveness of pre-event policies for reconstruction and efforts to prioritize restoration for lifeline and infrastructure systems.

B. Research on methods to enhance adaptive, flexible, creative management during disasters (i.e., how to handle surprises not addressed by the planning process).

C. Research on strategies for financing of disaster recovery efforts (e.g., burden sharing).

IV. Other research topics

A. Research on methods to determine socially acceptable levels of risk for performance based design.

B. Research needed to develop education programs on earthquake topics for the public, decision makers and design professionals (e.g., on earthquake threat, preparedness activities, mitigation efforts, response procedures, recovery activities, etc.).

Mechanisms to Improve Exchange of Research Information, Data and Personnel

I. Hold Disciplinary-Focused Workshops.

Workshops should be held related to the socio-economic and planning issues related to preparedness, recovery and reconstruction. While workshops on a variety of related technical topics would benefit from the inclusion of social scientists and urban planners, it is believed that one or more disciplinary-focused workshops are desirable to allow social scientists and urban planners from the U.S. and Japan to exchange information on work in progress and/or to develop detailed research plans that could be the basis for future cooperative projects. A particular benefit of these workshops would be a comparison and analysis of the similarities and differences among the theoretical orientations, methodological approaches and application perspectives of scientists and planners in the two countries. These workshops would be especially productive since the earthquake disasters in Kobe and Northridge have brought many new social scientists into the disaster research area.

II. Continue Existing U.S.-Japan Cooperative Programs Related to Social Science and Planning.

Current cooperative socio-science programs related to mitigation of urban earthquake disasters should be continued. Activities, such as the U.S.-Japan Workshops on Urban Earthquake Hazard Reduction (cooperatively organized by EERI in the U.S. and ISSS in Japan), are believed to be a valuable means of exchanging information in this area and should be continued.

III. Incorporate Social Science and Planning Issues in Existing U.S.-Japan Cooperative Programs.

Social science and planning issues and specialists should be included in other U.S.-Japan cooperative research activities. Current U.S.-Japan cooperative efforts (e.g., UJNR) should be encouraged to incorporate activities addressing issues where social scientists and planners can participate.

IV. Encourage Multi-Disciplinary Research Teams

Multi-disciplinary research teams, incorporating social scientists and planners, should be encouraged. The effectiveness of coordinated U.S.-Japan research projects related to recovery and reconstruction as well as various technical issues (e.g., performance-based design) can be enhanced using a multi-disciplinary approach involving technical specialists, engineers, social scientists and planners.

APPENDIX J

WORKING GROUP REPORT ON

PRE- AND POST-EARTHQUAKE EVALUATION AND REHABILITATION AND URBAN PLANNING

Overview

The Northridge and Hyogo-ken Nanbu earthquakes provided important lessons regarding the importance of vulnerability assessment, both before and after the occurrence of a major earthquake. In addition to the urgent needs for innovative, cost effective and reliable methods for rehabilitation and repair from a technical perspective, important questions have arisen as a consequence of these and other urban earthquakes regarding the need for urban planning, policy making and other disaster mitigation activities related to evaluation and rehabilitation from a societal point of view.

Opportunities for joint research between researchers from the U.S. and Japan were identified for technical aspects of evaluation and rehabilitation as well as for urban planning. Recommendations were also developed for other related activities and needed facilities.

Research Needs on Rehabilitation and Repair

Three specific issues were identified where innovative research and cooperation might be beneficial to both Japan and the U.S. related to the engineering aspects of pre-earthquake evaluation and rehabilitation and post-event evaluation and repair. These issues are: condition assessment, vulnerability assessment, and rehabilitation and repair strategies. Specific high priority research needs, suitable for joint investigation, for each of these issues are outlined below. Consideration is given to related planning and policy issues in a subsequent section

1. Condition Assessment

   Knowledge of the condition of a building, bridge or other structure is essential if intelligent decisions are to be made regarding rehabilitation or repair. Important needed research topics are as follows:

   - Develop methods for reliable assessment of material properties. This includes both non-destructive and other test methods, in the pre-event as well as damaged condition.

- Develop methods for rapid post-earthquake evaluation of damage. This might include rapid (near-real time) processing and interpreting ground motion and structural response records.
- Develop methods for determining the condition of the foundation and soil at a site, including liquefaction potential
- Develop accurate and innovative methods for determining the condition of structural members and systems.
- Identify the importance of any pre-earthquake damage that is detected.

2. Vulnerability Assessment

   Vulnerability of existing buildings, bridges and other structures must be assessed for determining proper rehabilitation or repair strategies. Some important issues regarding vulnerability assessment are as follows:

   - Develop performance objectives for urban structures exposed to earthquake hazards.
   - Develop reliable estimates of the seismic hazard including near-source effects, site effects and probability of occurrence.
   - Determine acceptance criteria for various levels of risk.
   - Develop more reliable analysis and design procedures for determining or attaining performance objectives for specific seismic hazards.
   - Develop rehabilitation and repair techniques what can be implemented with minimal disturbance to occupants.
   - Investigate the effects of system redundancy on seismic performance.

3. Rehabilitation and Repair Strategies

   Reliable and cost-effective rehabilitation and repair strategies to achieve performance levels need to be developed. Specific issues are as follows:

   - Develop innovative procedures for modification and/or repair techniques for structural components such as steel and wood connections, reinforced concrete and steel members including bridge piers and bearings.
   - Develop new and efficient methods for rehabilitation and repair of structural systems. These will include the use of new materials and technologies.
   - Develop innovative methods for evaluation and repair of bridge and building foundations including soil improvement.
   - Develop systematic temporary rehabilitation methods.

Research Needs Related to Urban Planning and Policy Development

Research scientists and engineers generate the technical bases for designing the built environment to minimize earthquake and collateral losses. Social scientists, policy analysts, and city planners are concerned with finding ways to implement technical solutions through (informed) public choice mechanisms that allocate scarce public and private resources based on full appreciation of the risks and tradeoffs.

Research into pre-event processes of planning for and implementing preferred post-event landscapes and into effective strategies for post-event repair and recovery is a vital ingredient of effective science and engineering research.

Towards this end, a research strategy for cooperative research between investigators in the U.S. and Japan is proposed which identifies effective pre-event planning processes leading to public decisions about preferable post-event landscapes and the means of achieving those landscapes. Within this rubric are six research components, ranging from decision-making processes to evaluating methods of implementation.

The recommended research strategy consists of six components. The first is understanding the nature of the risks involved and how to define acceptable levels of risk across different communities. The second identifies ways of minimizing damage to the built environment while the third poses approaches to planning for post-event landscapes in such a manner as to improve long-term societal well-being after major events. The fourth generates methods of rationally allocating scarce resources for retrofitting and rehabilitation in a manner consistent with plans for post-event landscapes. The fifth recognizes the many potential similarities in hazard mitigation associated with other than earthquakes and suggest research to economize on approaches applicable to multi-hazard landscapes. The last step focuses on issues related to implementation of the results of all previous steps through building code design, adoption, and application.

Naturally, all components are highly related and must be considered as a whole. Hence, there is a need for an integrated research strategy.

Despite differences in culture and economic conditions, there are potentially many ways in which joint U.S.-Japan efforts can address and benefit from the following recommended research efforts.

1. Develop Effective Planning and Policy Mechanisms for Pre- And Post-Earthquake Hazard Mitigation

   There is virtually no synthesis of methods of community risk assessment into an overall approach that enables communities to decide their acceptable levels of risk in the context of earthquakes. NCEER will hold a conference on this topic during 1996. However, systematic research into effective methods of community determination of acceptable levels of risks has not yet been undertaken. Absent this research and evaluation of research applications, communities will continue to make sub-optimal decisions regarding preparation for and recovery from major events.

2. Planning to Reduce Damage

Scientific and engineering research alone cannot achieve the goal of mitigating urban earthquake disasters. One area of research would be in identifying effective land use planning and other processes and policies that lead to desired post-event landscapes, including pre-event landscapes that should be preserved before, during, and after major events. Recent research shows that when data assembly and analysis are combined with certain (but not all) policies, damage from earthquakes is reduced significantly. The kind of data that need to be collected, evaluated, and applied to specific regulatory approaches are not well understood. Research and verification of the effectiveness of information assessment, planning processes, and policies in different locations and countries is needed to conclusively identify effective approaches in reducing potential earthquake damage. At minimum, the U.S. and Japan should facilitate the sharing of information, methodologies, and insights from ongoing and new research in this area.

3. Pre-Event Reconstruction Planning Leading to the Desired Post-Event Landscape

After disastrous events, reconstruction usually recreates the pre-event landscape. This is problematic especially when the previous landscape was sub-optimal and its form resulted in extensive damage and loss. There is virtually no research into the application of decision-making processes to determine whether landscapes should be rebuilt and, if so, for which kinds of purposes and in what form. Moreover, there has been virtually no research into the role of pre-event reconstruction planning in achieving desired post-event landscapes; research to date has generally focused on planning to minimize damage without respect to desired post-event landscapes.

There is thus need for research into effective processes of to pre-event reconstruction planning that facilitates realization of the most desirable post-event landscape.

4. Prioritizing Investments

Once rehabilitation (retrofitting) is identified as a public (and private) investment need, decisions need to be made on where and where not to make retrofitting investments. Methods of prioritizing bridge and lifeline retrofitting investments offer a starting point for analysis of the factors underlying allocation decisions, although such decisions are usually made in the absence of decisions on desired post-event landscapes. Analytic methods and implementing devises are needed to help communities make rational decisions about prioritizing scarce resources for retrofitting. By simple extension, there is also need for research into methods of prioritizing post-event resource allocation for repair and reconstruction.

These two areas can be combined into an overall effort to research methods of pre- and post-event investment prioritization in the context of desired post-event landscapes. Such research can generate a theory and means by which decision makers can evaluate the socio-economic benefits and costs of various resource allocation options considering such factors as life cycle costs, risks, and the economics of a dynamic built environment.

5. Economizing Earthquake Hazard Planning and Implementation Through Multi-Hazard Approaches

   Earthquake events lead to research into landscapes subject to shaking and its effect on the built environment. Flooding, high wind, and wild fire events lead to other kinds of research into their effects on the built environment. What is emerging is a panoply of scientific, engineering, and policy approaches designed for specific landscapes, many of which face two or more such threats. There is emerging need for research into methods that optimize a mix of strategies applicable to multi-hazard landscapes. The result can be more efficient allocation of public and private hazard-related resources.

6. Building Code Design, Adoption, and Effective Implementation

   In many parts of the U.S., building code adoption and enforcement is sub-optimal under normal conditions and much less so for earthquake hazards. Effective incentives need to be investigated to induce (1) local governmental units to adopt and adequately enforce building codes with seismic rehabilitation and repair elements, and (2) owners to undertake mandatory or voluntary rehabilitation and repair actions. Research into effective building code adoption and enforcement under non-mandatory conditions is also needed. This issue is probably limited to the U.S., though it is also of importance in Japan especially regarding rehabilitation.

APPENDIX K

WORKING GROUP REPORT ON

MATERIALS, CONSTRUCTION AND ADVANCED TECHNOLOGY FOR URBAN EARTHQUAKE DISASTER REDUCTION

Overview

The Working Group discussed a broad range of topics, including base isolation, passive energy dissipation, active and semi-active control, smart and high-performance materials, monitoring (including health diagnosis), hybrid control (including mixed active/passive and active/base isolation) and smart sensors. Discussions were channeled to identify current research activities and opportunities in each country, gaps in current knowledge, research needs and opportunities for joint research, beneficial possibilities for sharing facilities, and recommendations.

Current Research/Implementation Activities

Participants identified a number of recent or ongoing research efforts within each country on various topics related to the subject of this Working Group. Soong initiated the discussion by describing the projects listed in Table K.1.

Feng described four additional projects related to advanced technologies. These were:

1. HITEC - a evaluation program for base isolation and energy dissipation devices conducted as part of an ASCE program to encourage the utilization of advanced technologies in the U.S.
2. Caltrans/FHWA - a project to evaluate bridge retrofit using fiber-composite materials
3. Research program on Mega-Sub-Control of Tall Buildings funded by the HPEC and NCEER
4. Research on the response of an seismically instrumented bridge in the Hanshin Expressway - funded by HPEC and NCEER

Ohtsuka then described several major ongoing research and development projects at PWRI. These included:

1. Retrofit of damaged bridge structures using seismic isolation.

2. Research on the use of carbon-fiber wrap to enhance the strength and ductility of bridge columns.

Table K.1 Some Recent and Ongoing Research Projects Related to Advanced Technologies and Materials

Organization	Brief Project Description
NSF	Research Initiative on Structural Control (1992-97) - focused research program with 50 investigators and research on active and hybrid control
NSF/CUREe	US Panel on Structural Control (1990-present) - Working with the Japan Panel on Structural Response Control
NSF/NCEER	Intelligent Protective Systems - Project involving Japanese construction companies and research on base isolation, passive energy dissipation, active control, and hybrid control.
Caltrans	Protective Systems for Bridges - project at UC Berkeley focusing on seismic isolation and passive control of bridge structures.
-	Japan Panel on Structural Response Control (1990-present)
BRI	Various projects including: High-damping Systems (1995-1997) Base Isolation for Houses (1995-1997) High-Performance Materials (1995-97)
JSPS	Structural Control (1995-1996) - Project focusing on active control.

Discussion

The participants then discussed various issues and potential research topics. Soong described some issues germane to the implementation of advanced technologies, and the status of the use of advanced technologies in the U.S. and Japan. He indicated that base isolation, passive energy dissipation and high performance materials have each been implemented in both the U.S. and Japan; active and hybrid systems have only been implemented in Japan. Some advanced technologies were "tested" during the Northridge and Kobe earthquake disasters: base isolation systems (in both Kobe and Northridge); hybrid systems (Kobe only). Although the advanced technologies have experienced earthquake shaking, none have been fully tested in the intense motions characteristic of a large urban earthquake.

Several research issues were suggested for further discussion, including correlation studies, benchmark problems, demonstration projects and codes and design provisions. Liu discussed the need to develop inexpensive, robust, maintenance-free sensor hardware to implement active control systems and for health monitoring and issues related to the implementation of advanced materials in intelligent structures.

Several key issues were identified by various participants related to the implementation of various types of advanced technologies for mitigation of earthquake risk. These were summarized by Soong in the listing below:

- Seismic isolation – guidelines, applications
- Passive control – guidelines, hardware, applications
- Other response control procedures and high performance materials – knowledge base related to shape memory alloys, electro- and magneto-rheological fluids, carbon- and glass-fiber composites, etc.

Soong identified three areas of research: performance of devices, performance of systems, and relative merits of different systems.

Thirteen potential recommendations were identified by the members of the Working Group. During discussion, these recommendations were combined and parsed into four topical areas: Research Recommendations, Cooperative Activities, Shared Resources, and New Resources. These are presented below in the form presented to the Plenary Session.

Recommendations for Cooperative Research

The following research areas are deemed by the Working Group to be of high priority. They would particularly benefit from joint research.

1. Development of the hardware and software necessary to sense and monitor the built environment in real time (or near-real time).
2. Application of advanced technologies for risk mitigation in the built environment subjected to large near-source earthquake ground motions.
3. Development of analysis procedures for the implementation of all classes of passive energy dissipation devices.
4. Analytical and experimental development of high performance materials for use in (a) seismic isolation systems, (b) passive and active control hardware, (c) new conventional construction, and (d) retrofit applications.
5. Development of new technologies to address risk mitigation issues including (a) fire control and suppression, (b) remote sensing, (c) inspection, and (d) smart structural members.

Recommendations for Cooperative Activities

In addition to the recommended research activities, a number of important activities were identified that should be conducted on a cooperative basis between the two countries. These include:

1. Analytical and experimental evaluation of benchmark structural systems.
2. Execution of model and full-scale demonstration projects
3. Development of provisions and commentary for the implementation of advanced technologies and materials.

Recommendations for Shared Resources

Several opportunities for sharing resources were recommended by the members to accelerate the implementation of new materials and technologies.

1. Full-scale tests structure in Kyoto, Japan
2. Earthquake simulator facilities in Japan and the U.S.
3. Model structures in Japan and the U.S.

Recommendations for New Resources

The new resources listed below were deemed necessary for the rapid and rigorous implementation of advanced technologies and new materials.

1. Full-scale test structure in the U.S.
2. Full-scale "generic" test structure(s) in Japan for assessing control hardware and sensing technologies - to be tested on existing large Japanese shaking tables.

APPENDIX L

WORKING GROUP REPORT ON IMPROVED INTERNATIONAL COOPERATION AND COMMUNICATIONS

Overview

Various discussions occurred throughout the Workshop examining different mechanisms for improving international cooperation and communications. For instance, each of the Working Groups addressed the suitability of various topics for joint cooperation and the need for improved technical communications and exchange of data and personnel. A Plenary Session on Improved International Cooperation and Communications was also held on the first and third days of the Workshop, constituting a committee of the whole. The Workshop recommendations and resolutions contained in the main body of the report are in large part a product of these discussions. It was felt that accelerated research within each country could significantly reduce the disastrous impacts of urban earthquakes, that many opportunities exist for joint research, and that both countries would benefit significantly from cooperative efforts in this area.

Recommended activities relate to exchange of information, research findings and personnel as well as to improved coordination. Because many smaller and several large cooperative projects and programs are being undertaken or proposed, and that many of the high priority activities of these efforts are interrelated or interdependent, the participants felt that it would be highly beneficial to establish a special mechanism to foster coordination and communication among the various joint U.S.-Japan cooperative research projects and programs.

Establish a Mechanism for Cooperation and Coordination

The participants believed, in order to facilitate progress toward cooperative efforts to conduct research for mitigation of urban earthquake disasters, that an effective joint coordinating mechanism which can carry out sustained operation should be established. To this end, a Joint Technical Coordinating Committee consisting of approximately 10 individuals from both countries is recommended to facilitate the harmonious progress of research throughout the entire cooperative effort. A secure source of funding should be sought to mobilize the activities of the Joint Technical Coordinating Committee on a sustained basis.

The benefits ensuing from the Joint Technical Coordinating Committee would include rapid and systematic exchange of information about existing and planned activities. This would avoid unnecessary and potentially confusing duplication of effort. The Joint Technical Coordinating Committee is viewed as providing a nurturing or benevolent umbrella under which various programs can effectively exchange information and coordinate activities. Examples of activities that might be undertaken by the Joint Technical Coordinating Committee include:

- Collecting and providing information about existing and planned activities and cooperative research efforts.
- Providing benevolent coordination and facilitation among various programs and projects.
- Supporting and encouraging projects, particularly the development of new and emerging groups.
- Facilitating communication of research needs and results: among the various cooperative research programs as well as between the cooperative projects and the broader hazard mitigation community.
- Encouraging the dissemination and utilization of research findings within the affected user community.
- Encouraging the use of modern communication methods, including Internet, World Wide Web, email, tele- and video-conferencing, and so on.
- Interacting with other related cooperative scientific activities.
- Interacting with similar activities and interests in third countries.

It is anticipated that the Joint Technical Coordinating Committee would meet one or twice a year to review and exchange information on the status of US.-Japan activities on research to mitigate urban earthquake disasters.

Topics with widespread interest and complexity should be identified for formal cooperative action to be undertaken by Joint Working Groups. Smaller or more focused joint research endeavors should also be encouraged. They might become affiliated with one or more of the Joint Working Groups or directly with the Joint Technical Coordinating Committee in order to benefit from the mechanisms established to exchange information.

Establish Joint Working Groups Focusing on Specific High Priority Research Areas

Joint Working Groups should be established among researchers actively pursuing research on specific bilateral projects. Multiple channels for funding these research areas should be developed within each country.

Possible Joint Working Groups with a high priority for initial consideration were discussed. It was believed that joint discussions and research activities on a number of topics had advanced to a stage where a Joint Working Group is desirable. These topical areas include:

a. Steel structures
b. Social, political and economic issues
c. Infrastructure systems
d. Near-source ground motions and their effects on structures
e. Performance-based design
f. Evaluation and rehabilitation (retrofit) of existing reinforced concrete structures.

Enhance Efforts to Exchange Research Findings and Data

Because of the rapid pace of developments in research related to mitigation of urban earthquake disasters, and the need by the broad research and user communities for the knowledge and data being generated, specific mechanisms should be developed for the timely synthesis and exchange of information. These mechanisms should include:

a. Utilization of the World Wide Web and Internet to exchange research results, databases, digital data of test results and recorded earthquake responses, video and photographic images, and so on.

b. Convening of frequent meetings, workshops and symposia on various topics in order to better define research directions and coordinate activities,

c. Establishing a jointly operated Information Clearinghouse that would be tasked with the responsibility for collecting and sharing information on proposed and on-going research and testing work and results occurring in both countries. The Clearinghouse could be initially focus on information related to steel research as there is considerable research activity underway already in both countries. The Clearinghouse could be established using existing facilities and would be governed by a steering committee of experts in various fields from both countries.

d. The exchange of personnel to work cooperatively on joint projects as well as for short term visits.

Encourage Joint Field Reconnaissance Missions

Because of the infrequent occurrence of damaging earthquakes, lessons learned from Kobe and Northridge are particularly valuable and will have far-reaching impacts on design and construction practices in both countries. Many of these lessons were first discovered during reconnaissance visits to the affected regions by research teams from both countries. These cooperative visits are extremely useful and every effort should be made to encourage and facilitate future exchange visits as the opportunities arise. In particular, improved efforts to capture perishable data immediately following an earthquake are encouraged.

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