Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VIII)

SK-R1

State-of-the Art Report
URBAN SEISMIC RISK REDUCTION
-STATE OF THE ARTS OF RESEARCH AND IMPLEMENTATION-

Haresh C.Shah

Chairman, Department of Civil Engineering
Stanford University

SUMMARY

The eventual goal of all the earthquake related research in engineering, ground motion studies, seismology, geology, planning, socio-economic considerations, and behavioral and psychological aspects is to reduce the impact of earthquakes on our societies. With the continuous urbanization of our populations, it is becoming especially important that we integrate the know-how from all the above disciplines and develop options to reduce urban seismic risk. This paper discusses the current state of the art towards meeting this goal and points out both the accomplishments in this area and the major challenges that need to be addressed. It is not possible to discuss all the relevant research currently underway around the world. However, if the Ninth World Conference on Earthquake Engineering (9WCEE) is a representative sample of this work, then this paper provides a fairly good assessment of the current state of the art.

INTRODUCTION

As Professor Kameda pointed out in his summary paper, 50% of the world's population will live in urban areas by the turn of the century, up from only 29% in 1950. If one wishes to reduce the risk to large urban areas located in seismically active regions, then a concerted effort will have to be carried out to integrate the knowledge from various disciplines. This integrated knowledge base must then be converted into actions which can mitigate the effects of damaging earthquakes. Amongst the many actions needed to achieve reduction in seismic risk, the following five are important:

1. Engineering. This includes newer codes, better design and analysis technology for newer structures, methods for retrofitting existing structures, development of devices to absorb and/or dissipate energy, etc.

2. City and Regional Planning. This includes land use planning, siting, development of regulatory options for facility uses, etc.

3. Disaster Preparedness. This includes planning for fires, transport and treatment of casualties, control of panic, dissemination of information, etc.

4. Financial Planning. This includes insurance, reinsurance, distribution of risk through portfolio management, banking and investment options, etc.

5. Government Actions

Thus, to discuss the state of the art in research and implementation for urban seismic risk reduction, we have to look not only at what is happening in the above disciplines, but also in seismology, geology, architecture, and other related fields. Looking at this issue of urban seismic risk reduction from a different point of view, it can be said that output from the following areas needs to be considered (adapted from H. Kameda's work (Ref. 1)).

1. Seismic hazard assessment: seismicity, ground motion, ground failure, tsunami, etc.

2. Structural problems: structural response, failure and damage of buildings and other civil engineering structures.

3. Lifeline earthquake engineering: system reliability and post-earthquake restoration of urban infrastructures.

4. Disaster propagation problems: fire following earthquakes, combined disasters at industrial plants, etc.

5. Information and behavioral sciences aspects: evacuation, information management, human behavior in emergency, etc.

6. Regional planning and socio-economic aspects: econometric effects, urban seismic development and re-development planning, etc.

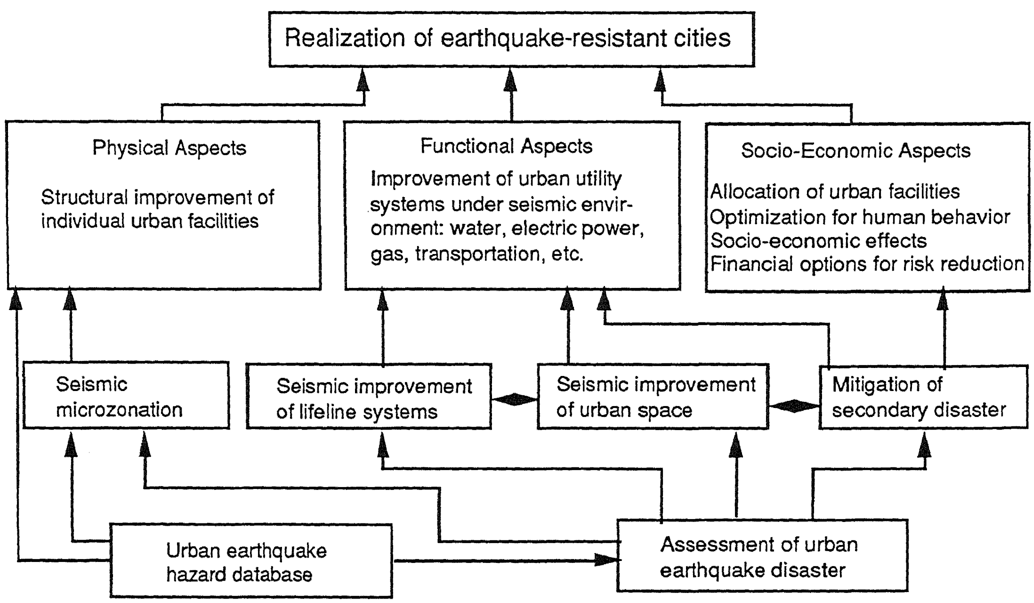

Figure 1: Multi-Disciplinary Aspects of Urban Seismic Risk Reduction
(Adapted from H. Kameda)

Integration of appropriate knowledge from each of the above areas would provide a good strategy for urban risk reduction. Figure 1 provides a look at the multi-disciplinary aspects of this problem. Figure 2 (adapted from H. Kameda's work) shows the roles and interrelationships of different fields in urban risk reduction. The four axes, representing physical processes, problem orientation, methodology orientation, and integration provide a suitable state-space representation of different disciplines.

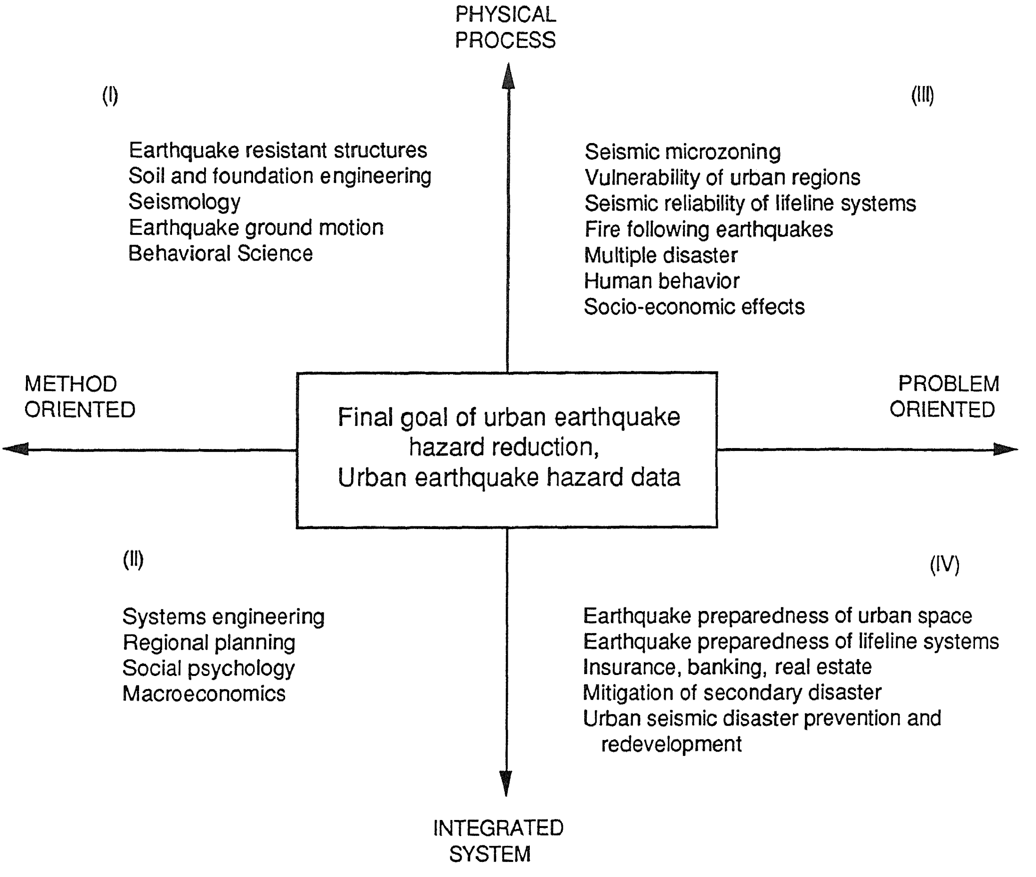

Figure 2: Research Area of Urban Earthquake Hazard Reduction and Related Fields
(Adapted from H. Kameda)

In this paper, we will first discuss the state of the art in separate disciplines described above and then point out the needed efforts to improve our current ability to provide a "minimal risk" urban environment.

SEISMIC HAZARD ASSESSMENT

Over the past two decades, considerable work has been conducted worldwide in estimating seismic hazard for a site or a region. Various empirical, geophysical, and combination models are in the literature for practical utilization. The most commonly used models are empirical. Figure 3 summarizes the steps one follows in estimating seismic hazard for a region or a site. As can be seen from this figure, deterministic and probabilistic procedures are available. The more appropriate of these two for non critical facilities is the probabilistic approach. More recently, fuzzy set theory has been introduced to model linguistic and/or fuzzy information on past occurrence data or source modeling or attenuation relationships.

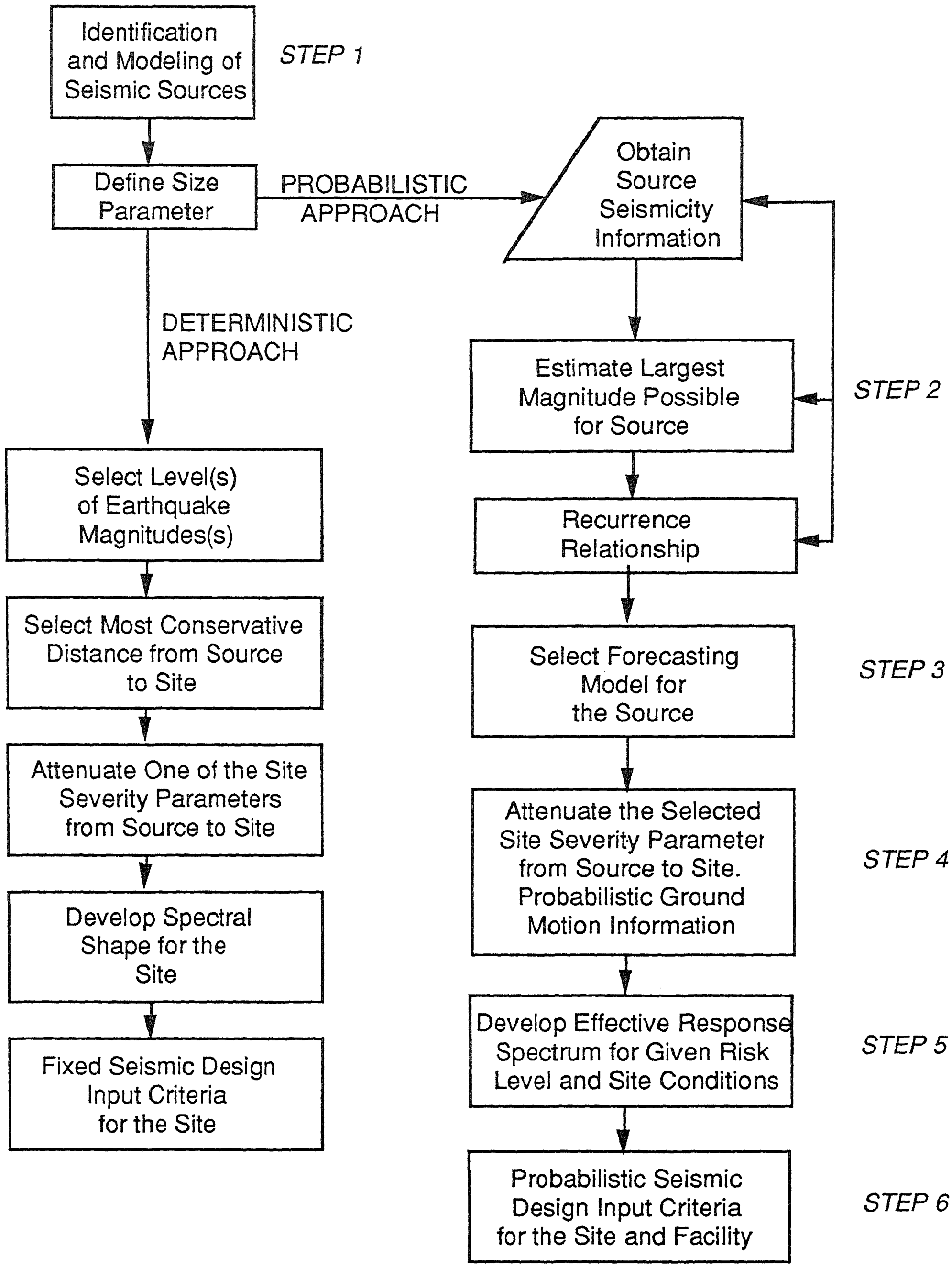

Figure 3: General Flow Chart for Empirical Seismic Hazard Models

Even within the empirical seismic hazard models, some researchers have suggested time homogeneous models (such as Poisson) for occurrence whereas others have suggested time dependent models (Markov, Semi-Markov, or Renewal Process). Anagnos and Kiremidjian (Ref. 2) give an excellent summary of the available occurrence models.

During the past decade various researchers from seismology and earthquake engineering have suggested geophysical models for estimating site or regional seismic hazards. These researchers have suggested modeling of the source mechanism, wave propagation, and structural modeling of the earth. Some work is also available in which empirical and geophysical models are combined. Suzuki and Kiremidjian (Ref. 3) provide a good summary of the available literature in this field. They also demonstrate the use of such models to a specific example region.

At this 9WCEE, approximately 40 papers are devoted to various aspects of seismic hazard modeling. These parers discuss methods for compiling and processing past data, source modeling, occurrence modeling, attenuation relationship, and site specific spectral loading. Examples from various seismic regions of the world are presented. Empirical and geophysical models are suggested. From these papers, it is evident that the general methodology of figure 3 has matured to the point where its use is routine around the world. The only recent improvements are towards modeling available information through realistic probabilistic and fuzzy set models. Also, introduction of expert system tools has greatly simplified the implementation of this vast array of models. Shah and Dong (Ref. 4) have summarized the problems and possibilities of improving the widely used empirical models of seismic hazard assessment. The reader of this SOA report would find the papers presented in sessions D05, D06, D07, D08, G02, and SA to be relevant for understanding the current know-how in seismic hazard assessment.

Treatment of other earthquake related hazards such as liquefaction, landslide, ground failure, tsunami, etc. have also received widespread attention. Through macro and microzoning procedures, areas susceptible to these "secondary" hazards can be (and, in some regions of the world, have been) identified. Many sessions at this conference have been devoted to these issues.

STRUCTURAL PROBLEMS

Analysis and design of new structures and evaluation of existing structures for earthquake loadings is one of the most widely researched and studied topics in earthquake engineering. A very large proportion of papers at this 9WCEE are devoted to this topic. For urban seismic risk reduction, one of the most important considerations is the response and behavior of existing structures. This topic has been given considerable importance during the past decade. How one addresses the problem of existing structures from the engineering, social, regulatory, and economic point of view has occupied the attention of numerous researchers and planners. From a purely engineering point of view, many performance evaluation and strengthening procedures have been developed. Some of these procedures are conventional (such as grouting, providing frames or shear walls, buttressing, tying walls with floors and roof, building a cage around the exiting structure, etc.), where as others provide energy absorption and/or dissipation devices (such as isolators, dampers, etc.). The main problem under this category can be divided into the following sub issues:

1. Methods for evaluation the vulnerability of existing structures
2. Capacity evaluation of existing structures
3. Retrofitting of existing structures
4. Behavior estimation of retrofitted structures
5. Repair procedures and costs of damaged structures
6. Retrofitting of damaged structures

The 9WCEE has many sessions (CO1, CO2, G07, G08, G09, G10, G11, G12, SH, SJ, SL) devoted to the discussion of the above topics. The application of research know-how about the existing structures and their earthquake performance has been somewhat less than spectacular. The problem has not been engineering knowledge, but rather political, social, and economical. The main issue has been who pays, who gains, and who suffers in implementing engineering solutions for existing structures. It seems that an isolated and in depth understanding of the engineering implications for existing structures is not going to provide our communities with risk reduction options. What we need is to translate the current engineering know-how into implementable options which can answer the social, political, and economic concerns.

It is worth noting that many researchers have developed expert systems to evaluate the vulnerability of existing structures. There is also considerable work being done in that direction for estimating regional vulnerability and risk. Again, most models currently under practical use are either empirical or a mixture of empirical and mechanistic analysis. Applied Technology Council has recently developed a procedure for seismic evaluation of existing structures (Ref. 5). Iwasaki (Ref. 6) has developed a manual for repair of damaged structures. All these types of procedures provide invaluable information resources in mitigating future earthquake risks. The current research efforts are not only for existing buildings, but also for dams, bridges, ancient monuments, art objects, historic buildings, and critical facilities.

LIFELINE ISSUES

One of the most important considerations in evaluating vulnerability and risk of an urban region is the performance of lifelines. This consideration includes the study of water and sewage lines, gas and electric supply, transportation, communication, and infrastructure organization. From the engineering point of view, lifelines have been studied for their performance both above and below ground. The problem of spatial distribution of load has been studied by many researchers. The system problem of network performance and network analysis has also been studied and presented. The functional problem of fire fighting, transportation, and disaster response due to lifeline failure has also received considerable attention in the literature. It seems that the ability to *analyze* lifeline networks under moving spatial loads has far exceeded our ability to *utilize the results* for improving existing systems or improving our ability to develop options and actions to fight future earthquakes. This dichotomy is mainly due to economic and political considerations.

Most of the papers presented at the 9WCEE address the engineering problem of estimating stresses, strains, or performance of pipelines. Very few discuss the ways in which the current knowledge can be utilized to mitigate future lifeline damage. It seems that an information integrating study needs to be conducted to provide options and suggestions for mitigating the effects of future earthquakes on our urban lifelines. Out of 32 papers on lifelines, only about five deal with issues related to reducing urban risk due to lifeline failures. The reader would find sessions H06, H07, and H08 to be relevant to this topic.

DISASTER PROPAGATION AND PLANNING ISSUES

Even though ground motion is a major cause of damage and loss of life, it is not the only cause. The resulting secondary hazards such as ground failure, liquefaction, landslide, etc. may result in rupture of gas pipes resulting in fires. The failure of the transportation network and the water pipes may further add to the problem of fire fighting. Chemical and oil spills also increase the loss and injury potential for an affected region. There is relatively little work available in this field. The work of Scawthorn et al. (Ref. 7) is one such example. These authors have developed a method for estimating building collapses, fires, and serious releases of hazardous materials following an earthquake. Shah et al. (Ref. 8) have developed an expert system which can estimate not only the damage potential of a building or a region due to ground motion, but also the losses due to fire following an earthquake. Miyasato and Shah (Ref.9) have developed a decision support system which incorporates fire and other tertiary hazards. Much more work needs to be done in this area. At the 9WCEE, sessions H09, H10, H11, H12, SK, G01, and G02 are relevant to this topic.

INFORMATION AND BEHAVIORAL SCIENCES ASPECTS

A community's ability to survive a major earthquake disaster depends not only on the engineering performance of buildings and lifelines, but also on its disaster preparedness. How a community has planned for emergency evacuation, information management and distribution, police and firefighting functions, education of the public for disasters, etc., will determine the level of short and long term impact. Considerable work is available in the literature on these topics - not only for earthquakes, but for other natural disasters as well. An excellent paper by Nigg (Ref. 10) discusses the knowledge utilization and dissemination processes for hazard reduction.

Figure 4, which has been adapted from Yin and Moore (Ref. 11) provides an illustration of a mutually influencing network between researchers and users.

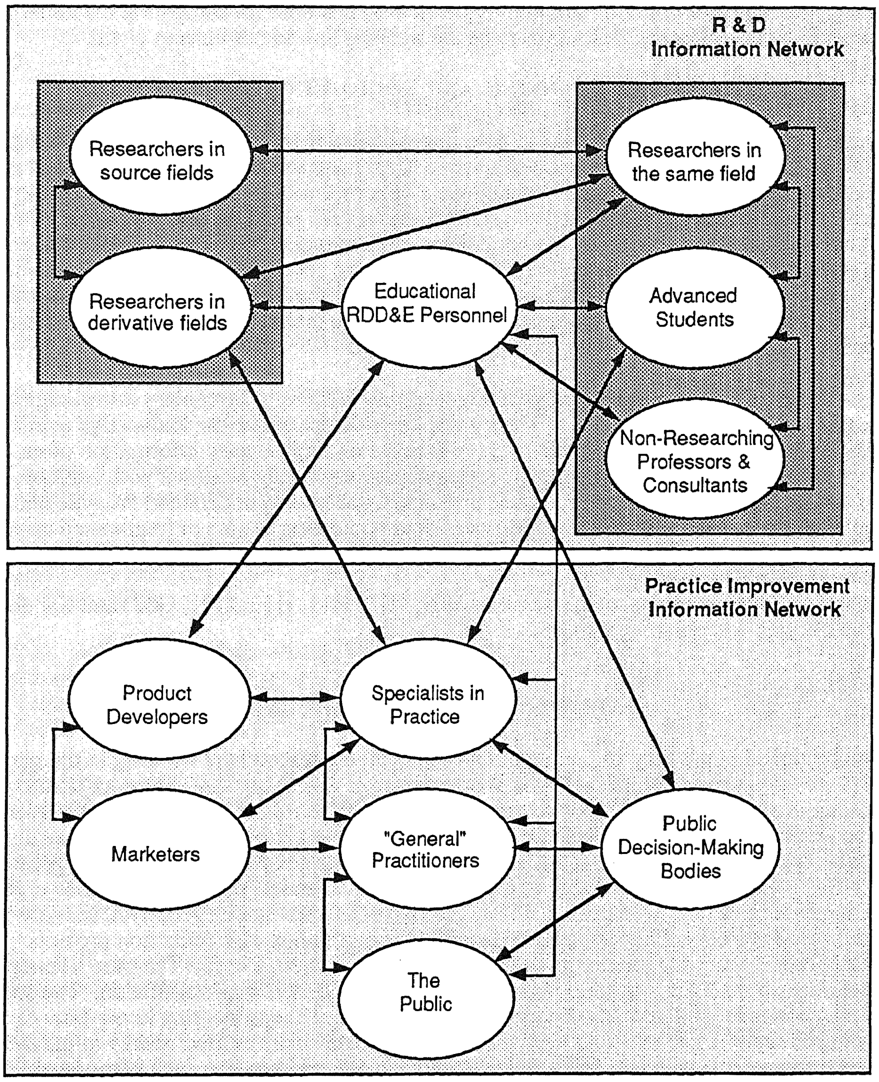

Figure 4: An Illustration of a Mutually-Influencing Network of Research Producers and Users (Source: Yin and Moore, 1985)

Some excellent papers on this topic are presented at this conference, particularly in Session H10, *Human Behavior and Socio-Economic Aspects*. An integrating approach in which the behavioral, social, political, and educational options would be included together with the engineering, economic, planning, and regulatory options would provide the best potential for mitigating the consequences of earthquakes. Unfortunately, this seems to be the weakest link in our current chain.

REGIONAL PLANNING AND SOCIO-ECONOMIC ASPECTS

Many communities around the world have implemented regulations for land use, siting, and facility use based on the level and type of seismic hazard and seismic risk. Over the past twenty years numerous papers have been written explaining the options through planning to reduce earthquake impact. These planning issues have been studied with social, political, and economic constraints taken into account. Even the planning options available to reduce earthquake losses can not be studied in isolation without understanding the social and economic costs. Many engineering studies have developed elegant and rather accurate methods to either estimate or reduce future earthquake losses. However, very few of them have integrated within their methodology the social, economic, and political constraints. This is where more effort is needed.

As a matter of fact, earthquake engineering literature is full of fragmentary knowledge about economic and financial implications. Money managers do not utilize the knowledge available from earth scientists or engineers. Decision making is based on fragmentary information often used out of context. Similarly, earth scientists, engineers, and planners rarely sit down with bankers, insurance risk managers, and financial and real estate investment analysts to understand the type and level of financial concerns and constraints. This lack of communication results in fragmented contributions. The synergy of integration is thus not available for risk reduction.

In the 9WCEE, many papers in sessions H09, H10, H11, H12, G01, G02, and SK address these socio-economic and planning issues.

OBSERVATIONS AND CONCLUSIONS

As mentioned in the very beginning of this paper, all the researchers working in the general field of earthquake engineering contribute towards urban seismic risk reduction. Thus, an urban community's ability to survive an earthquake without major short and long term consequences will depend on how the community has utilized the state-of-the-art knowledge from various disciplines to develop implementable options. This is where the current state of knowledge has its greatest weakness. An integrated knowledge base and an integrated action portfolio should be urgently developed. As an example, earth scientists (geologists, seismologists, geophysicists) are working in parallel with engineers, planners, and risk analysts on earthquake risk reduction projects. But they generally do not work together to provide a synergistic knowledge base. The pure science and engineering aspects related to earthquakes have far outpaced their implementation. The social, political, economic, and psychological constraints are such that engineering know-how can not be easily implemented to benefit society. It is really time to devote mind and energy to the development of integration models which would provide implementable options to reduce urban seismic risk.

In this conference, there are approximately 1325 papers, of which only about 45 address this issue of implementation through integration of knowledge. If we could apply the current state of engineering and earth science know-how to urban risk reduction projects, we could really make a difference. Unfortunately, we currently do not know how we can implement our knowledge into actions without violating social, economic, planning, and political constraints.

The upcoming United Nations program called the International Decade for Natural Hazard Reduction (IDNHR) (Ref. 12) could act as an excellent vehicle to conduct more research towards integration. Such a world wide program could focus on efforts to develop synergistic and integrating methods to reduce earthquake risk.

REFERENCES

1. Kameda, H., Iwai, S., Kitahara, A., Nojima, N., "Urban Earthquake Hazards Reduction - Problem Areas and Needs for Multi-Disciplinary Research," *Proceeding of the US/Asia Conference on Engineering for Mitigating Natural Hazards Damage*, Bangkok, December 1987, pp. D9-1 - D9-12.

2. Anagnos, T. and Kiremidjian, A.S., "A Review of Earthquake Occurrence Models for Seismic Hazard Analysis," *Journal of Probabilistic Engineering Mechanics,* Vol. 3, No. 1, 1988.

3. Suzuki, S., Kiremidjian, A.S., "Site Hazard Analysis Methods with Empirical and Geophysical Ground Motion Models," *Technical Report No. 80*, The John A. Blume Earthquake Engineering Center, Stanford University, August 1986.

4. Shah, H.C. and Dong, W.M., "A Re-Evaluation of the Current Seismic Hazard Assessment Methodologies," *Proceedings of the 8th World Conference on Earthquake Engineering,* July 1984, Vol. I, pp. 247-254, Prentice Hall.

5. Poland, C.D., "ACT 14: A Methodology for the Seismic Evaluation of Existing Buildings," *Proceedings of the 9WCEE*, August 1988.

6. Iwasaki, T., "Development of Manual for Repair Methods for Civil Engineering Structures Damaged by Earthquakes," *Proceedings of the 9WCEE*, 1988.

7. Scawthorn, C., Bouhafs, M., and Blackburn, F., "Demand and Provision for Post Earthquake Emergency Services: Case Study of San Francisco Fire Department," *Proceedings of the 9WCEE*, 1988.

8. Shah, H.C., Wong, F.S., Dong, W.M., Lamarre, M., Miyasato, G.H., "IRAS - An Expert System for Earthquake Insurance and Investment Risk Assessment," *Proceedings of the US/Asia Conference on Engineering for Mitigating Natural Hazards Damage*, Bangkok, Thailand, 1987, pp. D6-1 - D6-11. Also published in the *Proceedings of the 9WCEE*, 1988.

9. Miyasato, G.H. and Shah, H.C., "A Decision Support System for Seismic Risk Evaluation," *Proceedings of the 9WCEE*, 1988.

10. Nigg, J.M. "Knowledge Utilization and Dissemination Processes: Application for Hazard Reduction Efforts," *Proceedings of the CCNAA-AIT Joint Seminar on Research and Application for Multiple Hazards Mitigation*, Taipei, 1988, pp. 223-236.

11. Yin, R.K. and Moore, G.B. "The Utilization of Research: Lessons from the Natural Hazards Field," The Cosmos Corporation, Washington, D.C.

12. National Research Council, *Confronting Natural Disasters: An International Decade for Natural Hazard Reduction*, National Academy of Sciences Press, Washington, D.C..